Nanotechnology in a Nutshell

By Pearl Chin, PhD, MBA

In the movie Spiderman, Peter Parker, the high school science geek turned superhero, had read all the papers on nanotechnology by his arch-nemesis, the Green Goblin. In Jackie Chan's new movie, "The Tuxedo" released in late September, our hero, an overly shy taxi driver, is transformed into a world class super spy by wearing his boss' nanotechnology gadget laden tuxedo. Michael Crichton's new book titled "Prey" which was released in November had a closely guarded secret plot, but was said to involve political intrigue and nanotechnology. 20th Century Fox has just bought the movie rights for about $5 million. The Borg in Star Trek assimilated bodies by injecting them with nanobots that would implant mechanical devices to take over their hosts. As early as 1995, Russell Crowe in the movie "Virtuosity as Sid 6.7, harnessed nanomachines to bring himself to life as a silicon based menace. And for the kids, the Powerpuff Girls fight evil squid shaped nanobots that terrorize the world by eating all the carbon in buildings, cars, clothes, etc. There's a little nanotechnology something for everyone. However, even with all this media attention, most of us still don't know what nanotechnology really is and why it is important to us.

So we've been hearing a lot about nanotechnology lately. Most people I talk to have only a slight clue as to what it is. I would even venture to say even researchers, even the ones involved in nanotechnology research, don't quite understand it thoroughly even though they probably understand it more than the average person does. There are many articles talking about how to invest in nanotechnology but not too many explaining just exactly what it is to people who need to know. It may surprise you to realize that the most important people who need to know is the average person whose taxpayer dollars are going to fund nanotechnology and for whom nanotechnology ultimately serves. Nanotechnology is useful in a broad range of industries, such as energy, semiconductors, computers, biotech and cosmetics, to just name a few.

The government, starting with the Clinton administrations in 1993 and now with the Bush administration has been pumping money into nanotechnology research with the federal government's appointment of the National Science and Technology Council (NSTC) to create and operate the National Nanotechnology Initiative(NNI). The NNI allocates monies to four cabinet level agencies (Commerce, Defense, Energy, and Transportation), the National Institute of Health (NIH), the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). There is approximately $600 million for year 2002 and until very recently, there was an approved 17% increase in National Science Foundation (NSF) nanotechnology funding for the year 2003 to $710 million by the House of Representatives. Much of this funding was slated for university research and the rest was to be distributed among the government labs, which often collaborate with the universities. There is also the little publicized federal Advanced Technology Program (ATP) that supports commercialization of high-risk technologies.

However, President George W. Bush approved **S189** also known as the **21st Century Nanotechnology Research and Development Act** on **December 3, 2003**. Starting in 2005, this Act will provide **$3.7 billion** over the next **four** years for federal nanotechnology programs, and reorganizes government and research communities under a **National Nanotechnology Coordination Office (NNCO)**. Bush also approved **$849 million** for fiscal year 2004. Funding from **S189** starts **October 2005**, the beginning of the government's next fiscal year. Nanotech funding has increased 83 percent since 2001, according to the White House. It is estimated that a whopping 95 percent of the **$3.7 Billion** authorized will go to scientific research and development -- roughly 60 percent for academia and 35 percent for government labs. It also emphasizes interdisciplinary research, seeks to address concerns raised by nanotechnology, and requires outside reviews of the programs.

The signing of the bill by President Bush makes nanotechnology the highest federally funded basic science and technology effort since the space race. Funding that in the past was at the discretion of the president is now mandated. The bill calls for the president to establish a national program to undertake long-term basic nanoscience and engineering research. Emphasis will be on potential breakthroughs in materials and manufacturing, nanoelectronics, medicine and health care, computation and IT and national

security. The fruits of nanotechnology are a lot closer on the horizon than we think if government spending is any indication.

The NSF estimates that global governmental spending on nano R&D is about $2.2 billion in 2002. At least 30 countries have initiated nanotechnology initiatives. Europe and Asia, especially Japan, are already investing heavily in nanotechnology research. Japan has made nanotechnology one of its top research priorities. Japan, for example, accounts for over one-fourth of the global investment in this area. China claims it can beat Japan's spending. The United States accounts for about one-fourth of the total, and Europe for about one-fifth. Taiwan plans to begin introducing nanotechnology in its schools, starting at the equivalent of our junior high school level. This is more than just one country trying to outdo the other in terms of innovation and spending. This can be also cause for concern as much of it might be defense related nanotechnology research. So this approximate tenfold increase in approved funding nanotechnology by the US is more than just an ego trip.

So why is so much of your hard-earned taxpayer money being pumped into nanotechnology research? Some of it may seem pie-in-the-sky research but it's a lot more practical than you think. Many venture capital firms point out that many nanotech investments are expected to take 15 years to 20 years before they are able to provide profits for their investors. Does the government know something the venture capital firms don't. Probably. Since the 9-11 attack on the World Trade Center in New York City, we have found that we are more vulnerable than we would like to believe. Nanotechnology can make ultra sensitive nanosensors possible that can make detection of incoming dangerous chemical, biological and nuclear weapons possible. It can also make for more sophisticated military arms and protective soldier uniforms if we are ever subject to attack again. Obviously there are implications about nanotechnology from both the defensive and offensive perspectives which we will not get into here. The government certainly knows that certain nanotechnologies are going to be viable earlier than the venture capital firms project. Otherwise, there wouldn't such a huge increase in funding policy. There are reasons for that which I won't go into now but suffice it to say it is related to national security.

On the commercial side, according to the NNI, spending on commercial products begotten from nanotechnology will reach $1 trillion per year in 10-15 years. The larger technical companies such as IBM, Motorola, Hewlett Packard, Lucent, Hitachi, Mitsubishi, NEC, Corning, Dow Chemical, and 3M have launched nanotechnology research initiatives of their own, many of them collaborating with universities. It is no wonder IBM continues to be a leader in cutting edge as well as basic research in general. At this point, whenever I hear about IBM doubling their data storage capacity, I just yawn since their advances are so prolific and ubiquitous to almost be considered the norm. IBM is one of those tech companies that should be emulated.

So it's important that we understand what nanotechnology is about and that the NNI and NSF has your taxpayer support.

So what is nanotechnology exactly?

Nanotechnology is the study of things on a nanometer (nm) scale or 10^{-9} meters (m) or one thousandth of a micron or micrometer (10^{-6} m or 0.001 μm). The Greek prefix nano- or nannos- means dwarf and one-billionth so a nanometer is one billionth of a meter. That scale is on a molecular or atomic scale. Technology also has Greek roots meaning something that is derived from application of the scientific method for commercial objectives. Literally, nanotechnology means being able to manipulate small things to make a profit. Perhaps nanotechnology is a more accurate word in terms of Greek derivation, but nanoscience is probably a more applicable term without all the negative connotations that the word "technology" seems to be raise these days.

However everything is made up of atoms and molecules, so just about everything can be related to nanotechnology. Nanotechnology typically describes systems smaller than 100 nm. To put it in perspective, 3-6 atoms, depending on the type of elements, together are about a nanometer in length. Viruses are about 50-100 nm in size and bacteria are about 500-1500 nm in size. Visible light wavelengths are on the order of a several hundred nanometers. A nanometer is about 1/80,000 the

diameter of a human hair. This all sounds simple enough but what exactly does this all really mean? If you think of nanotechnology as just that narrow and specific definition, then that definition doesn't tell you much of anything because you don't know how to use it, like a word without context or without a sentence. In context, nanotechnology is not so much a technology or an industry but more of a concept and approach. What provides the context are the implications of all this which I'll try to develop further.

The following was excerpted from the National Science and Technology Council (NSTC)'s NNI most recent definition of nanotechnology: "Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale. This can then be used to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size." "Nanotechnology is concerned with materials and systems whose structures and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes due to their nanoscale size. The aim is to exploit these properties by gaining control of structures and devices at atomic, molecular, and supramolecular levels and to learn to efficiently manufacture and use these devices" was excerpted from the NNI's implementation plan from July 2000. The NSTC was created by executive order in 1993 to coordinate federal spending in science and technology.

The reason the nanometer scale is interesting is that at this scale, materials behave differently than in bulk because quantum effects become dominant at that scale. Take a table and then imagine it a billion times smaller where it now sticks to your finger or starts to float around or hangs upside down instead of behaving like a table subjected to gravity. A bulk size table behaves that way because it obeys the laws of physics for large objects subjected to the gravitational force, which overwhelms quantum effects even though quantum behavior is still occurring. You just can't see it. However, a nanoscale table can behave differently because it is governed mostly by quantum effects that only come into play for things that tiny. Why this is important is if we know how these materials behave at that level, we can exploit these properties to design and build structures that push our current technical limits, such as making chips even smaller and more powerful.

There is consensus about one thing - Nanotechnology is the new buzzword. It's everywhere and as I pointed out earlier, even Hollywood has gotten the nanotechnology bug big time. However, nanotechnology is not a new concept. In 1959, Richard Feynman, 1965 Nobel Prize physicist, predicted the advent of nanotechnology in a famous speech he gave to his fellow physicists at the American Physical Society entitled "There's Plenty of Room at the Bottom". Professor Feynman talked about research on the very small scale and set forth research challenges, such as being able to manipulate atoms one by one. This, by the way, is a challenge that we, or IBM really, have overcome in 1996 if albeit crudely. However it wasn't until 1974 when Norio Taniguchi, a professor from Tokyo Science University first coined the term "nanotechnology" then K. Eric Drexler made the term "nanotechnology" famous in 1986 in his book, Engines of Creation that nanotechnology has evolved to what it is now.

So why should we care about nanotechnology? What can it do for me?

Now you've probably been hearing a lot about how nanotechnology is either going to save the world or destroy it. Well, both perspectives are valid even though they are the extremes. The fear of "gray goo" which is the scenario of nanorobots, more affectionately known as nanobots, run amuck by self-replicating, though somewhat far-fetched, has actually inspired more discussion about the implications of artificial intelligence because of this. Making nanobots is still not easy right now so this issue is a long way off in coming. What scenarios should concern us more is the prevention of mutual destruction via chemical and biological weapons that can be created via nanotechnology. Not to worry because some of the NNI funding is already being allocated to address the ethical, legal and socio-politico-economic implications of nanotechnology on the world.

On the upside, cures for cancer and diabetes are much closer. Now in terms of saving the world, the idea of being able to build things at will, atom by atom, can save the world from poverty and hunger. If someone needs food or a house and if you get the right combination of atoms, you can build yourself a

pizza or a hot fudge sundae or anything else for that matter. You just have to program it to put together the atoms, atom by atom, in the right sequence with the right intermolecular forces to bind it all together. Now that's some futuristic food recipe and an interesting grocery list (…one-part carbon atoms, equal parts nitrogen, handful of oxygen, dash of hydrogen…). Well, it's much like the way the Star Trek crew would get their dinner on board the Enterprise. It seems a little far-fetched but in theory, it can be done but it's not that easy to do with the tools and understanding we already have. It will be at least several generations before we can just ask for roast chicken and in minutes, it will appear. We've just gotten past the point where the scientists at IBM can manipulate Xenon (Xe) atoms to spell "IBM" with a scanning tunneling microscope (STM) to spelling "IBM NANO" with 20 nm thick silicon dioxide lines using atomic force microscopes (AFM). That wasn't so easy too so we've got a long way to go from there.

Other research areas involve viruses being designed for use as nanobuilders for molecular scale computer chips or nanosensors. Nanocapsules are being created that can reverse diabetes and Parkinson's Disease. Dendrimers or polymer stars are being designed to detect, seek out, diagnose and destroy cancer cells. There is already nanoscience research that has applications in diagnosing whatever is making a baby sick depending on what color their diapers are fluorescing after a bowel movement. And did you know in Australia they can teleport a laser beam from one place to another a meter away in a blink of an eye by exploiting quantum entanglement behavior? Unfortunately, the laser beam was destroyed in the process so don't get ready to say "Beam me up, Scotty" just yet. Science is always riddled with setbacks to overcome, which they ultimately do.

Many think that nanotechnology is still much in the research and development (R&D) stages but that's just not true. This reflects the lack of understanding in nanotechnology. To wit, Phillip Bond, the U.S. Undersecretary of Commerce for technology reports that 93% of commercial research and 58% of academic labs working on nanotechnology believe they are going to have a product or service as early as next year. Nanotechnology is so broad and diverse that the technological advances are happening in a continuum where there is no real obvious beginning or end and tend to overlap. As mentioned, some technologies are already far advanced while others are in their infancy.

For current examples of nanotechnology for everyday applications, already there are commercially available coatings to make tennis balls last longer and fabrics, sunglasses and tiles resist scratching and repel dirt and stains. Antibacterial ceramic coatings for toilet bowls are being developed and commercialized. There are even nanocapsules in cosmetics to deliver age defying retinol to deep below the skin, supposedly much more effectively than liposomes. There are nanoparticle based sunscreens that are inherently hypoallergenic and carbon nanotube based tennis rackets that are 5 times more rigid and hence more powerful than the current graphite fiber based rackets. This is certainly an exciting everyday use range of nanotechnology's everyday applications! You can now bring nanotechnology to the tennis court or the beach! So nanotechnology is already well on its way to being commercialized and obviously, there is already so much research going on all with short term real life everyday applications in mind.

That's not to say that it's been smooth sailing for nanotechnology innovations. For most of the more esoteric applications, it's the cost effective manufacturing on large scale that is the main obstacles of nanotechnology to overcome. Here is where self-assembling systems can save us a lot of aggravation with nanotechnology manufacturing. And I'm sure the scientists in Australia were none too happy about the teleported laser being destroyed on the other end but I'm sure they're already working on solving that problem too. They'll probably stick to lasers for a while so the animal rights activists won't have to worry about them trying to teleport a human or just a fly just yet.

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Prior to that, she was a Management Consultant with Pittiglio Rabin Todd & McGrath (PRTM)'s Chemicals, Engineered Materials and Packaged Goods group. Dr. Chin will be advising the Cornell University JGSM's student run VC fund, Big Red Venture Fund (BRVF), on investing in nanotechnology. She is a Senior Associate of The Foresight Institute in the US and was the US Representative of the Institute of Nanotechnology in the UK. She was an alternate finalist for a Congressional Fellowship with the Materials Research Society. She was also a Guest Scientist collaborating with the National Institute of Standards & Technology (NIST) Polymer Division's Electronic Materials Group under the US Department of Commerce. Dr. Chin is a US Citizen born and raised in New York City.