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

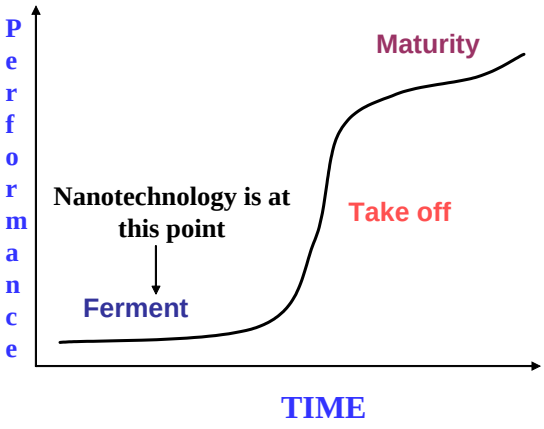
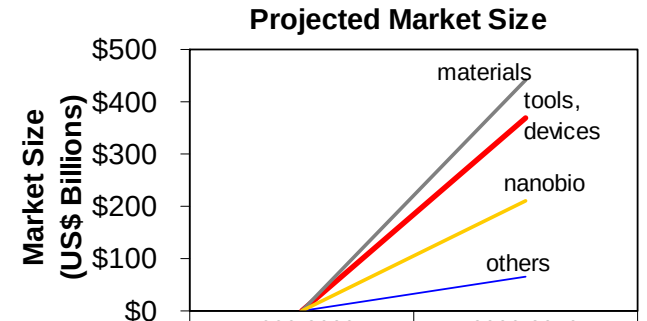


Figure 1: A clear point in the industrial life cycle of nanotechnology development



	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.

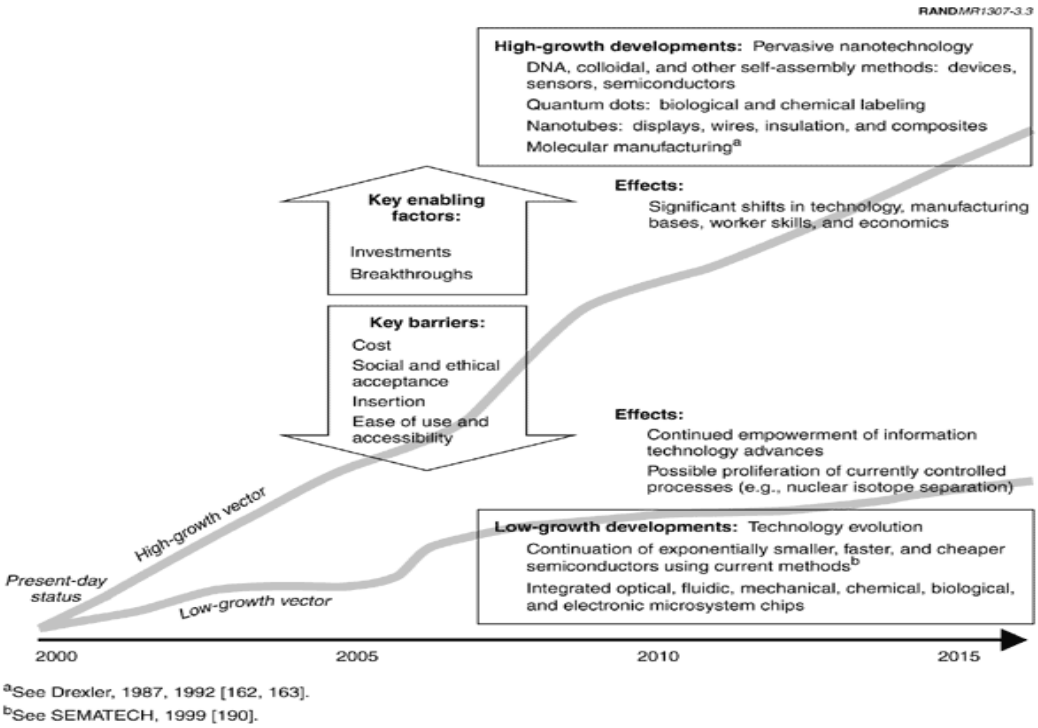


Figure 3: Range of Possible Future Developments of Nanotechnology

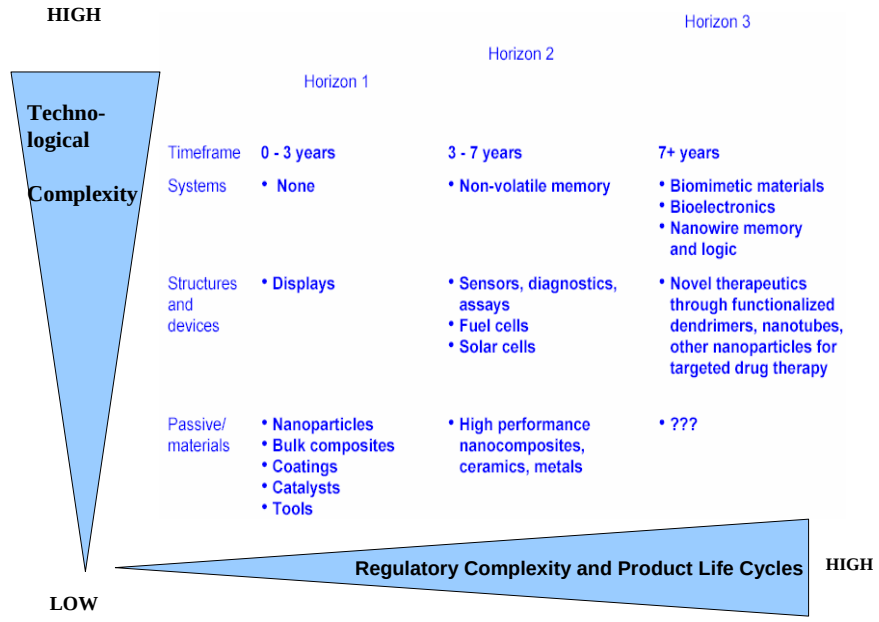


Figure 4a: Market Impact of Nanotechnology (Atom works, 2003[5])

[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.

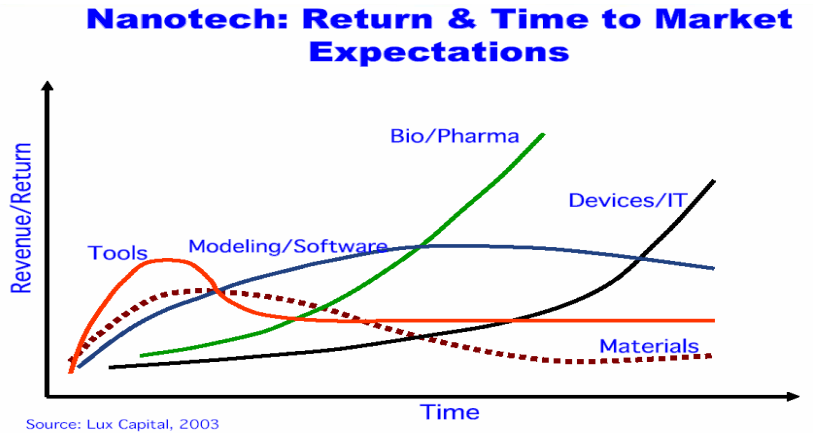


Figure 4b: Market Acceptance for each sub sector (Lux Capital, 2003[6])

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.

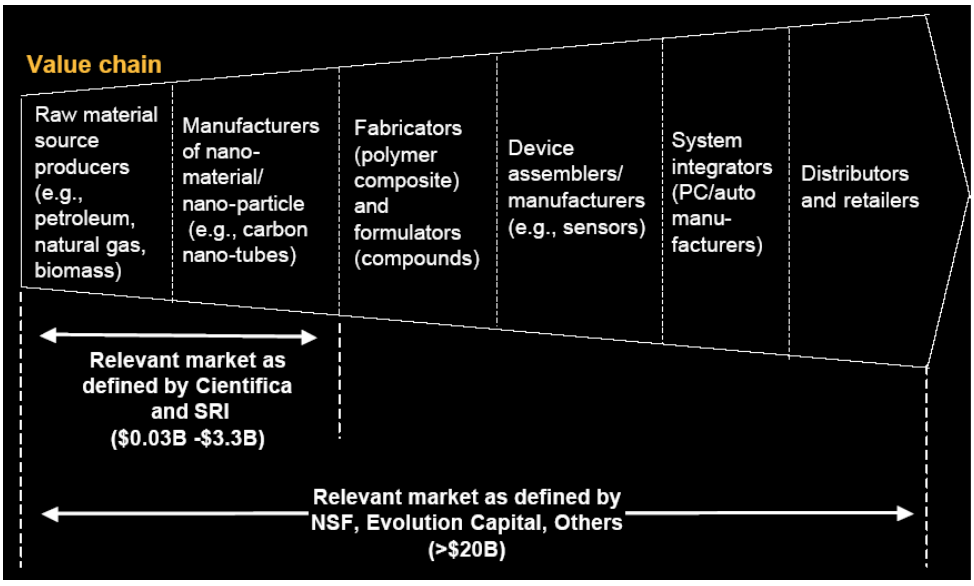


Figure 5: Based on the nanotech market definition effect on market forecasting[7]

[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.

Advanced Materials Sector Report

Technology Roadmap Project

Prepared by:

ADVANCED MATERIALS

Introduction

This summary provides an overview of advanced materials, in order to assist in the identification of a few sub sectors that are of greater interest to CEG. Due to the vastness of the materials field, a brief overview and definition of materials and advanced materials are offered. Next, alternative ways in which activity associated to materials can create value in the economy and region are described. This is followed by a brief description of a number of different sectors that, based on their position in product lifecycle, technological lifecycle, current market size and market potential, appear to be among the most attractive areas to focus on.

'Materials' is a very inclusive term, since it is the basic building block of all physical products. Materials are typically broken down into five groups: metals, polymers (thermoplastics and thermosets), ceramics, glasses and composites. This delineation offers insights into likely applications, since these materials have very different atomic and structural properties leading to very different properties and suitability for different applications and purposes. The most common ways in which materials are categorized [1] are: by industry (based on the compatibility with the requirements of a specific industry), by application (such as pressure vessels), or by a material subgroup (such as martenitic steel or low-density polyethylene). In the case of industry, examples of delineations are: medical materials (compatibility with human body), electronic materials (focus is on electronic and optical properties), and aerospace materials (focus is on low weight and characteristics that limit the likelihood of catastrophic failure).

Advanced materials can be defined in numerous ways; the broadest definition is to refer to all materials that represent advances over the traditional materials that have been used for hundreds or even thousands of years. From this perspective advanced materials refer to all new materials and modifications to existing materials to obtain superior performance in one or more characteristics that are critical for the application under consideration. A more insightful and focused approach to advanced materials is to consider materials that are early in their product and/or technology lifecycle. In other words, there is significant room for growth in terms of the improvement of the performance characteristics (technology lifecycle) and their sales volume (product lifecycle). The latter definition is what will be focused on here. Prior to considering the advanced materials, some brief comments are offered on materials as an industry to demonstrate size and pervasiveness.

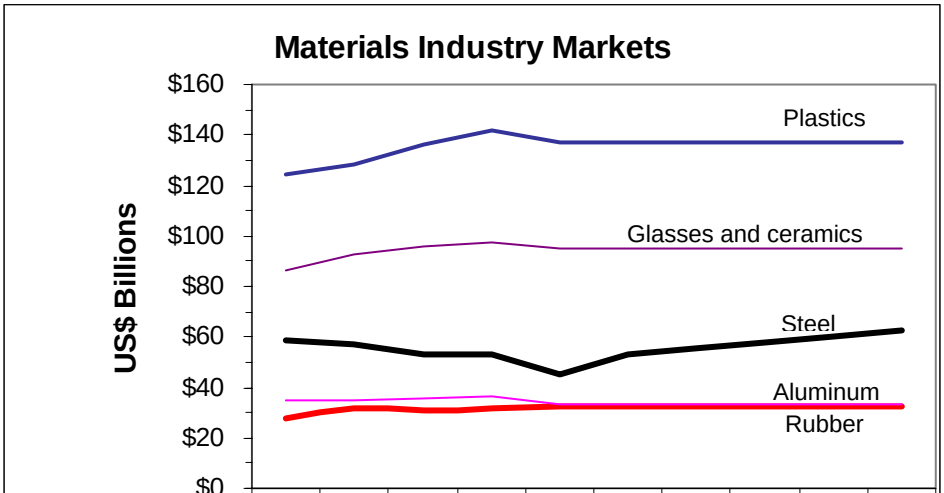
1. Market size

Market size figures are available for traditional materials, but are usually unavailable for emerging technologies (see Figure 1 below). If values are available for emerging technologies they are often based on the opinions of experts, rendering the forecasts as more of a guidepost than a decision making tool [2]. However, the market size for traditional materials is important, since it offers an indication of the potential market for advanced materials that replace traditional

[1] See for example: ASM Handbooks, ASM International, Metals Park, Ohio.

[2] Linton, J. D., *Determining Demand, Supply and Pricing for Emerging Markets and Technologies*, Technological Forecasting and Social Change, Volume 71, Number 1/2, pp. 105-120, 2004.

materials. From the figure, one can see that the market for traditional materials is fairly flat in terms of $ sales. However, it is important to take into account the dematerialization of most products. Over time products are providing the same level of benefit and value through the use of less material. In some cases this is the result of better use of existing materials. In other cases, dematerialization is driven by the use of smaller quantities of more expensive (on a per unit basis) advanced materials.



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Steel	58	57	53	53	45	53	56	58	60	62
Aluminum	28	31	31	32	33	33	33	33	33	33
Plastics	124	129	137	142	137	137	137	137	137	137
Rubber	35	35	35	36	33	33	33	33	33	33
Glasses Ceramics	86	93	96	97	95	95	95	95	95	95

Figure 1: Reported and predicted size of major US material markets [3]

The worldwide production of steel is about 780 million metric tons annually [4]. In 2002, the North American aluminum supply was 10 million metric tons (5.2% above 2001) [5] and the European aluminum market was about 7 million metric tons in 2003 [6]. The aluminum market is currently supplied by a mixture of secondary (metal from recycling) and primary (virgin material) production. Markets for polymers, both thermoplastics and thermosets, are large and continue to grow [7]. Since composites are a combination of other materials their volumes are included in the values reported above. Having given an indication of the size of the global

[3] Sources: Data for 1997-2001: Statistics for Industry Groups and Industries 2001 Annual Survey of Manufacturers, US Census Bureau, Department of Commerce Economic and Statistics Administration, Washington DC, 2003; Steel Data 2002-2006: Steel Industry Profile Reference Code: 72-998, Datamonitor, New York, 2002.; Other Data 2002-2006: Forecast based on regression of earlier sales.

[4] Steel Works Industry Yearbook, Jan2001/2002 (Business Source Premier) United States Steel: Datamonitor Industry Profiles; 2002.

[5] The Aluminum Association (Hwww.aluminum.orgH).

[6] The Aluminum Association (Hwww.aluminum.orgH).

[7] Thermoset production grew from 8,003 Million lbs to 8,312 Million lbs and the thermoplastics production grew from 85,828 Million lbs. Source: APC Plastics Industry Producers' Statistics Group (PIPS), as compiled by VERIS Consulting, LLC.

materials markets, the manner in which economic value can be extracted from materials is considered.

2. Value chain - extracting economic benefit from materials

There are a number of different ways that economic growth associated to advanced materials can occur. The most common types of businesses are briefly considered below:

- Materials production. Materials production facilities tend to offer a mix of unskilled, semi-skilled and skilled labor. The facilities tend to be large.
- Supply equipment or services to materials producers and processors. Producers and processors of materials require supply of capital equipment, consumables, and services. This is especially the case for advanced materials that often require new capital equipment, services with high knowledge value-added, new test equipment for in-process monitoring and out-going quality control. These businesses tend to have a smaller workforce with a higher skill set, but usually have low environmental impacts.
- Processing of materials into high-value added niche applications. These businesses focus on the needs of specific industries and/or applications and select or develop materials to offer these benefits. These firms can be very attractive, since a niche might be too small to attract major competitors, but large enough to offer a stable and profitable market. These businesses are typically in between the above mentioned businesses in terms of their employee mix.
- Development of a new process for the manufacture of materials. Businesses have been based on the production of a material using a new process. If the new process is successful, the result is a transfer of economic activity from the firms that utilize the old processes to the firm(s) that are pioneering the new processes. New manufacturing processes can be protected not only with patents, but with the concentration of tacit knowledge at or near the firm's site. Examples of this for new processes for existing materials include the Pilkington tin float process [8] and mini-mills at Nucor and Chapparal steel [9]. The risk associated with a new process is that the novel process may not succeed, for example the failure of the float zone process for the production of semiconductor grade silicon. Even riskier, but with greater upside potential, is the production of a new material with a new process; for example nanotechnology which is examined in detail in another section.

Having addressed different ways in which economic value can be extracted from advanced materials, some advanced material sub sectors with high growth potential will now be briefly described [10].

3. Significance for economic development

So far the size, breadth and the complexity of the materials field has been described. With such scope to work from hundreds of advanced materials sub sectors can be identified. This section

[8] Utterback James M., Mastering the Dynamics of Innovation: Haw companies can seize opportunities in the face of technological change, Harvard Business School Press, Boston MA, 1994.

[9] Linton, J.D. and Walsh, S.T. *A Theory of Innovation for Nanotechnologies and other Process-Based Innovations*, with Steven Walsh, IEMC-2003, Engineering Management Society of the IEEE, November 2003, Troy, NY.

[10] Due to the breadth and pervasiveness of materials it is not possible to offer a value chain at this level.

focuses on five areas that appear to have excellent potential. It is suggested that two areas be selected for further study. The areas to be considered are:

- Electronic materials
- Medical materials
- Nanomaterials
- Reprocessing of waste materials
- Superconductivity

The electronic materials sector is already a huge field with a large number of firms actively participating. This sector, however, offers tremendous potential since the field is undergoing rapid change to allow for continued miniaturization of components. This miniaturization provides new requirements for materials, processing and test equipment, consumables and services.

Medical materials have tremendous growth potential due not only to developed economy demographics, but due to its relatively primitive state. Historically, the most advanced medical materials were the domain of dentistry. However, greater attention has recently been focused on medical materials [11]. This attention considers the novel use of existing materials for medical purposes and hybrid methods which use new materials to assist the body in self repair. Medical materials typically are high value added, but regulatory requirements can create delays in commercialization and additional overheads associated with compliance to regulations.

The nanomaterials sector is worth considering separately from nanotechnologies, since it focuses on the development of a material while focusing on structure at the near atomic level. This offers the potential for materials with properties that are at their theoretical limit, thus able to vastly outperform existing materials and command a higher price. The industry is still young and there is a mixture of small, medium and large firms active in this area. This is an opportunity to target location of all sizes of firms, since the novelty of the material is such that firms will probably opt for Greenfield sites that provide some physical and intellectual distance from the manufacture of existing products and business units. Nanomaterials offer potential for all types of materials [12]. The domestic market is expected to be greater than US$ 1 billion, by 2007, as a result of the application of nanotechnology in many different types of materials for a wide range of product applications [13].

Superconductivity, the ability to transfer electricity across great distance without losses through resistance, was the focus of tremendous interest in the mid to late 1980's, due to a string of discoveries. These discoveries found that materials based on oxides of rare-earth metals exhibited superconducting properties well above absolute zero. The premature hope was that a material would be found which is superconducting at room temperature. However, within the last

[11] Interest has increased significantly recently. Consequently, the ASM held its first conference on Medical Devices in September of 2003. This is significant, since this is one of the major sectors that was not being directly addressed by materials associations meetings.

[12] For example see: Lowe, T., The Revolution in NanoMetals, Advanced Materials and Processes, pp. 63-65. January 2002.

[13] Freedonia Group, Nanomaterials to 2007 – Market Size, Market Share, Demand Forecast and Sales, Cleveland, Ohio, 2003.

year a new form of matter that has superconducting properties has been discovered. This discovery should accelerate research and eventual development of superconducting materials. This field has tremendous future potential, but is risky since it is still far from development and the timeline for development is not clear.

Reprocessing of waste materials is different from the other sub sectors that have been considered so far, since it is based on legislation in North America, Europe and Asia. In many Counties, States and Countries laws that encourage or require reprocessing of post consumer waste are in place, pending or under development. The most notable examples are the decade old German laws requiring the take-back and recycling of packaging materials and the more recent European Union requirement for all member countries to take-back and reprocess post consumer electronic waste. Similar regulations are enacted or under consideration in many US jurisdictions [14]. Reprocessing of post consumer waste can be in the form of remanufacturing (product recovery) or recycling (material recovery). These markets will continue to grow in the future due to legislative requirements. In the case of recycling, opportunities are expected to be co-located with the waste producing population since it is a low value added process and is greatly affected by the cost of transportation. However, remanufacturing (product recovery) can be high value added. Significant remanufacturing operations currently exist in the United States, but the industry is relatively invisible since it is not recognized as an industry [15]. Remanufacturing has been described as attractive for economic development, since it requires high levels of unskilled labor [16]. The coupling of future growth due to changes in legislation in the US and abroad with the high labor intensity makes this an interesting sector to consider further.

4. Summary

The field of materials has hundreds of sub sectors that constitute advanced materials. Five of these sub sectors have been briefly considered. As the potential of a sub sector increases, so does the risk since the market potential remains undeveloped and clear. From least risky to most risky (least potential to most potential economic development potential), the sub sectors are roughly in the order: electronic materials, reprocessing of waste materials, medical materials, nanomaterials, and superconductors.

[14] Linton, J.D., and Yeomans, J.S. *Materials Recycling and Industrial Ecology*, Nature Materials, Volume 3, Number 4, pp. 199-201, 2004.

[15] Participant firms are counted in the industry that their product is sold to. For example automotive remanufacturers are grouped with automotive component manufacturers. This has led to Robert Lund referring to it as a hidden giant, see Lund, R. *The Remanufacturing Industry: Hidden Giant*. Boston University, Boston MA. 1996.

[16] Lund, R. *Remanufacturing: United States experience and implications for developing nations*, The World Bank: Washington, DC. 1983.

Biotechnology Sector Report

Technology Roadmap Project

Prepared by:

BIOTECHNOLOGY / LIFE SCIENCES

1. Defining the biotechnology industry

1.1 Definition of biotechnology industry by technology:
Biotechnology, as a term used to define a set of technologies, usually refers to the application of molecular and cellular processes to solve problems, conduct research, and create goods and services. Under this technology based definition, biotechnology includes a diverse collection of technologies that manipulate cellular, subcellular, or molecular components in living things for applications in various scientific fields and industries such as medicine, animal health, agriculture, marine life, and environmental management [1]. A relevant term also used for core biotechnology-based companies is **life sciences or biosciences companies** and these terms will be used interchangeably with **biotechnology** in this report. Companies in the biotechnology industry are most frequently classified into the two following industrial NAICS codes:

NAICS 5417 – Scientific Research and Development Services
NAICS 541710 (SIC 8731) R&D in the Physical Engineering and Life Sciences;
and
NAICS 3254 Pharmaceutical and Medicine Manufacturing
NAICS 325411-325414 Medicinal, Botanical, Pharmaceutical preparation, in vitro
(SIC 2833-2836) diagnostic substance and biological product manufacturing

1.2 Definition of biotechnology industry by application [2]:
Biotechnology as a technology has an impact on several industries broadly classified as:

Human and animal therapeutics and diagnostics – including biopharmaceutical companies
Also includes tool developers - genomics, bioinformatics, proteomics companies and companies developing advanced materials for human therapeutics
NAICS 3254 Pharmaceutical and Medicine Manufacturing
NAICS 5417 Research and Development in the Physical, Engineering, and Life Sciences

Agriculture, aquaculture, animal health and food – includes seed and livestock development.
NAICS 3253 Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing
NAICS 32519 Other Basic Organic Chemical Manufacturing
NAICS 11511, 11521 Support Activities for Crop and Animal Production
NAICS 112 Animal Production; raise animals for the sale of animals or animal products
NAICS 5417 Research and Development in the Physical, Engineering, and Life Sciences

Industrial and agriculture derived processing – including chemical manufacturing companies
NAICS 32519 Other Basic Organic Chemical Manufacturing
NAICS 32531, 32532 Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing

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[1] *A survey of the use of biotechnology in U.S. industry*, US Dept of Commerce publication, October 2003.
[2] European Classification of Biotechnology: EuropaBio has given biotechnology applications a color to help differentiate between them. White biotech mostly refers to the industrial manufacturing of products using microorganisms and enzymes to make goods like vitamins, detergents, biofuels, etc. Green biotechnology refers to biotechnology used in agricultural applications and red biotechnology deals with biotechnologies applied to human medicine, diagnostics and new therapies.

Environmental remediation – including utilities, petroleum industry.
NAICS 5629 Waste management and remediation services

However, the majority of biotechnology companies (58%[3] to 74%[4]) are focused on health care applications, with 98% of all economic activity in this sector reported by these life sciences companies [4]. Since these companies incorporate the critical leading advances in genomics, proteomics and related technologies and science, they also serve as leading indicators of the growth in other applications of the life sciences and are used as the primary group for analysis of this technology / industry.

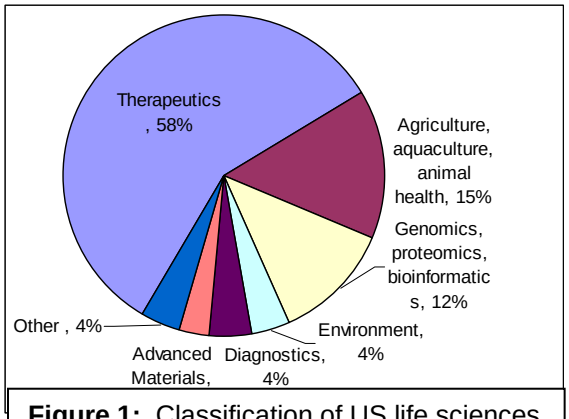


Figure 1: Classification of US life sciences companies [3]

Within the above broad classifications, there are many sub-sectors defined by a complex mix of technology class and application space. However, it is equally necessary to define what biotechnology is not. Biotechnology does not include medical technology (devices and instruments), high-tech medicine or medical informatics for medical records, as these disciplines are unconnected to genetic and cellular manipulation. An important exception to this group is the production of software and tools for gene sequencing and analysis (bioinformatics).

An extension of the pharmaceutical industry? Among health applications, biotechnology companies are primarily defined as those with services and products based on life sciences, not traditional chemically synthesized products, as typical in the pharmaceutical (pharma) industry until a few decades ago. However, these distinctions are blurring as mature biotechnology companies are slowly becoming indistinguishable from large pharmaceutical companies.

2. Industry status, markets and outlook:

2.1 Current Status in USA

There are about 1,466 life sciences firms in the U.S., employing a total of 194,600 persons. Between 1993 and 1999, the industry doubled in size. The life sciences industry is dominated by small firms: the median biotechnology firm has 31 employees, annual revenues of $4.5 million, and is highly dependent on innovation for continued financing.

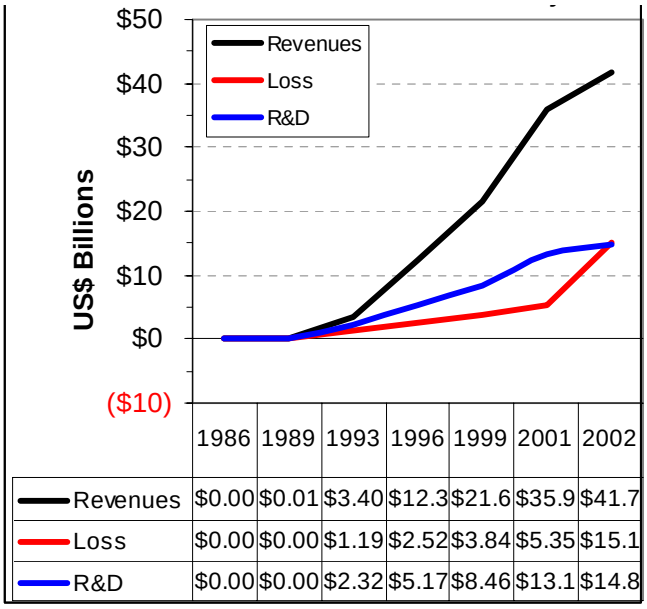
There are more than 370 biotech drug products and vaccines currently in clinical trials targeting more than 200 diseases, including various cancers, Alzheimer's disease, heart disease, diabetes, multiple sclerosis, AIDS and arthritis [5]. This is an R&D intensive industry, which spends an

[3] *Resilience*: *Americas Biotechnology Report*, Ernst and Young, 2003
[4] *A survey of the use of biotechnology in U.S. industry*, U.S. Department of Commerce Technology Administration and Bureau of Industry and Security publication, October 2003.
[5] Biotechnology Industry Organization www.bio.org

average of $121,000 per employee on R&D (compared to pharma's $30,600), and employees workers with an average wage about 85% higher than the average for all other sectors.

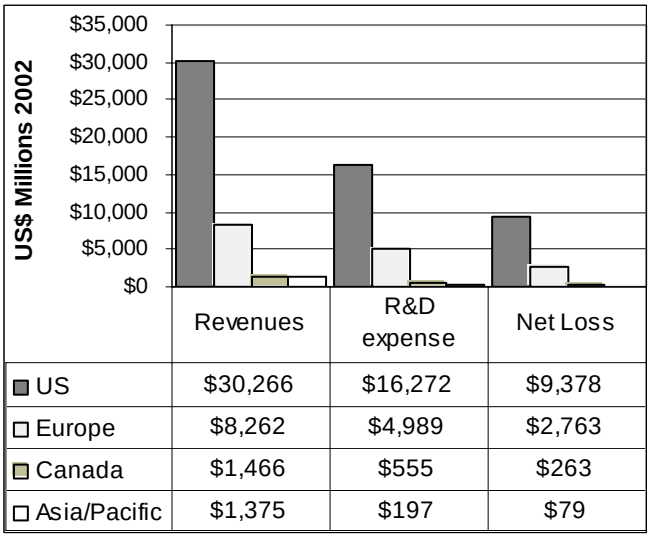
2.2 Global revenues distribution

Globally, the industry generated revenues of about $43 billion in 2002, with the bulk of those revenues ($30 billion) captured by US companies (Figure 2, 3) [6]. These revenues have shown a 20% growth rate over the last few years and are projected to continue at this rate for the next four years, exceeding $125 billion by 2008. Correspondingly, the total number of life sciences companies in the US continues to grow (Figure 4, 5) with active mergers and partnering.



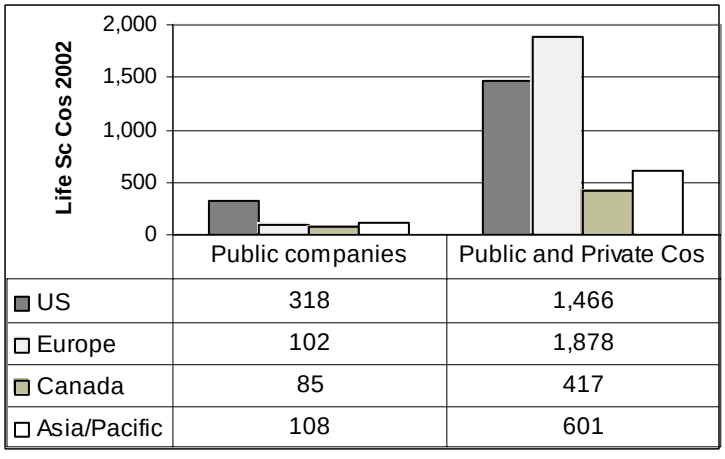
	1986	1989	1993	1996	1999	2001	2002
Revenues	$0.00	$0.01	$3.40	$12.3	$21.6	$35.9	$41.7
Loss	$0.00	$0.00	$1.19	$2.52	$3.84	$5.35	$15.1
R&D	$0.00	$0.00	$2.32	$5.17	$8.46	$13.1	$14.8

Figure 2. Global financials[7]



	Revenues	R&D expense	Net Loss
US	$30,266	$16,272	$9,378
Europe	$8,262	$4,989	$2,763
Canada	$1,466	$555	$263
Asia/Pacific	$1,375	$197	$79

Figure 3. Global distribution of revenues



	Public companies	Public and Private Cos
US	318	1,466
Europe	102	1,878
Canada	85	417
Asia/Pacific	108	601

Figure 4: Global distribution of life sciences companies

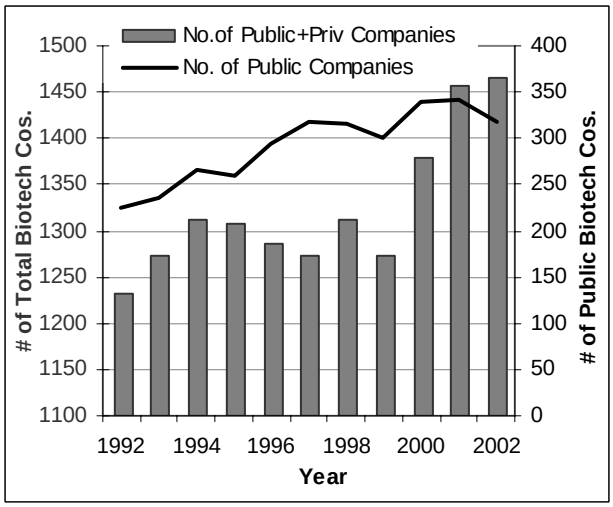


Figure 5: US life sciences companies growth

[6] *Beyond borders*: *The global biotechnology report*, Ernst and Young, 2003.
[7] Source: *Nature Biotechnology* – presentation by editor

2.3 USA regional distribution of life sciences companies

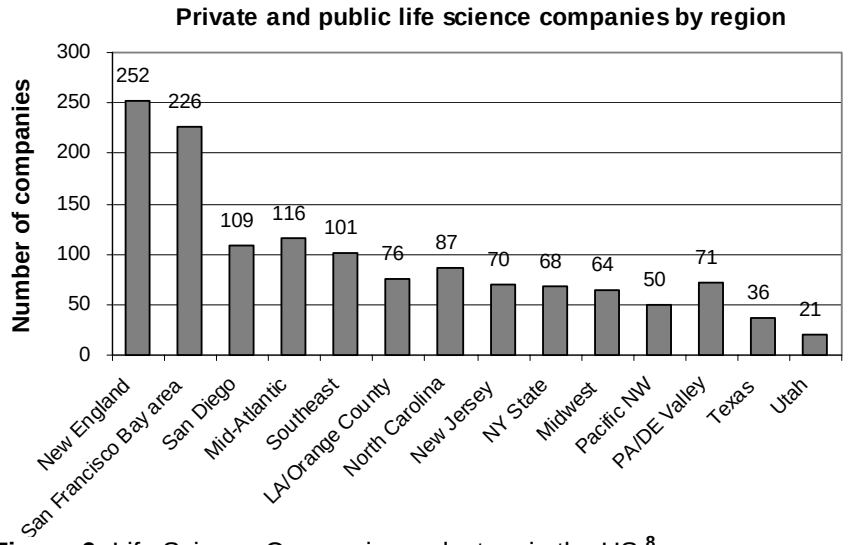
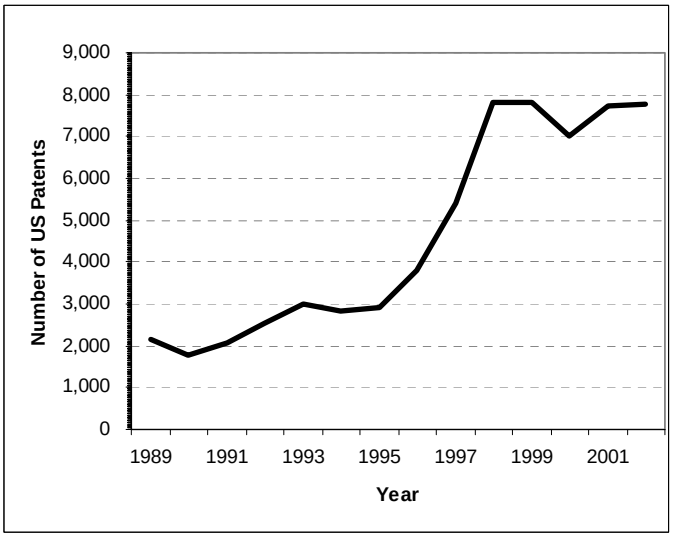


Figure 6: Life Science Companies – clusters in the US [8]

These US companies are primarily located in nine metro areas. These nine areas account for three-fourths of the nation's largest biotechnology firms and for three-fourths of the biotech firms formed in the past decade.

Cortright, J and Mayer, H, *Signs of Life*, The Brookings Institution Center on Urban and Metropolitan Policy, 2002.

3. Technology trends



Patent data underscore the dynamic and rapidly evolving nature of biotechnology. Patents are vital to the development of this industry. In the last quarter of 2002, respondents to the Department of Commerce survey of biotechnology companies indicated that they had pending U.S. patent applications for 33,131 new biotech-related products or processes, compared to 23,992 current U.S. biotechnology-related patents in their portfolios [9].

Figure 7 Biotechnology patents in USA
Sources: US Patent and Trademark Office and BIO

3.1 Key technology milestones:

The modern concepts of life sciences could reasonably be said to have started with the elucidation of the structure of the DNA molecule by Watson and Crick in 1953. The application of biotechnology in the pharmaceutical industry started in the mid-1970s, with the development of key scientific techniques, mainly genetic engineering and antibody production.

[8] *Global Biotechnology Industry Report: Beyond Borders*, Ernst & Young LLP, 2003 and www.bio.org.
[9] *A survey of the use of biotechnology in U.S. industry*, U.S. Department of Commerce Technology Administration and Bureau of Industry and Security publication, October 2003.

However, an industry that started off with these two basic technologies in 1985, recombinant DNA (rDNA) and monoclonal AntiBody (mAB) production, has now accumulated several breakthroughs in its technology platforms, leading to an ever-increasing range of applications going beyond basic manufacturing techniques to enhance the entire supply chain in drug and diagnostic development as shown in Figure 8 [10].

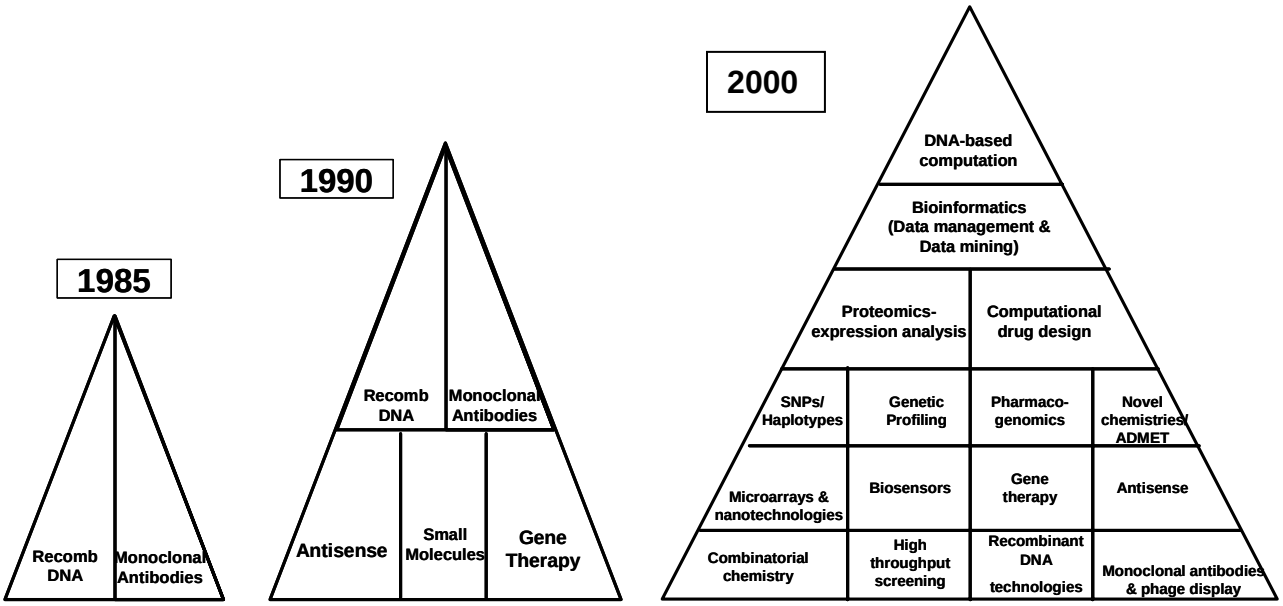


Figure 8: Technology evolution and growth in the life sciences.[9]

3.2 Emerging and existing technologies in the life sciences industry

DNA-based:

HapMap (Haplotype Map) Project (completion date 2005),diagnostic gene testing; gene probes, DNA markers, DNA chips, Bioinformatics, Genomics, pharmacogenetics, DNA sequencing/synthesis/, amplification, genetic engineering, gene therapies and vaccines.

Biochemistry/Immunology:

Vaccines/immune stimulants, drug design & delivery, diagnostic tests, antibiotics, synthesis/sequencing of proteins and peptides, cell receptors/signaling, structural biology, combinatorial chemistry, 3-d molecular modeling, biomaterials, microbiology, virology, microbial ecology, proteomics; metabolomics.

Bioprocessing-based:

Culturing/manipulation of cells, tissues, embryos, stem cells, gene therapy, extractions, purifications, separations, Fermentation, bioprocessing, biotransformation.

Environmental:

Bioleaching, biopulping, biobleaching, biodesulfurization, bioremediation, biofiltration

3.3 Overlap with other emerging technology areas

Recent discovery, development, and application of life sciences are not only creating entirely new types of products and services, but biotech processes and products are now applied in all types of manufacturing, agriculture, aquaculture, and even at the microbial and nano-scales. Biotechnology has convergent applications with other technologies such as IT, Nanotech, Advanced Materials and Energy as reflected in Figure 8.

[10] Figures adapted from Alta Partners data presentation.

4. Industry drivers

The surge in public companies in the year 2000 in the USA resulted from the confluence of a number of coincident singular events – a large number of biological product approvals (32), lively public financing markets with high valuations and appetite for new technologies and the completion of the Human Genome Project [11]. Although the number of product approvals per year has since dropped to 24, it is expected to stabilize to about 21 per year over the next few years [12]. The Human Genome project brought the life sciences industry to the public view and the interest in this industry continues unabated, largely due to its potential to significantly impact our daily lives and health.

4.1 Demographics

An aging population worldwide will spend more on health care over the next few decades, driving growth in the health care industry, in which life sciences plays a key role. The global population over 65 years of age is forecast to rise from 380 million in 1997 to nearly 700 million by 2025. In the US alone, people 65+ represented 12.4% of the population in the year 2000 but are expected to grow to be 20% of the population by 2030. The elderly are the single largest group of users of prescription drugs, consuming three times as many pharmaceutical medicines as younger patients do. These demographics ensure an expanding global market for cutting-edge biotech, pharmaceuticals, and medical devices.

4.2 Financing

The life sciences industry is still in net loss and its long and expensive development cycles need external capital. The presence of private and public investments has been mentioned as a driver. There continues to be an influx of capital into the industry from government, venture capital, public markets and pharmaceutical partnerships.

NIH: Total NIH spending for research has more than doubled during the 1990s, from about $6.5 billion in 1991 to more than $13 billion in 2000. Congress approved a total fiscal-year 2003 budget of more than $27.3 billion for NIH, an increase of 16% over the previous fiscal year; however, the 2004 budget has only a 1% increase over the previous year [13].

Venture capital: The biotechnology industry raised $2.1 billion in all venture capital financing in 2002, and almost $2.5 billion in 2003, which is greater than twice the 1997 levels of $1 billion [14]. Proximity to venture capital is a key factor in the formation and growth of life science clusters.

Pharmaceutical R&D Investment, Outsourcing and M&A: The pharmaceutical industry acts as the commercialization arm for life sciences companies and plays a significant role in financing. Global pharmaceutical R&D is projected to grow to about $70 billion in 2007 from $41.8 billion spent in 2000 [15]. The R&D outsourcing market is predicted to grow from $9.3 billion in 2001 to $36.0 billion by 2010, representing an average annual growth rate of 16.3%.

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[11] http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml Last accessed 15 March 2004.
[12] Acumen Journal, Vol II, Number II, p.45. March 2004
[13] www.nih.gov National Institutes of Health website.
[14] *Resilience: Americas Biotechnology Report* Ernst and Young, 2003.
[15] *Parexel's Pharmaceutical R&D Statistical Sourcebook*, Parexel Inc., 2003.

Contract research organizations will focus increasingly on higher profitability services such as preclinical and bioanalytical testing, laboratory services, drug discovery and informatics [16].

4.3 New discoveries, products and technologies

All life science industry clusters are located in proximity to a major research university with high levels of NIH funding [17]. Increasing levels of biotechnology patents are driving the industry growth, as many small firms develop and sell these patents to large pharma or other partners to finance their internal R&D and continue innovating. New technologies that are being developed through aggressive R&D investments and the introduction of new products is a primary driver for growth in the industry.

4.4 Regulatory changes

Regulatory uncertainty remains very high, with only 70% - 75% of submitted applications making it past the final review process. However, recent changes are positive for the industry. The FDA approval cycles have been shortening (from over 20 months to 12 months in 1999 before going up to a 15 month approval cycle in 2000) with increased efficiency and better guidance being issued. The percentage of NMEs (new molecular entities) that are approved within 12 months of submission has remained relatively constant in recent years at around 40% [18]. The FDA has committed to working closely with sponsors to help prevent repeat submissions.

5. SUMMARY

5.1 Relevance to economic development

As healthcare expenditure already equals about 14% of the national GDP and continues to grow, there is little doubt that the life sciences industry will play a major role in the economy of the country and of the globe. Some estimates put the life sciences occupying about 12-14% of the GDP over the next two decades, making it a multi-trillion dollar industry.

This relatively new industry already has a significant impact on regional and national economies. In 1999, the combined direct, indirect and induced activities of the life sciences industry contributed a total of 437,400 jobs and $47 billion in business revenues to the U.S. economy. The public sector also benefited significantly from the life sciences industry through additional federal, state and local taxes, estimated to be $10 billion in 1999 [19].

Direct impact - $20.2 billion in 2001 from revenues, with 150,800 employees supported.
Indirect impact through purchases of equipment, materials, services etc = $4.8 Billion in revenues to non life sciences companies, with 45,000 employees supported in these companies
Induced impact: purchases, exchange of goods and services = revenues of $21.5 Billion into the consumer goods and services industry, with 241,600 employees supported in this industry.

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[16] *Pharmaceutical R&D outsourcing strategies*, Reuters Business Insight Healthcare report: 2002.
[17] Cortright, J. and Mayer, H., *Signs of Life*, The Brookings Institution Center on Urban and Metropolitan Policy, 2002.
[18] US Food and Drug Administration www.fda.gov
[19] "Economic Contributions of the Biotech Industry to the U.S. Economy," report prepared by Ernst & Young for the Biotechnology Industry Organization (BIO), May 2000 (accessed at www.bio.org).

It has been estimated that for every direct job created by life sciences, roughly two additional indirect jobs are created in support services such as business supplies and legal services and in related consumer spending [20].

According to the Brookings Institute report on life sciences cluster formation:

> **The formation and flourishing of biotechnology firms ought ultimately to be the objectives of biotechnology development strategies and the result of an effective combination of research capability, knowledge creation activity, and investment capital.**

5.2 Sub sector attractiveness and growth listed in decreasing order of attractiveness

Sub-sector	Technology/ Product	Growth	Issues, Drivers
Biopharmaceutical companies	Primarily human monoclonal antibodies and biological drugs, vaccines.	16-20% CAGR growth over the next four years. US public companies revenues increasing to about $60 billion by 2007. (E&Y, industry reports, BCC research reports, BIO)	Expected new biologic products approvals (accounting for failures in current pipeline of over 370 products) in the next four to six years.
In vitro diagnostics and biosensors (includes clinical diagnostics) **Research Tools** such as – Drug target screening, ID and validation	Nucleic tests, Microarrays, laboratory testing, point-of-care testing, Bioinformatics, Pharmacogenomics, Proteomics	Worldwide (WW) 2003 $ 23 billion 15-20% growth over next four years (NES reports) 2007 $48 billion 2010 $83 billion (Sources: Kalorama Information Research and BCC research reported in Acumen vol II(II): 60, Mar 2004; NES reports.)	Acceptance of surrogate markers in clinical trials, increasing use of tools to assess drug failure or success before in vivo testing. High throughput technologies and automation, partnership between therapeutics and diagnostics. Overlap with materials and nanotech sectors.
Industrial Biotech (White biotech)	Bioprocessing; biomanufacturing novel enzymes.	By 2010 industrial biotech will generate about $470 billion WW with a $160 billion value impact on chemicals. (Burrill and Co. Dec'03)	Industrial biotechnology applications are increasing within established industries – food processing, energy, chemicals, environmental remediation.
Gene and cell therapy (regenerative medicine)	Cell replacement, gene delivery, siRNA, stem cell research, cancer therapies.	Cell therapy market WW is about $20.2 billion in 2002, $35.7 billion projected by 2007. (Jain Pharmabiotech reports). The global market for regenerative medicine could be worth in excess of $30 billion in 10 years (Cambridge Consultants report).	The emphasis will continue to be on cancer therapy as the first products to reach market. Delivery systems being improved. (BCC research) Stem cells, cardiology, bone and joint, skin applications are also in forefront of regenerative medicine.
Bioinformatics	Data analysis and advanced computing in biological research.	Projected to exceed $1.5 billion by 2005. (NES research)	Increasing automation in experiments, data glut, interest in in silico biology. Intersection with IT sector.
Ag-Bio / Food	Agriculture R&D; plant and animal genetics; agri- products processing.	Top 10 global AG-Biotech companies had global revenues of $22 billion in 2002, 4% increase over 2001.	New varieties of plants being brought on the market and acreage of GM crops increasing annually. Functional foods increasingly accepted globally.

Related sub-sector of interest:

Sub-sector	Technology/ Product	Growth	Issues, Drivers
Laboratory products	Chromatography, electrophoresis, cell culture incubators, centrifuges Media, Sera and reagents	1996: $1.75 B; 2001: $2.17 B Filters 37% growth; Bioseparations 31% growth over next five years (Source: NES reports) U.S. market for media, sera and reagents is expected to be $915.6 million in 2003. It is further expected to grow at an AAGR (avg annual growth rate) of 13.1% and reach $1.7 billion by 2008.	Increased biopharmaceutical manufacturing demand with more mAB product approvals. Biomanufacturing is increasing and revolution in cell culture techniques is taking the research to commercial scale processes. (BCC reports.)

[20] "Economic Contributions of the Biotech Industry to the U.S. Economy," report prepared by Ernst & Young for the Biotechnology Industry Organization (BIO), (accessed at www.bio.org). May 2000.

Glossary

ADMET	acronym for parameters used to understand drug behaviour in a living system Absorption, Distribution (among the tissues), Metabolism, Excretion and Toxicology
Antisense	A nucleic acid sequence that is complementary to the coding sequence of DNA or mRNA.
Bioinformatics	The use of extensive computerized databases to solve information problems in the biological sciences. These databases generally contain protein and nucleic acid sequences, genomes, etc. Bioinformatics also encompasses computer techniques such as 3-D molecular modeling, statistical database analysis, data mining etc.
Cellular	pertaining to the functioning of single cells or cell types that make up a particular tissue
Chromatography	A process in which a chemical mixture carried by a liquid or gas is separated into components as a result of differential distribution of the solutes as they flow around or over a stationary liquid or solid phase
Electrophoresis	A method of separating large molecules (such as DNA fragments or proteins) from a mixture of similar molecules. An electric current is passed through a medium containing the mixture, and each kind of molecule travels through the medium at a different rate, depending on its electrical charge and size. Separation is based on these differences. Agarose and acrylamide gels are the media commonly used for electrophoresis of proteins and nucleic acids
Gene sequencing	The process of determining the sequence of nucleotides in a particular piece of DNA. Also called DNA sequencing
Gene Therapy	Treatment that alters genes (the basic units of heredity found in all cells in the body). In early studies of gene therapy for cancer, researchers were trying to improve the body's natural ability to fight the disease or to make the tumor more sensitive to other kinds of therapy. This treatment may involve the addition of a functional gene or group of genes to a cell by gene insertion to correct a hereditary disease.
Genomics	The identification and functional characterization of genes.
In silico biology	The use of computational algorithms to create virtual systems that emulate molecular pathways, entire cells, or more complex living systems. The use of computers to simulate or analyze a biological experiment.
Metabolomics	The study of the whole metabolism of an organism.
Microbiology	A branch of biology dealing especially with microscopic forms of life
Molecular components	Individual macromolecules of cellular mechanisms are proteins, glycoproteins, lipids and sugars.
Monoclonal AntiBody (mAB)	Highly specific, purified antibody that is derived from only one clone of cells and recognizes only one antigen

Phage display	A technique in which phage are engineered to fuse a foreign peptide or protein with their capsid (surface) proteins and hence display it on their cell surfaces. The immobilized phage may then be used as a screen to see what ligands bind to the expressed fusion protein exhibited (displayed) on the phage surface
Pharmacogenomics	Pharmacogenomics is the study of the stratification of the pharmacological response to a drug by a population based on the genetic variation of that population.
Proteomics	The study of gene expression at the protein level, by the identification and characterization of proteins present in a biological sample.
Recombinant DNA (rDNA)	A combination of DNA molecules of different origin that are joined using recombinant DNA technologies.
Subcellular	Below the cellular level.
SNPs	SNP -- pronounced "snip" -- is short for "single nucleotide polymorphism". A SNP is a place in the genetic code where DNA differs from one person to the next by a single letter. These slight genetic variations between human beings may predispose some people to disease and explain why some respond better to certain drugs. See also pharmacogenomics.
Virology	Study of viruses

Energy Sector Report

Technology Roadmap Project

Prepared by:

ENERGY

1. Segments and sub sectors

The energy sector can be classified broadly based upon the primary *sources*: fossil, nuclear, hydroelectric, and renewable categories. The nonrenewable energy sources are exhaustible and comprise more traditional sectors such as coal, natural gas, and petroleum. As the name suggests, the renewable energy sources emphasize recycling energy gained from sources such as wind, wave, solar, geothermal, biomass, and waste. These energy categories have spawned a whole range of products and services that can be viewed as making up the value chain in the respective sub sectors. In terms of economic activity, a major difficulty in identifying energy sectors is represented by the fact that the boundaries between energy goods and services are blurred. This unified approach to energy is probably explained by the market structure of the sector. Until recently the energy sector has been dominated by state-owned, vertically integrated companies, which performed all energy related economic activities, from the production of energy to its distribution to the final consumers. In recent years, privatization of public suppliers and complete or partial deregulation in the sector has led to a separation of energy related economic activities and to the identification of energy services as distinct form energy goods. Following is a qualitative description of the various sub sectors in the energy industry [1].

- *Coal:* This sector includes the extraction of all types of coal (hard coal, lignite, peat) as well as associated preparation processes including cleaning, crushing, screening and sizing of coal.
- *Petroleum:* Activities in this sector include exploration and extraction of crude oil, drilling, completing and equipping wells services activities in support of oil exploration and production and the manufacture of refined petroleum products (gasoline, kerosene, distillate fuel oils, residual fuel oils, lubricants, and so forth).
- *Electricity:* The supply of electricity involves several activities including: purchasing of fuel; constructing power stations and generating electricity; expanding, operating and maintaining transmission and distribution networks; trading bulk electricity (both nationally and internationally); supplying and metering; and operating customer billing and accounting systems.
- *Gas:* Exploration and production of natural gas is closely linked to exploration and production of oil and the establishments involved in these activities are often also involved in transmission and distribution.
- *Nuclear energy:* Nuclear energy activities involve: (a) production of uranium from open pit or underground mining methods; (b) the conversion of uranium oxide into uranium hexafluoride (representing 3% of the total cost of the fuel), which possesses the required chemical purity for enrichment and fabrication; (c) enrichment by means of gas diffusion or centrifugal separation (25% of total cost); (d) fuel fabrication, where the enriched uranium is used to produce the final fuels elements to be placed into the reactors (11% of

[1] World Trade Organization, *Background Note by the Secretariat*, Energy Services, C/W/52, Council for Trade in Services (98-3480). 1998.

total cost); (e) production of secondary energy from nuclear reaction; (f) storage (disposal) and reprocessing of discharged fuels.

- *Renewable energies:* Renewable energy sources are not depleted by their exploitation to produce electricity, heat or liquid fuels. Renewable energies include: hydroelectric power, biomass, geothermal energy, wind power and solar energy. With the exception of biomass (the conversion of wood, wood residues and crops into heat, electricity or liquid fuels), renewable energy is almost free of pollution.

The North American Industry Classification (NAIC) for the energy sector is summarized in Table 1. This classification is consistent with the aforementioned description of sectors within the energy industry.

TABLE 1. North American Industry Classification System (NAICS) codes for various sub sectors in the energy industry

2002 NAICS	1987 SIC	Corresponding Index Entries
237130	1629	All energy power plant construction except hydroelectric
237990	1629	Power plant, hydroelectric, construction
221119		Electric power generation, (except fossil fuel, hydroelectric, nuclear) solar, tidal, wind, electric

Source: US Census Bureau

2. Industrial life cycle

2.1 Market growth

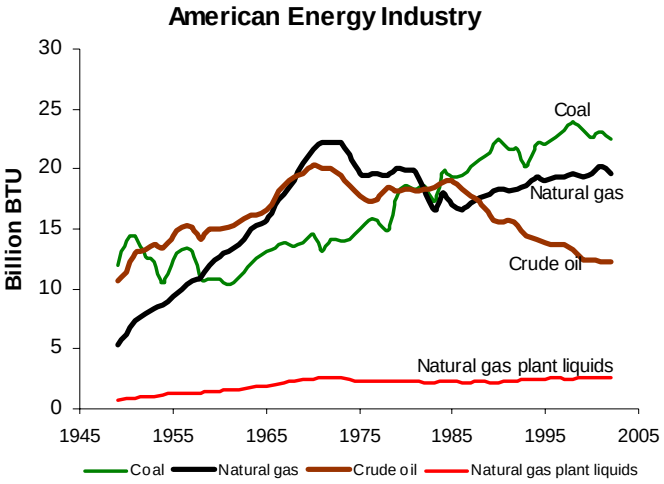
The energy industry is relatively large and global – of the order of trillions of dollars annually. Corresponding to the massive size of the energy industry, growth rates for the conventional forms of energy are relatively modest – in the range of 1-3% per year. This is to be expected: these segments of industrial activity are so mature that they simply cannot grow much faster than population or economic growth. North America is the largest consumer of oil in the world, accounting for more than one-fourth of total demand in 2001. Oil consumption in the transportation sector currently represents 66 percent of North America's total oil demand [2]. That share is expected to continue to increase as oil use declines in other end-use sectors (for example, natural gas is expected to displace most oil use for electricity generation).

Even though the absolute values for the renewables are much smaller in magnitude several of the renewable energy sectors within the industry are growing at a very rapid rate. It is likely that such robust growth rates for renewable energy markets will continue in the future. Markets for renewable energy could grow by close to 30% per year for the remainder of this decade .

[2] Energy Information Administration (EIA), 2004. Report #: DOE/EIA-0484 (2003).

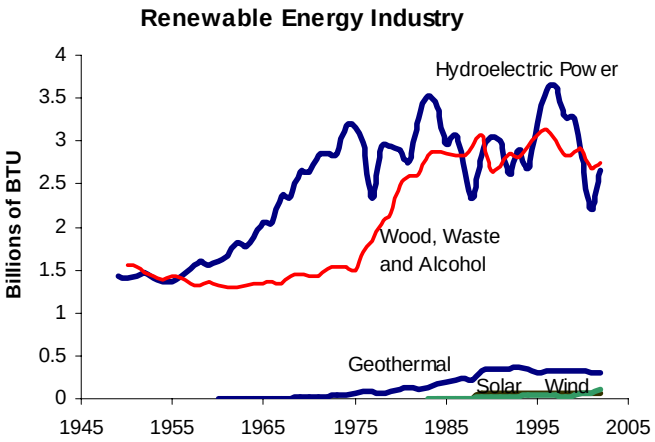
2.2 Market size

As seen in Figures 1A and 1B, the market size for conventional energy sources is much larger than that for renewable energy sources. The energy production for coal and natural gas shows a slight decline though they are the largest sources of energy production while the production from crude oil exhibits a declining trend. In the case of renewable energy sources, the production from hydroelectric power has been a major source up until 1975 and thereafter shows upward and downward swings. Energy production from wood, waste, and alcohol grew until around 1985 and shows a convergence with the production from hydroelectric power. While geothermal energy production has been in progress for some time, wind and solar energy production is relatively new and emerging.



Source: Department of Energy Annual Energy Review 2002

Figure 1A. Energy production (in BTU) for conventional energy sources



Source: Department of Energy Annual Energy Review 2002 (Table 1.2)

Figure 1B. Energy production market (in US$ Billions) for renewable energy sources

Figure 1. Market size in terms of energy production for various sub sectors from 1949 to present

2.3 Technology trends in industry

Some of the dominant technological trends in the energy industry are across the value chain, developing and modifying the industry structure constantly. Table 2 highlights the commercial applications and technology trends for various energy sources, likely to emerge within the next few years across the four stages of the value chain: extraction, processing and transformation, transmission, and retail and services. The technological innovations are primarily focused on the development of affordable energy that reduces costs and improves energy efficiencies. The general technological trend in the mature traditional sectors (such as, coal and gas) is visible on the services side of the value chain, although efforts are being made in the coal industry to improve processes in the front end of the value chain. On the other hand, several opportunities exist for development of new technologies at various stages in the value chain for renewable energy sources.

TABLE 2. Emerging or key technologies in various energy sub sectors and segments

Energy Source	Emerging or key technologies and trends by value chain segment			
	Extraction	**Processing and transformation**	**Transmission**	**Retail/Services**
Coal	Underground coal gasification. Coal and biotechnology	Integrated coal gasification cycle ; A combination of fluidized bed and gasification technologies; Direct coal combustion gas turbines; Ultra-supercritical steam Kalina cycle; Humid air turbine	Supercritical Pulverized Fuel (PF). Magneto-hydrodynamics (MHD)	Hydrogen – electrochemical Battery technology for electric and hybrid vehicles High speed rails
Gas			Fuel cells	Liquefied petroleum gas (LPG). Compressed natural gas (CNG). Methanol-powered flexible-fuel vehicles; Hydrogen; Fuel cells
Nuclear	Improved reactor and fuel management systems are being developed.		Reactor design concepts are being improved	
Wave		Further R&D is needed on the hydrodynamics	Ocean thermal energy conversion (OTEC)	.
Biomass	Development in the clean-up process, vessel sizes, the fuel-handling systems and the agricultural infrastructure needed to produce the energy crops			Sunflower, soya, groundnut, cottonseed, rapeseed, palm oil and castor oil. Biomass utilization technologies
Photo-voltaics	Cadmium telluride (CdTe) thin films and other materials. Copper-indium-diselenide materials			
Wind	Trends: Locating wind turbines in offshore locations.			
Solar thermal	Continuing R&D			
Hydro-electric	Hot dry rock used for geothermal energy…			

3. Value chain

The energy industry continues its transformation, driven by business imperatives to enhance customer value, meet industry-restructuring standards, and realize the benefits of economic and technological advances. As shown in Table 2, the energy value chain can be described using four segments, which are continually evolving through the combination of previously separate segments and the splitting of previously single segments into multiple segments. In the case of the oil and natural gas sector value chain, shown in Figure 2A (generated using publicly available data), a majority of the establishments in the value chain in 2002 are concentrated at the front and back ends of the value chain. However, although not shown in the figure, the retail segment is split into two to three markets, one focused on large customers, another focused on the mass market (both typically involving choice of retail energy supplier) and possibly a third market focused on the remaining regulated retail (including utility provider of last resort).

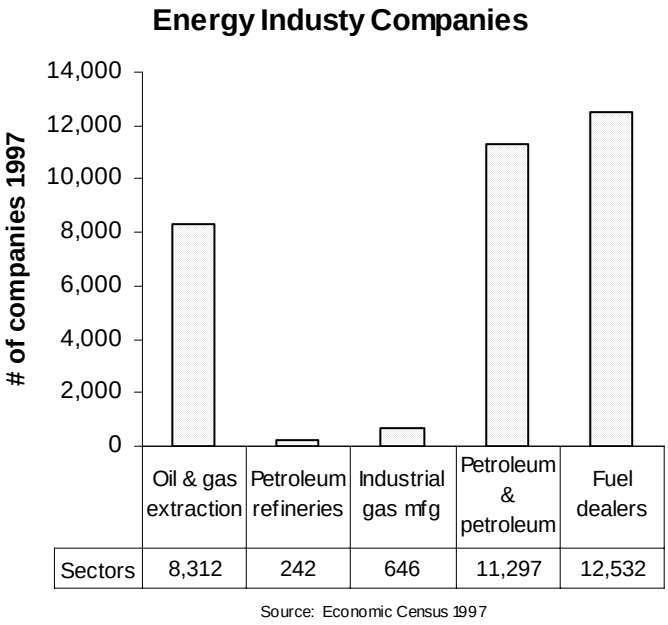


Figure 2A. Number of companies in the oil and natural gas value chain for the year 2002

The large oil and gas companies, with subsidiary operations in extraction, processing/wholesale, transmission, distribution, large customer retail, and mass-market retail, are representative of large players who seek to participate in most or all segments of the value chain. During 2001-05, despite the recent slow-down in deregulation and restructuring efforts in the U.S. market, a continued move toward separation in each segment of the energy value chain is expected to occur, with each segment forming a distinct business model. Although companies may choose to operate in some or all of these segments, the era of vertically integrated monopolies is phasing out gradually.

A dramatically opposite business strategy of horizontal specialization, where companies choose to focus on one or two segments of the value chain and possibly extend their capabilities to other similar industries, is pursued by the emerging companies in the renewable sub sector. As seen in Figure 2B, the renewable photovoltaic industry shows a simultaneous growth in almost all the value chain segments for both 2001 and 2002. However, the number of establishments in all the segments is relatively much smaller than those for oil and natural gas. The phenomenon of vertical integration evident in conventional energy sectors is markedly absent in the photovoltaic industry. Other strategies, which could be combined with either vertical or horizontal specialization, include convergence (a focus on multiple commodities such as electricity, gas, water, and telecommunication) and geographic reach (regional, national, and international). Each segment will focus on a primary value discipline as the basis for strategy.

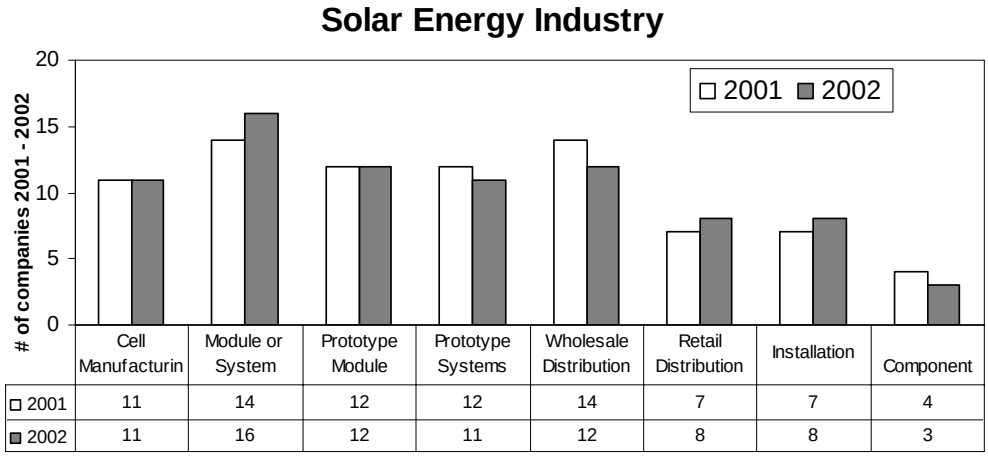


Figure 2B. Number of companies for segments in the photovoltaics value chain

4. Target for economic development

Defining a target for economic development in the energy sector is to choose between: a) expanding conventional natural gas power plants with or without inclusion of environmental costs (for example, whether CO_2 extraction is carried out or not), and b) renewable energy resources with virtually nonexistent environmental impacts. Natural gas power with CO_2 extraction will not be economically competitive (in price) compared to conventional production of gas power without calculation of these costs. Carbon extraction increases the costs of generating power with the use of fossil fuels and contributes to more realistic conditions of competition for renewable energy [3].

On the other hand, renewable energy sources enjoy the benefits of reduced energy costs, risk management by diversifying generation options, job creation and economic benefits, and environmental benefits. These benefits are well documented in the literature [4]. Electricity generated from oil is the most expensive of all forms of electricity from fossil fuel. As a result, if coal and natural gas are readily available, a very low fraction of electricity is produced from oil. Most renewable energy sources have little or no fuel cost. These include wind, hydro, solar, geothermal, Ocean Thermal Energy Conversion (OTEC), and wave. There may be costs associated with some types of biomass, but these costs tend to be more predictable and controllable [5].

Wages in the unconventional energy industry are bid above the national average for the energy industry as a result of rapid growth in labor demand [6]. As can be seen in the case of the photovoltaics industry (figure 2B) value chain, most of the local jobs would come from the installation, operation and maintenance, and marketing of the renewable systems. Jobs could arise indirectly from businesses that supply renewable energy companies with raw materials, transportation, equipment, and professional services, such as accounting and clerical services. The wages and salaries generated from these jobs provide additional income in the local economy. The National Renewable Energy Laboratory (NREL) reports that renewable energy is already bringing important economic benefits to the United States. For example, in 1996 the photovoltaic industry generated more that $800 million of revenues and employed 15,000 people at over 800 companies, most of them in high quality jobs, such as manufacturing, engineering, sales, installation, servicing and maintenance [7]. Renewable energy companies also contribute more tax revenue locally than conventional energy sources. In 1997, the United States spent about $65 billion dollars outside the country to pay for fossil fuels. But as one of the world's leading manufacturers of renewable energy systems, the United States can bring in more money with the increased use of renewable energy sources around the world. Currently, for example, the United States manufactures about two-thirds of the world's photovoltaic (PV)

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[3] Palm, T, Buch, C., Kruse, B., Sauar, S., *Green Heat and Power, Report* 3:1999

[4] GDS Associates, Inc., *Analysis of Renewable Portfolio Standard Options For Hawaii*. 2001.

[5] Energy Information Administration. *Electric Power Monthly*, December 2000 and HECO and MECO *FERC Form 1* and HELCO and KE *Annual Reports* for 1999.

[6] Sterman, John D., *The Energy Transition and the Economy: A System Dynamics Approach* (MIT PhD Thesis, Volume I., Sloan School of Management), pp. 2-3, 8-24, 352-369. December 1981.

[7] National Renewable Energy Laboratory, *Choices for a Brighter Future: Perspectives on Renewable Energy*. DOE/GO-1099-878. September 1999.

systems. U.S manufacturers export about 70% of these PV systems, mostly to developing nations, resulting in annual export sales of more than $300 million [8].

5. Conclusion

The analysis of the energy sector based on publicly available data indicates that the sector consists of a mix of both conventional and upcoming sources, which have led to the development of several sub-sectors. Major trends in the overall political and economic environment that are shaping this new global energy system include globalization, the information revolution, liberalization of national economies, and privatization of the industry. The conventional sectors are relatively saturated. The growth in the conventional arena is more likely to be related to the use of information technology to coordinate processes across the supply chain. The value in the conventional sector will result from providing more responsive services to customers at competitive prices. The energy efficiencies will result from a streamlined flow of goods and services throughout the value chain.

There could also be opportunities for economic development in integrating the two types of technologies related to conventional and renewable sources. For example, a distributed energy systems consisting of a combination of the two types of technologies will enable one to offset some of the economic disadvantages of the emerging renewable technologies. However, under the current energy services company (ESCO) model, a combination of the two types of technologies is not likely to be feasible. While utility (electricity and gas) companies can potentially become a major engine for change helping the adoption of renewable energy technologies, they also, in many cases, become a barrier to adoption of new technologies. This is inevitably an outcome of the size of large integrated utility companies.

Another way to integrate the various technologies to meet the energy demand is to integrate incremental and radical changes irrespective of the conventional and renewable sources. For example, in the near term, for electricity generation systems, the incremental technologies related to ultra clean coal testing, industrial gas turbines, photovoltaic, wind, and biomass can be integrated with the development of fuel cells, distributed energy production system introduction, wave and tidal power evaluation, and geothermal resource definition. Similarly, in the long run, for natural gas systems, disruptive technologies such as high pressure consumer gas, high (>15%) hydrogen additions, methane hydrates fuel resource, hydrates (transport, storage), and gas storage technologies can be combined with incremental development of thermo-photovoltaic appliances. Cross-sectoral spillovers across biotechnology and nanotechnology in the case of renewables like photovoltaics and biomass can drive economic growth.

[8] National Renewable Energy Laboratory web site. *Jobs and the Economy*. (http://www.nrel.gov).

Information Technology Sector Report

Technology Roadmap Project

Prepared by:

INFORMATION TECHNOLOGY

Introduction

The Information Technology (IT) industry can be broadly segmented into hardware, software and services sub-sectors. The hardware sub-sector encompasses the manufacturing and distribution of computer and telecommunications equipment. The software sector encompasses a wide array of software products including systems software, infrastructure software, application software and software that power a host of end user devices such as cell phones, PDAs and other wireless devices. The IT services sector includes a variety of processing services including data processing and hosting services, IT-enabled process outsourcing and applications development, IT implementation and professional services and telecommunication services.

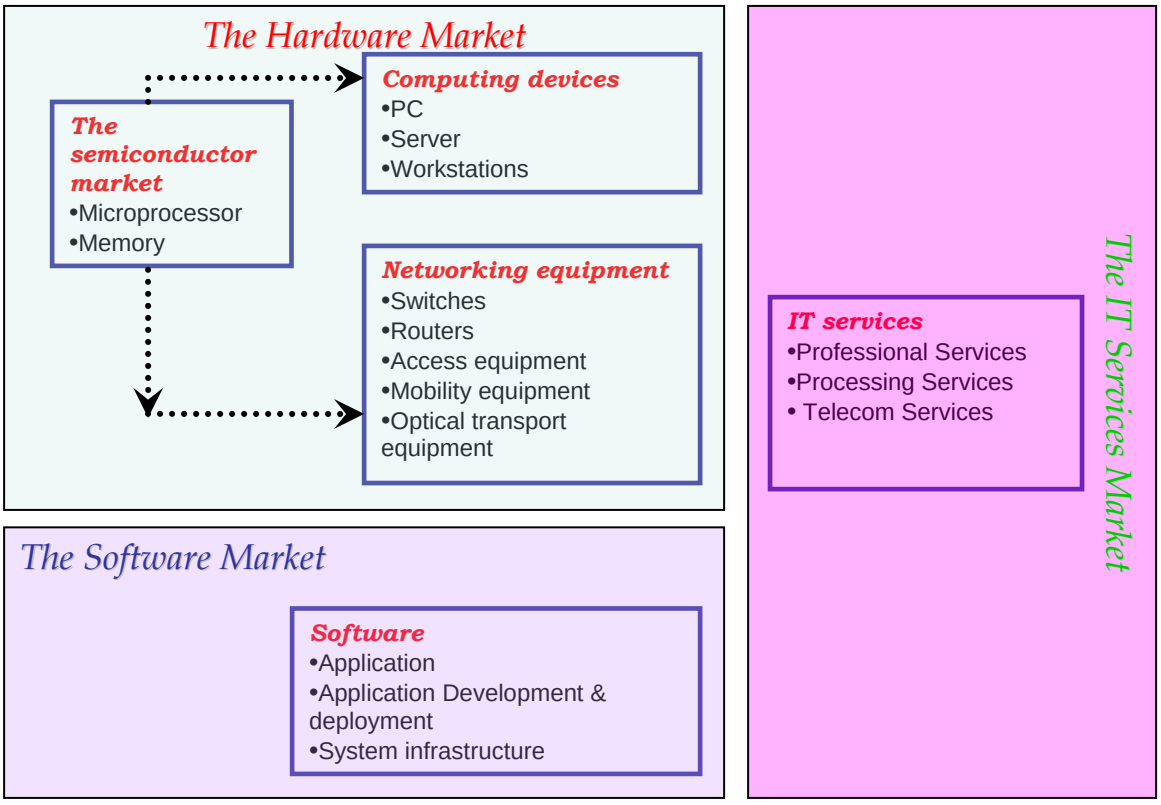
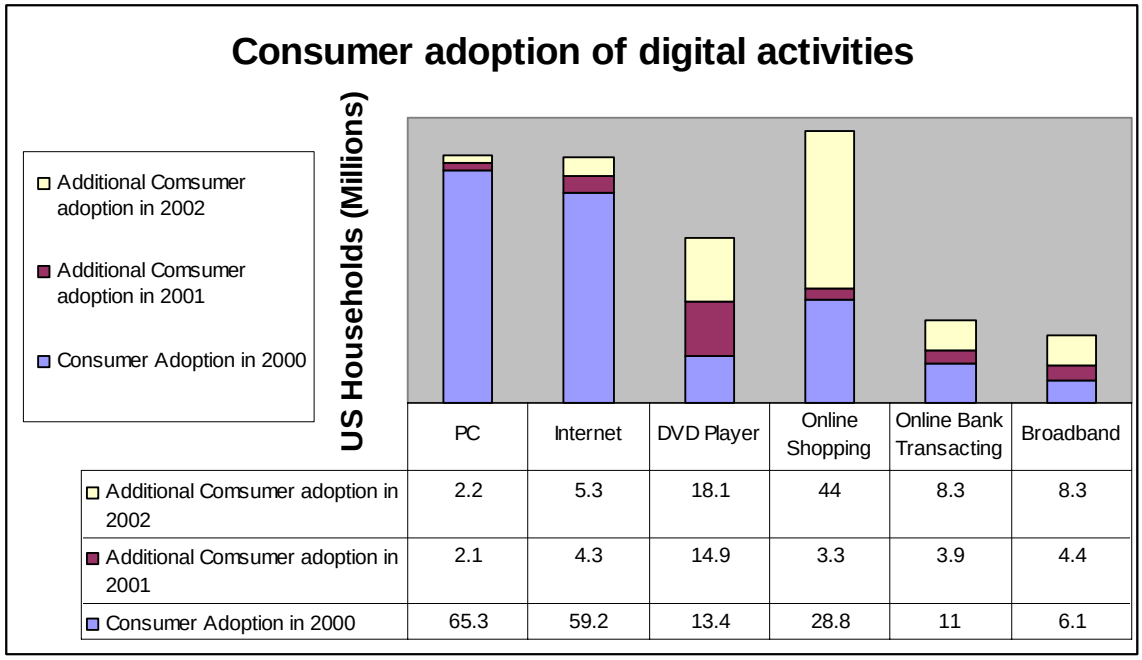


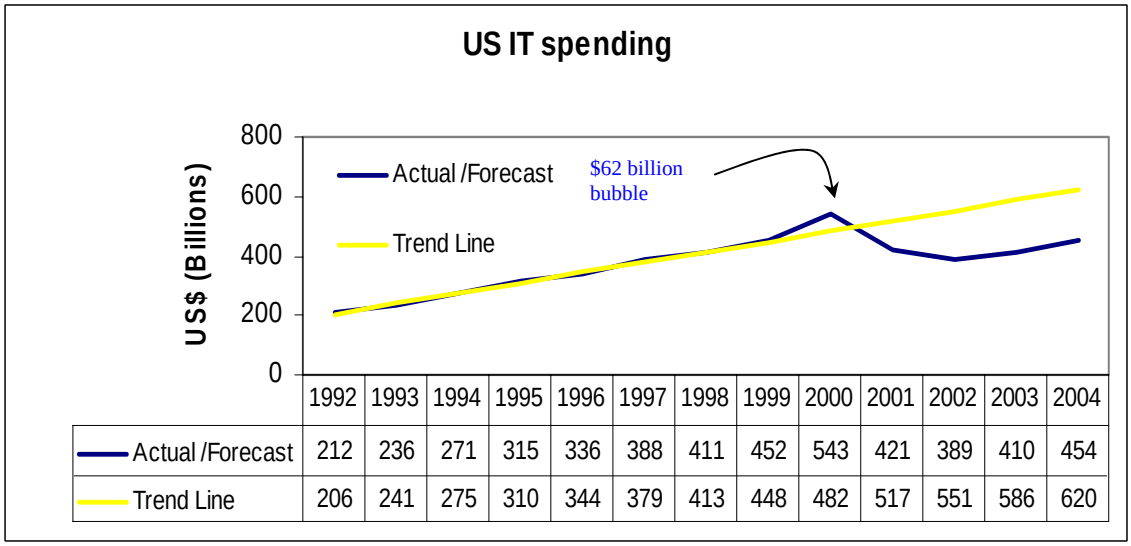
Figure 1: The IT Industry Value Web

The IT industry, which has witnessed rapid growth and change in the past, continues to exhibit the dynamism expected of this industry. The demand for IT products and services is primarily influenced by two factors: 1) corporate spending on information technology products and services and, 2) consumer spending on information technology, communication products and services and consumer electronics. During the recent economic downturn the IT sector witnessed a significant negative growth largely because of a slowdown in both corporate IT outlays and in consumer spending. As of 2004, the IT sector is again showing moderate growth.



	PC	Internet	DVD Player	Online Shopping	Online Bank Transacting	Broadband
Additional Comsumer adoption in 2002	2.2	5.3	18.1	44	8.3	8.3
Additional Comsumer adoption in 2001	2.1	4.3	14.9	3.3	3.9	4.4
Consumer Adoption in 2000	65.3	59.2	13.4	28.8	11	6.1

Figure 2: Consumer adoption of digital activities.
Source: Forrester Brief Highlight: Consumer Tech Adoption Forecast; June 24, 2002



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Actual /Forecast	212	236	271	315	336	388	411	452	543	421	389	410	454
Trend Line	206	241	275	310	344	379	413	448	482	517	551	586	620

Figure 3: US spending on IT
Source: Forrester Brief Highlight; June 24, 2002

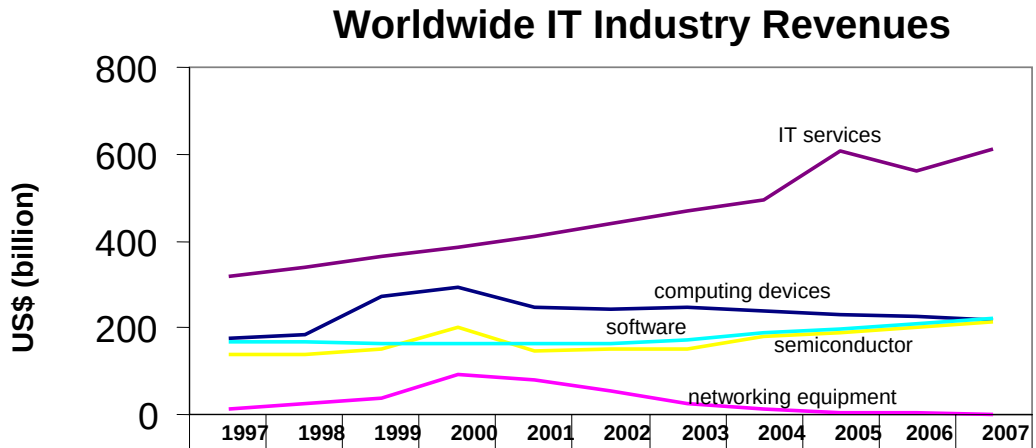
1. IT segments and sub sectors

1.1 Hardware

This sector includes the manufacturers of workstations, servers, mainframe computers, the semiconductor industry including microprocessor and other chip manufacturers, networking infrastructure technologies such as routers, switches, storage devices, peripherals such as printers, display devices and a variety of gadgets such as PDAs, pagers and cell phones. The

convergence of computing and communications has broadened the scope of the hardware sector to include the manufacture of communication infrastructure technologies and end user devices. According to IDC, IT spending reached nearly $1.0 trillion in 2001 and is expected to grow to roughly $1.5 trillion in 2006.

- Based on data from IDC for the first quarter of 2003, worldwide PC shipments rose 2.1%, year-to-year, and is forecasted to touch US$193 billion in 2004.
- Worldwide server shipments continued to show signs of stabilization in 2002 and are expected to touch US $46 billion in 2004.
- The workstation market remained weak with revenues of $14 billion in 2003.
- The semiconductor and microprocessor technologies remain an important part of the hardware sector, other than computing end products like PCs, and servers. After the sluggish sales during 2001-2002 following the boom of 2000, Standard & Poor's estimates that sales have grown by almost 12% in 2003.
- Computer networking equipment forms another important part of the IT hardware infrastructure. According to the Dell'Oro group this industry can be divided into five market segments – Ethernet switches ($12 billion, 2002), routers ($8 billion, 2002), access equipment ($4 billion, 2002), mobility equipment ($28 billion, 2002), and optical transport equipment ($7 billion, 2002).



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Computing Devices	175	186	273	292	247	243	248	240	232	224	217
Networking Equipment	14	23	38	92	81	55	25	11	5	2	1
Semiconductor	140	138	150	202	148	149	152	180	190	202	215
Software	167	166	165	164	163	162	173	187	197	208	220
IT Services	319	340	362	386	412	439	468	493	608	562	610

Figure 3: Worldwide IT revenues (all amounts in US$ billions)
Source: S&P Industry Reports – 2003

1.2 Software

The packaged software market could be broadly categorized into applications software, applications development and deployment and system infrastructure software.

- Applications software comprises programs that perform specific functions, such as word processing, desktop publishing and enterprise application platforms to name a few. According to IDC, the worldwide market for packaged applications software totaled $83 billion in 2002. This segment is expected to hit $108 billion by 2007.

- Application development and deployment includes information and data management (IDM) software, application design and construction tools (AD&CT), application life-cycle management (ALM), application development platforms (ADP), and middleware (MW), according to IDC. The worldwide application development and deployment market was approximately $31 billion in 2002. IDC forecasts this market will grow to approximately $41 billion in 2007.
- System infrastructure software comprises operating systems, operating system enhancements, and data center management. Its worldwide market decreased about 1.1% to $47 billion in 2002, down from $48 million in 2001, according to IDC. However, IDC forecasts this market will reach almost $70 billion in 2007 which would indicate a CAGR of 8.0%.

1.3 IT Services

According to Standard & Poor's, IT services can be categorized into two major sectors: consumer services and the internet, and commercial services. The consumer services and the internet can be further categorized into web hosting service providers, and Internet access service providers. The commercial services are mainly offered under two modes – professional services and processing services.

- According to IDC web hosting and related service market is projected at $10 billion in 2007 compared to $5 billion in 2003.
- IDC also estimates that the consumer ISP market in the United States will grow from $23 billion in 2000 to $80 billion in 2005.
- The broad professional services segment includes technology consulting, education, training, custom programming, systems integration, and outsourcing. IDC groups these underlying categories together as follows: consulting/systems integration ($125 billion in 2002), outsourcing ($118 billion), and support and training ($110 billion).
- Processing services comprises vendors that process their customers' transactions and data using their own computer systems (often with proprietary software). According to the latest available estimates from IDC, this group's revenues increased approximately 6.7% in 2002, to $80 billion.

TABLE 1: NAICS CODES FOR IT INDUSTRY

NAICS Code	Industry Description
Hardware	
334111	Electronic Computer Manufacturing
334112	Computer Storage Device Manufacturing
334113	Computer Terminal Manufacturing
334119	Other Computer Peripheral Equipment Manufacturing
344210	Telecommunications and computer networking equipment manufacturing
Software	
511210	Software Publishers, includes applications, operating systems and utility software
IT Services	
541511	Custom Computer Programming Services
518111	Internet Service Providers
518210	Data Processing, Hosting, and Related Services
541512	Computer Systems Design Services
541513	Computer Facilities Management Services
541519	Other Computer Related Services
541614	Process, Physical Distribution, and Logistics Consulting Services

2. Key technological trends

There are some signs that the IT industry is maturing. So far the industry has thrived on exponentials such as rapid improvements in the price-performance ratio of computers driven by Moore's law and exponential growth in network connectivity and traffic. Now some of these trends might be reaching their limits and the consequences for the industry are significant. Several trends, such as the commoditization of hardware, the emergence of a service model for software and of a utility model of computing, and the shift in the industry focus in some sub-sectors from innovation to execution, suggest that at least the traditional sub-sectors of the IT industry are rapidly maturing. At the same time some sectors of the industry have seen significant new technological development which could pave the way for innovative products and services in the near future. The major technological and business trends driving the IT industry currently are 1) sensory computing, 2) web services and componentization of software, 3) utility computing, 4) business process outsourcing and globalization of the software development, and 4) resurgence of telecommunication services.

2.1 Sensory Computing

Devices that can be connected to the internet are proliferating. The availability of radio frequency devices combined with the miniaturization of sensors is creating opportunities for building systems with "ambient intelligence"; systems that can sense their environment and connect to a network through wireless means. It is expected that the processors that are embedded in smart sensors will be an order of magnitude more in number than the computers that are connected to the internet. New technology standards are being actively developed to enable these devices to communicate through wireless networks and to put them to productive use. The immediate business application of the sensory computing ideas can be seen in the adoption of RFID to track products across the supply chain. The cost of passive RFID tags has dropped significantly in the last five years reaching a point where it is cost-feasible to tag items. Several retailers such as Wal-Mart, Target and the US military have mandated their suppliers to start using RFID in the near future. This is expected to further drive down costs of the tags and thereby fuel rapid growth in the manufacture and use of these tags. It is also likely to fuel growth in the software needed to use these sensors effectively.

2.2 Utility Computing

Today's server technologies make building datacenters expensive and time-consuming -- and force firms to buy much more processing capacity than they actually use. Utility computing has emerged as a new model of providing computing resources that instead of forcing computing power into server-sized buckets, will allow datacenters to deliver fluid computing horsepower on demand. This is expected to bring in commodity economics to the running of data centers and the consumption of computing in organizations. The utility computing model has evolved over the last five years and has now resulted in commercial offerings by firms such as IBM and HP.

2.3 Web Services

The software industry is evolving to a pay per use model with the development of web services technology and increased componentization of software applications. Web services allow firms to use a specific functionality of software hosted on a server as service. The standards that allow data interchange between systems, for defining services and for locating them have evolved to an

extent that web services are actively being used now. All packaged software vendors including desktop software vendors such as Microsoft and enterprise software vendors are componentizing their packages and developing service offerings. The use of web services is likely to increase significantly in the next two years creating opportunities in the software and services sectors.

2.4 Business Process Outsourcing (BPO)

Process outsourcing though not new has become more widely used and has become a major business trend in recent years. The low cost of communications and the availability of cheap telecommunications infrastructure has led to off-shoring and near-shoring to capitalize on low labor costs in other parts of the world. BPO creates demand for IT products and services in countries investing to build their infrastructure for service delivery. It is also creating demand for infrastructure upgrades by firms in the US to enable them to effectively outsource processes without losing control of these processes.

2.5 Telecommunication Services

The telecommunications sector, though still saddled with excess capacity, is showing signs of renewal and growth, especially in the services area. New technologies in the wireless space such as Wi-Fi and Wi-Max are driving growth. Other technologies such as VoIP have become mainstream with start up firms offering technologies that provide good quality voice transmission over the Internet. This is likely to create significant price competition in the marketplace for voice services.

3. Summary

The IT industry after a significant downturn has recovered well in the last two years. The major trends identified above seem to be shaping this industry in the U.S and in the rest of the world. Overall, there is a shift in the geographical focus of innovation and technology creation in the IT industry. All major IT players are investing aggressively in creating R&D and business development capabilities outside of the U.S. Moreover, many venture capitalists seem to emphasize the need for an off-shore strategy in the business plans of start ups to take advantage of the cost differentials. Given these trends, the Capital region has to think hard as to how best to position itself to attract IT ventures to locate here. One interesting opportunity is to focus at the intersection of IT with other sectors where the region already has some traction such as biotechnology, nanotechnology and media and arts. IT is likely to be extensively used in all emerging sectors and development of appropriate hardware, software and IT services to support these sectors could be a natural choice for this region. Another potential opportunity could be to focus on services in niche areas that are seeing significant resource inflows such as the healthcare, homeland defense and power transmission to name a few.