Nanotechnology Now
NanoNews-Now
Feature Article Interview Links Glossary Products Staff

Welcome to the second edition of NanoNews-Now, the monthly interactive newsletter from Nanotechnology Now. In this issue we take a look at the ramifications of the sudden interest in the regulation and control of nanotechnology research, development, and deployment, and discuss several possible scenarios.

If you are new to the world of nanotechnology, you may want to consult our glossary when you encounter a term you don't recognize. We've also made reading easier by linking the first use of any technical term to its glossary entry. Since this paid newsletter is prepared for those with a basic knowledge of nanotechnology and its capabilities, we will not rehash them here. The free Nanotech-Now newsletter and Nanotech-Now.com web portal are available if you need a refresher course on the science basics.

Riding the Tiger

The Nanotechnology Revolution has officially begun. While products are only beginning to arrive at the marketplace, its proponents are forecasting incredible possibilities for abundant food, cheap (clean) energy and consumer goods, and longer life. Meanwhile, critics warn of horrible cataclysms and devolution of the human condition. If nanotechnology is the "Tiger of Change," then it is quickly picking up speed, and there is a battle brewing between those who would ride and steer it, and those who would try to stop or cage it.

Nanotechnology is here!

Researchers and scientists have been blending nanoscale insights from different fields (chemistry, biology, physics, materials, etc.) for years—a trend that is rapidly increasing, and producing many interesting and potentially disruptive products. Business is quickly getting involved, as patents are becoming products, from stain-resistant clothing to smaller and better batteries and fuel cells (see Vol. 1 of this newsletter). As venture capitalists intersect with entrepreneurial scientists and researchers, business plans are developed and "theory" becomes "prototype" as applications are pushed through R&D and become products. As a result, governments, special interest groups, scientists, foundations and even a few leading-edge members of the general public are starting to take notice, and wondering aloud if regulation is in order.

next page

Mobile phones, stem cells, and nanotech

Stem cell research may seem like a clear parallel and good case study for discussion of reactions to technological discoveries, but mobile phones? Consider this: A mere fifteen years ago mobile phones were practically non-existent. The technology was in its infancy. There were some phones in cars, and the first few "portable" cell-based phones were making their appearance—if a seven pound "brick" with attached handset can be described as a portable device. Costs were extremely high, both for capital purchase and use. There was no discussion of the ethics or safety of the device's use—hardly anybody owned one. If you were a major manufacturer intent on being an early mover into this market, the possibility of government regulation hampering your ability to market your product was minimal. It was *all systems go* and don't look back.

Now, jump ahead to the early 2000s, and witness the fastest propagation and adoption of a new technological device in history. And now manufacturers and retailers of mobile phone are suddenly facing

possible regulation on their use in cars and public places (by the U.S. federal government), as well as in 50 different states and hundreds of local jurisdictions—and that's just in the U.S. Add to that the federal approval and adoption of devices that specifically *interfere* with the effective operation of the devices (mobile phone "jammers" that are in use in hospitals and may soon be marketed to theaters, restaurants and even individuals) and the business of manufacturing and marketing mobile technology just got a *lot* more complicated, and potentially less profitable.

"What we are seeing is the beginning of a revolution, caused by our ability to work on the same scale as nature. Nanotechnology will affect every aspect of our lives, from the medicines we use, to the power of our computers, the energy supplies we require, the food we eat, the cars we drive, the buildings we live in, and the clothes we wear. And it will happen sooner than most people think. By 2010 you won't be able to count the number of businesses affected by nanotechnology."

-- Tim Harper

Founder and Chief Executive Director of the European NanoBusiness Association

"The biggest challenges in implementing the nanotechnological future envisioned by Drexler will be moral and political challenges, not technological ones. This is not to underplay the significance of what scientists and technologists do. Rather, it is an expression of faith in their ability to achieve success, along with a worry that the social science side of things will do less well."

-- C. MacDonald

in a forthcoming essay, *"A Framework for Nanotech Ethics"*

Then there is the scientific parallel—stem cells. Those engaged in cutting edge stem cell research in 2002 were moving along based on scientific principles and well-established ethical and research guidelines. Perhaps they were looking for a cure for cancer or Parkinson's disease or some other worthwhile goal. And then, quite suddenly, there was an Executive Order entire research options were removed. If your business model was predicated on moving forward on a certain research schedule, this little roadblock might have effectively destroyed your viability as a commercial enterprise. It should be noted that stem cell research did have an additional strike against it, as it intersected with the religious/political battle over abortion. Nanotechnology may not have to contend with that issue, but that doesn't prevent it from being at the center of a different political or social firestorm.

For those engaged in research and development of nanotechnology with an eye towards practical applications, the threat of government regulation is no less real than it is for stem cell researchers, and for some of the same reasons. Major initiatives in the development of genetically modified food production have been stalled or limited by well-timed media events of "public concern" that were

next page

manipulated and exacerbated by groups with distinct anti-business or anti-technology orientations. It was not that the science might not have been worthy of further review, it was simply that it was never given a chance. Further, it is no small matter when a very visible (and yet somehow very badly briefed) Prince Charles can make public pronouncements about what types of technology should be controlled.

And the approach that government takes to limiting nanotechnology research might not look at all like the one taken with stem cells. They might treat it more like atomic energy research was treated in the 1950s and 1960s. A nanotechnology business manager could wake up one morning in 2005 to discover that their entire research enterprise was now considered classified. Their research staff might not even be cleared to be reading the papers they had been writing the night before. Worse yet, the CEO might be told that half of the staff would never be able to achieve the necessary government clearances to finish working their reports. A scary thought? Well, perhaps, but far from impossible.

"Because of nanotechnology, we will see more change in the next thirty years than we did during all of the twentieth century."

-- Mihail Roco

National Science Foundation (NSF) senior advisor and chair of NSTC's Subcommittee on Nanoscale Science, Engineering and Technology (NSET)

"My own judgement is that the nanotechnology revolution has the potential to change America on a scale equal to, if not greater than, the computer revolution."

-- Sen. Ron Wyden (D-Ore.)

"This next revolution (nanotechnology) is at least as fundamental as the IT revolution has been," he said. "This will be transforming, revolutionary. It is not hyperbole to say it will change everything, every facet of industry."

-- Phil Bond

U.S. Department of Commerce Undersecretary for Technology

The Focus of the Fears:
September 12th,
Gray Goo and
T-3/MATRIX

September 12th

There are a number of different horror scenarios that are presented as possible by those who would regulate or abolish nanotech research. Each of these possibilities has a basis in truth, which makes it easier for opponents of nanotechnology to use them as the touchstones for crisis scenarios. ***September 12th*** is a coined term for the fear that nanotechnology could get into the "wrong hands" and become the next weapon of mass destruction (WMD), or be used as blackmail against a government or nation. It would be impossible for anyone to be complacent about the potential threat of September 12th in light of September 11th, 2001.

Gray Goo

The term Gray Goo was actually first conceived by one of the founders of nanotech, Dr. K. Eric Drexler. It describes the easily preventable and usually misunderstood idea that self-replicating nanorobots could "run amok" and disassemble *everything*, turning the entire planet into goo. This horror-story scenario plays upon a cultural undercurrent of fear that has been propagated over the years by books, the press, and television.

next page

T-3/MATRIX

The horrible vision of the *Terminator* and *Matrix* films is machines that have taken over the earth and are working to exterminate (or enslave) humans. It is an extension of the concern that nanotechnology and robotics will intersect with nano-assembly technology to create self-replicating machines, which will achieve levels of artificial intelligence (AI) that no longer require humans.

The September 12th scenario might seem the most plausible to most readers, especially considering the war that was recently fought to prevent WMD from "falling into the hands of a madman." But the second and third scenarios are also bandied about by those promoting regulation of nanotechnology, and sometimes with just as much belief in their immediate risk. In addition to these three major touchstones, there are also those who fear that successful deployment of potential nanotechnologies in the hands of our own governments might lead to an invasion of privacy or totalitarian control over our lives.

The Optimistic View

"In a world in which the promise of nanotechnology were realized, practically anyone could live a life that would be extraordinary by today's standards, in terms of health (thanks to nano-medicine) and material possessions.

*Most physical goods could be manufactured **in situ** at low cost from cheap raw materials. Imagine owning an appliance the size of a refrigerator, full of nano-assemblers, that ran on sunlight and dirt and made pretty much everything you need, from clothing to food."*

-- Glenn Harlan Reynolds

The Science of the Small

The fears are out there, and in some cases are being presented by members of the scientific and research community. The media is always looking for an "interesting story with a good hook" and this allows individuals and organizations with assorted agendas to take up the banner of attacking nanotechnology and demand that "action be taken, now" to prevent a global catastrophe. The general public is not particularly involved in these discussions, and is mostly being "spun" by different public figures, scientists, and spokespeople.

Perhaps opponents of nanotechnology are living out their frustration that they were not able to control the scientific or technological advances of the past—nuclear energy, genetic engineering, etc.—or perhaps they have decided that the speculative capabilities of nanotechnology pose a greater risk. Whatever the reasons, they are now latching onto nanotechnology and attempting to stop it in its tracks. Self-serving and oftentimes totally uneducated politicians are jumping into the fray to confuse the issue further. And many popular media sources are playing up every bit of hysteria and misconception, such as the gray goo scenario.

Possible Approaches:
Relinquishment, Regulation,
Repression, or Responsible Ethics

There are a number of possible approaches to managing the risks of research and development of nanotechnology. Most of them have been discussed and proposed at one level or another, and all of them have their proponents and detractors.

Relinquishment

next page

Relinquishment is an idea proposed by Bill Joy of Sun Microsystems. It was first presented in an article in *WIRED* Magazine titled "Why the future doesn't need us". In his lengthy essay, Joy is especially concerned about the potential loss of humanity when nanotechnology-based robotics begin to meld with human physiology. He is quite concerned about human/technological hybrids that expand past the simple artificial limb, making human extinct. His solution is to "just say no" to nanotech R&D.

Quite thorough critiques of Joy's propositions on relinquishment have been written by a number of well-educated writers, including Max More of the Extropy Institute, and Virginia Postrel, Editor-at-Large for *Reason* Magazine. These writers have established quite conclusively that even if the risks that Joy outlines were valid, the methods of response would be ineffectual. There is no historic precedent for "unknowing" a discovery. The technology required to further the research and development of nanotech is *not* that complicated or hard to perform in secret. And the values promised by success, whether on an individual level (increased life span and health) or on a national level (a more robust economy, global power, etc.) are a guarantee that somebody, somewhere, will not abide by the voluntary decision to relinquish a new technology.

"The potential benefits of some areas of nanotechnology are enormous. Complacency about risks opens the doors to one nasty surprise creating a public backlash that will hit development well beyond the area of concern. We believe the risks to be slight and that where they do arise an adequate response will often be appropriate design of working conditions and labeling of containers. All of us interested in seeing this fascinating and promising collection of technologies continue to develop and bear fruit would be well advised to be proactive in hunting out the few risks that might arise."

-- Paul Holister

Chief Information Architect, Cientifica

"The major difference between a thing that might go wrong and a thing that cannot possibly go wrong is that when a thing that cannot possibly go wrong goes wrong, it usually turns out to be impossible to get at or repair"

-- Douglas Noel Adams, Author

Regulation

Regulation is a common governmental approach to many issues, and in many cases, rightly so. The infrastructure for implementing them is well honed, and the expertise at writing them established.

But U.S. federal regulations only affect the U.S., and technology knows no borders. Research *will* continue overseas, so the risks of technology getting into the wrong hands or being developed without sufficient safeguards will actually *increase* with U.S.-only regulations. Effective protocols must evolve within the international community, perhaps through some new global institution.

Repression

Repression of research and development could take a number of forms. One possibility outlined by Glenn Harlan Reynolds in a paper called "Paint It Black" is to militarize and classify all research related to nanotechnology. The situation outlined earlier, where the nanotech businessperson wakes up to find his business has been "classified" is based on actual events that occurred during the cold war in relation to atomic energy research.

If the manner in which the current U.S. administration has been able to stigmatize certain types of stem cell research is any example, then there are plenty of avenues for government repression of

next page

research. There are already many major national science foundations that no longer fund research simply because the situation became too volatile and political. Properly painted as a national or international security issue, it would be quite possible to dry up the venture capital and research funding necessary to move U.S. research in nanotechnology forward and keep it current. The only people who would be able to continue the research would be a well-funded terrorist operation or eccentric rich individuals with personal agendas. Again, a solution that doesn't achieve its objectives but limits U.S. R&D.

A Scenario for Success: Responsible Self-Regulation and Ethics

Once all the draconian approaches to minimizing the potential danger of nanotechnology R&D are dissected and dismissed, what is left? One possibility to be explored is responsible self-regulation by professionals in the field, coupled with the establishment of strong ethical guidelines to be adhered to in the implementation of nanotechnology.

The individual members of the nanotechnology community become their own policing force, moving to establish and maintain a peer-based set of practical guidelines and ethics. This is done *before* individual governments have the opportunity to step in and use the lack of such protections as an excuse to begin regulating, legislating, banning, burying, or classifying. At this time, a number of different nanotechnology pioneers have adopted or are proposing such guidelines, including Nanotech-Now.com, The Foresight Institute, The Center for Responsible Nanotechnology, and others. While these controls do nothing to prevent a rogue government or entity from doing research into nanotechnology, they leave the rest of us open to preemptively devise solutions to problems unleashed by rogues.

This type of initiative is most successful if it runs parallel with strong public education efforts, so that an informed populace can be kept aware of what is real and what is fictional. In this way, the populace themselves becomes a controlling mechanism to prevent the government or the military from subsuming nanotechnology for their own purposes. While many aspects of nanotech R&D might seem incredibly arcane

No review of the issues of nanotech ethics and regulation would be complete without reviewing the Nanotechnology Now ***Ethics of Nanotechnology Pages***

Why Open Code Matters

Often, in a discussion of possible solutions for managing the risks of nanotechnology research, the concept of Open Code will be mentioned. The basic principle of open code is that software is developed in an open and unprotected manner and distributed and released widely and without significant cost. It's not immediately clear to many why this style of software development has anything to do with controlling the risks of nanotechnology research, but it does.

In an open source environment, rather than having a closed and limited set of programmers working on creating the product and finding all the bugs, you have the entire population of users working with the product and improving it. Perhaps the changes and improvements are smaller and less significant, but there are thousands more being made at a time. And the chances of a significant bug or problem getting past a hundred thousand users is much smaller than it getting by a team of ten or twenty (or even a hundred) programmers.

So, when the concept of open source or open code is applied to nanotechnology research, what we are essentially talking about is transparency: R&D being done above-board and published in peer-reviewed journals, rather than in secret labs or basements or closed military or government research facilities. In this way, the largest possible base of "users" (the peers in the research community and the implementers in the business and industrial community) can contribute to and improve upon the products of nanotechnology and help to prevent any bugs from being released.

next page

and technical, there are those in the world of science and education who believe it is possible to make the underlying technology understandable without overly simplifying it or weakening the intellectual base upon which it is founded.

It is vitally important that proponents of the values of nanotechnology do not allow themselves to be drawn into petty battles with those who would try to limit or end research and development. Those who are active in the science and industry of nanotech must appreciate that the risks and fears that are played upon by the critics are real and valid in the minds of the public. Those who wish to lead in the development of nanotechnology must be prepared to accept responsibility for moving it forward safely and wisely—not by rolling over their opponents, but by illuminating their errors through reasoned debate.

A solution that creates an environment of openness and transparency, which allows for self-regulation, personal responsibility, and professional ethics, creates an environment which leads to the best possible outcome for humanity.

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LINKS to views from many points, from the past few months:
(*) Indicates simple registration required

Ethical Administration of Nanotechnology
http://www.nanotech-now.com/papers/?area=reader&read=00003

Responsible Nanotechnology: Looking Beyond the Good News
http://www.eurekalert.org/context.php?context=nano&show=essays&essaydate=1102

Mind the gap: science and ethics in nanotechnology
http://www.utoronto.ca/jcb/pdf/nanotechnology_paper.pdf

The Social and Economic Challenges of Nanotechnology
http://www.esrc.ac.uk/esrccontent/downloaddocs/nanotechnology.pdf

Greenpeace Environmental Trust: Future Technologies, Today's Choices
http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/5886.pdf

The Greenpeace Report, Part II: NanoWars
http://nanobot.blogspot.com/2003_07_20_nanobot_archive.html#105915612210166946

Greenpeace and Nanotechnology
http://www.techcentralstation.com/1051/techwrapper.jsp?PID=1051-250&CID=1051-073003B

Greenpeace to nanotechnology: let's be rational about this
http://www.nanotechweb.org/articles/column/2/8/1/1

CRN Offers Qualified Endorsement of Greenpeace Nanotech Report
http://nanotech-now.com/CRN-release-07312003.htm

next page

Greenpeace wades into nano debate with report that calls for caution
http://www.smalltimes.com/document_display.cfm?document_id=6408
(editor's note: We disagree with Mark Modzelewski, executive director of the NanoBusiness Alliance, and his calling the GreenPeace report "industrial terrorism." Our position is that the GP report is a moderate and reasonable first step towards debate.)

Science of the small poses big dilemma
http://www.swissinfo.org/sen/Swissinfo.html?siteSect=105&sid=3994671

Membership of Nanotechnology Working Group Announced
http://www.alphagalileo.org/index.cfm?fuseaction=readRelease&ReleaseID=14693

The Potential Dangers of MNT - A Debate
http://www.nanotech-now.com/mnt-dangers-debate.htm

Nanotechnology is "evil," man claims Sun says
http://www.theinquirer.net/?article=9184

As privacy vs. security debate heats up, NSF primes sensor pump
http://www.smalltimes.com/document_display.cfm?document_id=5904

Technology downsides should be debated first
http://seattlepi.nwsource.com/books/119089_book25.html

Nanotechnology: Is it the New GM?
(*) http://www.alphagalileo.org/index.cfm?fuseaction=readRelease&ReleaseID=14624

Moon Rocks - by Glenn Fishbine
http://www.nanomagazine.com/articles/moonrocks_html

Will nanotech control us, or can it be controlled?
http://www.thehill.com/news/050703/nanotech.aspx

Nanotechnology worries reach the palace
http://www.nanotechweb.org/articles/column/2/5/1/1

Wilson Center comments on nanotechnology debate
http://nanodot.org/article.pl?sid=03/02/19/2321251

The Ethics of Nanotechnology
http://www.actionbioscience.org/newfrontiers/chen.html

next page

ETHICS EDUCATION REGULATION

A look at where we stand with nanoscale technologies, August 2003

Exclusive interviews with leaders from around the world.

No informed person doubts that developments at the nanoscale will significantly impact society, in various and unpredictable ways, and sooner rather than later. We debate the time-frame, the magnitude, and the societal effects, but not the *likelihood* for large-scale change. The least speculative views suggest that we're in for changes of an order that justifies (if not *demands*) our undivided attention. We see technology advancing, faster and faster; even the rate of *advance* appears to be accelerating. Change will make its way into our lives at an ever-increasing pace. Will we be ready?

Is regulation necessary? If so, should the general public play a part in developing regulations? *What* do we regulate, if anything? *When* do we regulate - now, when a technology is nascent, later, when we better understand the potential, or never? Do we need to spell out and adopt a new set of ethics to safeguard us from these new technologies?

Answers to these questions will surely play a part in determining our collective destination. As individuals and nations, we must come together to speak of these things, in order that we be better informed when it comes time for making (or not) policy for them.

We contacted newly appointed members of the NTAG (link) (Nanotechnology Technical Advisory Group – part of the US President's Council of Advisors on Science and Technology (PCAST)), and policy-shapers from around the world. Many answered; a few declined for "time and energy" reasons (with which we can commiserate). Those who declined will be asked again in the future, as their input is germane - if not vital - to the process.

In order to kick-start a dialog, Nanotechnology Now Editor Rocky Rawstern - together with Chris Phoenix (CRN) and Tim Harper (Cientifica) - created the following questionnaire.

Questions:

1. From your point of view, what is nanotechnology?

2. Why are you involved with nanotechnology? What are your long-term goals for your area or field?

3. What is your vision regarding the changes that nanotechnology will bring to society?

4. How can government and educational institutions address the need for significantly larger numbers of nano-educated college grads?

5. Given that most people do not have advanced science training, how can they participate in the debate over advanced technologies? What, if anything, are you planning to do to educate or enable public debate in these areas?

next page

6. Given that any technology poses some degree of risk to people and the environment, what do we need to do in order to avoid serious and unexpected harm arising from nanotechnology?

7. Several leading researchers have predicted an unprecedented rapid development of extremely powerful technologies, and been proven correct. And the trend continues, upward. In your opinion, does this require the development of new ethics and/or regulations?

8. What risks do you expect from future nanotechnologies, including molecular manufacturing? What, if anything, are you planning to do to address public concerns about issues such as gray goo?

9. How can the benefits of new technology, including nanotechnology, be made available to all people, not just an elite?

10. By necessity, government plays a role in many aspects of our lives. What role do you see government playing in the development of nanoscale technologies?

11. What role can nanoscale technologies play in any given country's growth within the global economy?

12. If you could sit down with the leaders of every country and talk to them about the development of nanotechnology, what issues would you focus on?

Interviewees:

George Allen
Morten Bogedal
A. S. Daar
Neil Gordon
Tim Harper
Jeffrey R. Harrow
Lerwen Liu
Cathy Murphy
Vic Pena
Ottilia Saxl
Bo Varga
Dennis Wilson

1. From your point of view, what is nanotechnology?

G.Allen: Nanotechnology is the next generation of the technology revolution as we know it today; it will affect all aspects of the technology and science disciplines as we know them today, from electronics to material sciences and from energy to health sciences. Specifically, Nanotechnology is typically defined by size (that is 1 nanometer equaling 1 billionth of a meter), and deals with the ability to manipulate objects 1/100,000 the width of a human hair, and eventually generate materials with properties that are fundamentally new and superior to the bulk form of the same materials.

next page

M.Bogedal: To my view nanotechnology is also, besides from normal thinking, the path towards miniaturizing e.g. the adoption of know-how and managing the techniques to get to the scale of nanometres.

A.S.Daar: Nanotechnology involves the manipulation and control of material elements at an extremely small scale, 10^{-9} metres. This small scale allows for engineering of novel materials that exhibit characteristics which are specific to their molecular design.

N.Gordon: From my perspective of commercialization, nanotechnology or "Small Tech" is a series of enabling technologies that can improve products and services in many mainstream industries. These improvements can be evolutionary, and in time, disruptive. Nanotechnology is not an industry, a get rich quick scheme, nor a cure-all for every problem in life.

T.Harper: Nanotechnology is simply about understanding how things work on the atomic and molecular scale. We can then exploit this understanding to control properties of materials, whether it is in conducting polymers or drug delivery. It definitely isn't about little robots, and will not be for a long time.

J.Harrow: Nanotechnology is, as strictly defined by many, dealing with, studying, manipulating or otherwise interacting with matter below the size of 100 nanometers (billionths of a meter.) Less strictly, it's all about our learning from, and learning to deal with, the world of very tiny things which might be more broadly interpreted as things smaller than a micron (1,000 nanometers). But definitions aside, nanotechnology is about drastically shrinking the "tinker toys" we play with. Imagine building the 47 million transistors in a typical CPU chip, with your original Lego set -- even if the blocks were appropriately semi-conductive, it wouldn't work because the resulting size would be too big, introducing unacceptable speed-of-light delays to the signals. Yet today, working with far smaller "Legos," 47 million transistors in a thumbnail-sized patch of silicon that works quite well is routine.

As we shrink the "Legos" much further though, we find that the way that each Lego works, and how it interacts with other similarly-nano-sized Legos, changes dramatically (quantum physics). Also, as we learn to better understand and work with these ever-tinier building blocks, we're going to be blurring many of the "lines" we've historically drawn between individual "sciences," and even the lines between things living and dead. To me, it's this vast landscape of the unknown, and of the possible, that defines the promise of nanotechnology.

L.Liu: The ability to manipulate atoms, molecules and structures in the nanoscale

C.Murphy: To me, nanoscience is the fundamental study of matter on the 1-100 nm scale, especially for materials that have properties that are different on that size scale than bulk materials (e.g., metals and semiconductors). Nanotechnology is the manipulation of matter on the 1-100 nm scale, which includes device fabrication.

V.Peña: I consider nanotechnology to be the science and engineering of developing and producing, and commercializing products at the nanoscale, for the benefit of all mankind. The impact of nanotechnology as I define it here, will transcend the entire spectrum of the human experience, from machines to physical well being and societal and economic advances.

O.Saxl: Using the attributes of material at the nanoscale to create new functionalities at the macroscale.

next page

B.Varga: Nanotechnology is a set of enabling technologies which enable the manipulation of matter at the atomic and molecular level to disrupt current products and manufacturing processes in all realms of human interaction with matter.

D.Wilson: Nanotechnology in the simplest form is the development and use of materials and devices that have a size scale below a hundred nanometers. Our company is involved in the materials synthesis area of Nanotechnology. We produce precision –engineered metal and metal oxide nanoparticles between 10 and 100 nanometers.

2. Why are you involved with nanotechnology? What are your long-term goals for your area or field?

G.Allen: I am invigorated by the potential applications of nanotechnologies to transform all aspects of our economy in a magnificently positive way; unfortunately, in an area with so much potential, when we contemplate and debate nanotechnology, I would estimate that no more than 10% of the Senators or House members understand what nanoscience – nanotechnology is. Long-term, I think education, both in terms of awareness and participation, of members needs to be incorporated into any long-term plan as we debate and move legislation through the Congress.

M.Bogedal: The reason why I am involved with nanotechnology is because that I from several of years ago could see and predict a large and growing new area in with an enormous impact on the society today. The need for promotion and providing info to the general public and professionals on this area was not covered, and we thought that this was our call to action on this, in Scandinavia that is.

Our long term goal is to be able to help with further foundation of nanotechnology developments in the Scandinavian region. Furthermore we seek to be able to be actively involved (economical/technical) in several projects and start-ups.

A.S.Daar: Nanotechnology research is burgeoning, with huge expenditures in recent years by the governments of developed countries, and some developing countries. In order to avoid the type of controversy and misunderstandings that occurred with the emergence of genetically modified crops, it is essential that the public, and governments, be informed and given a forum for discussion of the ethical, economic, environmental, legal and social implications of nanotechnology (NE^3LSI *). We are concerned that there should not develop a "nano-divide" between developed and developing countries. We have published a paper, '*Mind the Gap*': *science and ethics in nanotechnology* in the journal *Nanotechnology*, the main thrust of which is that either the ethics of nanotechnology must speed up, or the science must slow down.

N.Gordon: Years ago I received my first nanotechnology business plan from a venture capitalist and he asked for my assessment of the company and the overall potential for this emerging technology. The more I researched the more I realized that this is the future of many things including my career.

Regarding my long-term goals, there's an expression "Pioneers get the land, settlers get the arrows." As a nanotech business consultant, analyst and association president, I have analyzed over 100 small tech companies to some degree, and the great majority are "pioneers" in their fields. During my work I regularly assess various technical and economic parameters, which are becoming increasingly accurate

  next page

in predicting the commercial viability of a nanotech venture. When the timing is right I intend to leverage this know-how and become closely involved with one or more of the "settlers."

T.Harper: I suppose I have been involved in nanotechnology since before it was widely used. My background is in surface analysis, electron microscopy and atomic force microscopy, all involving looking at scales of a few nanometres with various probes such as electrons, ions or sharp tips. As the field has developed I have spent less time in the lab, and more time discussing the business implications of nanotechnology, and the long term goal is for a strong sustainable economy based on appropriate technologies.

J.Harrow: I'm involved with nanotechnology because I see it as one of the basic "change the rules" inflection points in our evolution, on a par with the harnessing of electricity, oil, and semiconductors. The bottom line is that as we learn more about, and get better working with nanotechnology, we'll begin building things from the "ground-up" as Nature does, rather than from the "top-down" as our past and present manufacturing methods do (grinding, polishing, etc.) And at the level of building things atom by atom, or molecule by molecule, there may eventually be NO difference between how Nature builds things, and how we do. Which is both scary and tremendously powerful, at the same time. One of my goals is to help people (not just the "techies") understand the elements of nanotechnology at the "ground floor" level, so that we can all be prepared to engage in the many important nanotechnology dialogs surrounding safety, opportunities, and more. Also, with this knowledge, people will be better-poised to make intelligent and forward-looking decisions about how they, and their businesses, can prosper in this "changing of the rules."

L.Liu: I was trained as a nanoscientist and I believe in the future and science and technology-nanotech.

My role is to facilitate the global cooperation for this global technology particularly to enhance the Asia presence and competitiveness in the future.

C.Murphy: I think it is cool. Long-term, chemists such as myself would like to be easily able to make large quantities of inorganic nanoparticles of controlled size and shape - still a work in progress now - for ultimate applications in catalysis, sensors, and others.

V.Peña: I am involved in nanotechnology to contribute to advancement of the state of the science. My long-term goals are to position and promote our Company, nanoTITAN, Inc. to be a vital part in the development of this dynamic and important evolutionary phenomenon.

O.Saxl: I've been actively working at the leading edge of technology for 20 years, nanotechnology is just an extension of that. Long term goals - to continue to run the no1 nanotechnology organization.

B.Varga:
(i) To help solve key human problems of energy, water, pollution, sickness
(ii) To help build a new model value added consultancy in team building and business development
(iii) To have fun and stretch my mind

(i) Plug-and-play educational modules to enable the upload of any and all aspects of the human knowledge base
(ii) Substantial increase in human longevity
(iii) Download of human consciousness into very long-term interactive storage

next page

D.Wilson: When I was at the University of Texas, I always enjoyed getting involved in R&D projects at the very earliest stages. This is when the possibilities for "leap-frog" advances are greatest. Of course, this is also when the chances for failure are greatest as well.
First, our immediate goal is to reach profitability next year. Beyond that we want to maintain the flexibility to grow our business by developing a multi-prong long-term strategy that will involve business opportunities beyond us being just a material supplier.

(*)NE3LS: Nanotechnology's Ethical, Environmental, Economic, Legal, and Social Implications. From 'Mind the gap': science and ethics in nanotechnology. click here (requires free registration) [Anisa Mnyusiwalla, Abdallah S Daar and Peter A Singer 2003 Nanotechnology 14 R9-R13. 13 Feb 2003]

3. What is your vision regarding the changes that nanotechnology will bring to society?

G.Allen: Nanotechnology is still very much in its infancy, but as adaptations mature it will clearly have a tremendous impact on our daily lives.

Nanoscience is quickly transforming almost every aspect of our world and is already significantly improving our quality of life. From computer and electronic devices, to health care and pharmaceuticals, to agriculture, energy and our national defense, nanoscience will be the foundation of many of the revolutionary advances and discoveries in the decades to come and will soon occupy a major portion of the technology economy.

As production and innovation of nanotechnologies becomes easier, faster, more efficient and less costly, every market sector in the economy will begin to feel its impact.

That is why Senator Wyden and I introduced the 21st Century Nanotechnology Research & Development Act.

M.Bogedal: My vision is that nanotechnology will be adapted more and more in new products etc. giving the society new things to deal with. Perhaps the general public will not see the new products or the improved products as a nanotechnology driven product, but just as new/better product with new capabilities. The first real society change will come when the pot of SME's (89% of the workload Eurowide) also will adapt nanotechnology to their way of doing business, then major changes will take place.

Society will also have to deal with the ethical issues of nanotechnology.

A.S.Daar: It seems likely that nanotechnology will play a major role in engineering and product development within the next ten to twenty years. It may become a "disruptive" technology (in the good sense of the term, hopefully)

N.Gordon: Nanotechnology and small tech will bring many changes to society. Here is a small sample of high probability predictions:

Continued miniaturization: Industry, government and eventually consumers will be able to get better performing products for less cost, smaller footprint, less weight, less energy usage, etc.

next page

Reduced pollution: With the increased use of nanomaterials and miniature devices, we may be able to considerably reduce the overall consumption of steel and other principal materials. This could reduce pollution and improve our environment through less mining, drilling and harvesting natural resources; less energy for processing natural resources; less waste in processing raw materials; lighter products such as cars which in turn will use less fuel; less corrosion from new coatings so that the steel products can last longer without replacement, etc.

Early detection of trace quantities: With breakthroughs on the horizon in sensing technologies and associated infrastructure, we can expect new products that can detect trace amounts of chemical, biological, other things of interest in near real-time. This could include home and office detectors for human diseases like SARS; detectors in clothing to locate wondering Alzheimer's patients; and advanced warning systems for agricultural threats like mad cow disease; workers at risk in dangerous environments; oil spills at sea; cancerous tumors; and military threats for national security.

T.Harper: I think you have to be very careful here in distinguishing between nanotechnology and molecular nanotechnology. While proponents of the latter are excited by changes that will occur on a longer timescale than most people's lives, we have to look at the next ten years, so the space elevator is out for a start. While others have predicted the end of manufacturing as we know it, we will see a gradual penetration of nanotechnology into all areas of life, most of which will not be referred to as nanotechnology. The immediate effects will be simply to make better more functional products that people can buy. Whether it is alloy wheels that don't get caked with brake dust or a mobile phone, nanotechnology will not have a major societal effect. Also, through improved medical diagnostics, targeted drug delivery and the consequent life extension combined with the rapidly aging demographic profile of most developed countries we will see some interesting questions being raised. The shift to renewable energy sources may also produce some societal changes akin to the closure of the steel and coal based industries.

J.Harrow: Taken to its extreme, the entire value chain of our society, built around the relative scarcity of, and difficulty of producing "manufactured goods," could change. Imagine if we end up with "desktop manufactures" -- devices conceptually like an inkjet printer that, instead of building up layers of ink, build layers of atoms or molecules in exactly the correct 3D structures to produce a piece of silverware, or a working cell phone (of the latest design, of course, through licensing the "schematic" from the developer and downloading it over the Internet), or -- and here's where it gets really scary -- a living thing. "Intellectual property," rather than manufactured goods, might prevail, which would dramatically change our societies. (And, we'd better learn the "Napster" lesson, or there will be little long-term "product innovation"). See "*A gadget geek's dream come true*" for an example of preliminary work in this area.

This is an extreme vision, of course, and less dramatic advances may simply yield vastly more efficient machines (building at this atomic/molecular level is FAR more precise, and probably energy-efficient, than manufacturing the old way), vastly improved building materials, and improbable inventions based on our growing understanding of just how differently things work at the nanoscale. And, it seems increasingly likely that we'll be able to (eventually) manufacture tiny machines that could course through our bodies to target infections, root-out plaque from arteries, or even perform inside-out surgery.

The bottom line is we can only barely imagine the changes to come -- imagine if you were around at the introduction of electricity, the telephone, or gasoline -- could you have predicted what each (and in

next page

combination) have wrought? Flying machines; humans on the Moon; pocket cell phones; even air conditioning for the masses...

In fact, you WERE around only about ten years ago as the World Wide Web gained popularity and dramatically changed how many businesses operate. Few saw the potential. Yet the potential from nanotechnology could make those historical watersheds seem as a drop in the lake...

L.Liu: It is a disruptive technology and it will revolutionize every industry like other disruptive technologies.

C.Murphy: On the plus side: more powerful and lighter personal electronics such as laptops, iPods, palm pilots and things like that, which is just a straight, sort of short-term extrapolation from where we are now. IBM will be making circuits with 90 nm elements at their plant in Fishkill, NY, this year. The organic light-emitting diode (OLED) people, aka "plastic electronics" people, could be considered "nano," and very light and flexible displays (e.g. TV screens) could result from that. New nanoscale particles for catalysis (important in the chemical industry, catalytic converters in cars) might ultimately be possible. Some people think that fuel cells that have nanoscale particles in them for hydrogen storage might be better than what we have now. On the minus side: We have to make sure that people don't freak out about "gray goo" scenarios, and the health and environmental impacts of nanomaterials need to be examined now.

V.Peña: Nanotechnology is destined to be the most revolutionary advancement in the history of humankind. It will revolutionize every product, process, and production means as it evolves. By virtue of being able to design, develop, produce and commercialize from the "atom up," not yet imagined products and services will be available with less economic costs than ever in our history. With careful management of these evolutionary processes, all of mankind and its environment will benefit.

O.Saxl: Sustainability

B.Varga: Disruption of current academic, corporate, government, financial, political relationships in the short run. In the longer run a major upgrade in the quality of life for all humans on this planet (and later in the solar system and beyond).

D.Wilson: Since our company specializes in the synthesis of custom-application nanoparticles, I will focus on these applications. We already are seeing advancements in our society enabled by nanoparticals, such as: self-cleaning window coatings, anti-microbial nanosilver for chronic wound treatment, to surface coatings, and inexpensive biosensors. Nanomaterials are also extremely effective as catalysts and for micro-filtration, from water purification to chemical waste separation. Nanoparticles have already been used in timed-release drug delivery systems, and their pharmaceutical uses will expand. Finally, nanoparticles have also been used in creating novel optical films and in producing materials having optical or magnetic properties that enable new performance levels.

4. How can government and educational institutions address the need for significantly larger numbers of nano-educated college grads?

G.Allen: In my opinion, with the federal government's support, continued public awareness and positive growth in the industry, more students and young people will be attracted to the wide variety of nanotech fields and elect to pursue nanotechnology because of the opportunity it presents for a creative fulfilling

  next page

career.

M.Bogedal: Creating new national programs that will deal with this issue. In Denmark we have by law created the foundation for "producing" a large number of nanoeducated students, from bachelors to PhD's. More on this can be found on the Nanoforum webpages under Nanoforum Publications.

A.S.Daar: Governments should promote the development of graduate programs by providing funds for research, which should include studying NE^3LSI.

N.Gordon: Let's consider the context of my hometown Montreal and the NSF`s prediction of 2 million people worldwide working in nanotechnology in 10 to 15 years. If we assume that the US will account for 40% of the world's nanotech employment (800,000), Canada will have 1/10th of the US jobs based on the relative size of its population and economy (80,000), and Montreal will have about 25% of the Canadian jobs because of its multiple nanotech universities, government labs and related industrial base, then the estimated nanotech employment for Montreal should be about 20,000. This estimate is higher than Montreal's vibrant world-class biotech community, which currently employs 14,000 people.

Assuming an annual throughput of 200 graduates from the local universities, we are looking at 100 years for Montreal's 20,000 nanotech jobs to be filled. If we are going to be anywhere close to meeting these targets, it will be essential to retrain workers from related industries in addition to training new grads. Retraining a mature workforce from industry will likely include crash courses, continuing education and on-the-job training. And this can only be accomplished with the close collaboration of industry, universities and government.

T.Harper: Before we even address this issue, the problem of falling numbers of technology students has to be addressed. There is also a question here of whether anyone actually wants nanotechnology graduates, or whether physicists, chemist, biologist etc will do just fine, and whether the cross-disciplinary work should take place at a maters level. The nanotechnology degree course in Copenhagen was massively oversubscribed last year, so perhaps nanotechnology provides a way if making science seem more exciting, even if you still have to do the maths!

J.Harrow: Until nanotechnology assumes the popular mantles once held by the computer and software industries, it may take incentives to get schools to teach the technologies widely, and to convince students that this could be a key to a golden future. On the other hand, once nanotechnology DOES become well known, the educational institutions had best get ready for the rush! (Indeed, the tools of this realm-of-the-tiny are already becoming affordable by secondary schools (or their districts), such as an Atomic Force Microscope being sold by NanoSurf for about $8,000!

L.Liu: We must invest and prepare (for) our future.

C.Murphy: It is already underway. The National Science Foundation gives grants to educational institutions for many different types of scientific training programs. I am the Director of a Research Experience for Undergraduates site here with an emphasis on nanoscience (http://www.nano.sc.edu/reu). This program gives undergraduate science majors a 9-week intensive research experience doing nano-stuff. NSF also has training programs (IGERT is the acronym) for PhD students - nano could be a topic of them (we have a nano-IGERT grant pending there, don't know if we are funded yet or not). Penn State has some sort of partnership with their local community colleges to have associate degree people get training in nano-fabrication - you can check the web out for that.

(C.Murphy - Note: NSF gets peanuts in research $$ compared to NIH.... NSF also funds NSEC's, big Nanoscale Science and Engineering Centers, that must include educational and outreach activities in addition to cutting-edge research. Northwestern U has a good one.)

V.Peña: Government, as the responsible agent for Public Schools, and for establishing standards of education, and concurrently, educational institutions in general, has to recognize with urgency now, of preparing not only college graduates for the age of nanotechnology, which we at nanoTITAN call the "Diamond Age", but of refocusing our elementary and high schools to a curriculum that prepares youth to enter a society moving rapidly towards the age of nanotechnology. Curricula should certainly focus on science and engineering, but also in business, economics, ethics, law, policy and sociology, to prepare the producers as well as the consumers of nanotechnology. Government and educational institutions should be sensitive to the major workforce dislocations, as well as workforce requirements for retraining resulting from the age of nanotechnology.

O.Saxl: Very simply - By funding and developing more courses.

B.Varga: We are building a nanoEducation, Training, & Resource Center in Silicon Valley with the focus on (i) monthly forums to bring together people actually "doing it" - K-12, technical, undergraduate, graduate, professional education & training (ii) biannual conferences and job fairs in this field to create a pull as well as a push

D.Wilson: I believe that the bigger issue is attracting more college students to the basic science and engineering programs, with the nanotechnology field ultimately benefiting from broader science and engineering education. One way is for the federal government to take the lead in defining and articulating what I will call a few "grand challenges." They must then back this up with substantial and sustained funding. I am referring to something similar to the Apollo Program. When JFK announced this goal it energized the nation's engineering programs. It became a matter of national pride to be the best. This type of challenge and commitment is needed today.

5. **Given that most people do not have advanced science training, how can they participate in the debate over advanced technologies? What, if anything, are you planning to do to educate or enable public debate in these areas?**

G.Allen: Senator Wyden and I introduced the 21st Century Nanotechnology Research & Development Act, which inter alia, specifically creates the American Nanotechnology Preparedness Center to evaluate and educate the general public on the societal, ethical and environmental impacts of Nanotechnology. The creation of this center is a proactive step to better educate and enable the public to participate and understand nanotechnology and all its implications.

M.Bogedal: Nordic Nanotech is in the process of creating several things to address this problem. What we are doing to solve this is at first to communicate the nanotech issues in an understandable manner leaving no one behind others. Also we are creating an exhibition on nanotechnology matters by creating partnerships with nice and understandable user-interactive parties (such) as e.g. www.nanoreisen.de and artgroups (such) as Superflex (www.superflex.dk).

A.S.Daar: We intend to develop high school teaching modules; we are developing a Forum of NE^3LSI researchers, one of whose objectives is public engagement. We work with others to reach the public through lectures, op-ed pieces, publications in academic journals that are accompanied with press

  next page

releases, media interviews, etc. The academic community is in a unique position to mediate the public's expectations while nanotechnology is in its early years of development. There is a need for well-designed public engagement programs. These could include public education, citizen juries and enhancing the capacity of journalists to understand and communicate scientific developments.

N.Gordon: I would not underestimate the contribution from non-scientists to the nanotech debate, as their concerns and experiences can be very applicable to real life applications of technology.

The nanotech debate in Canada is being lead by lawyer Tim Caulfield from the University of Alberta, and doctors Peter Singer and Abdullah (A.S.) Daar from the University of Toronto. They have established the Canadian Nanotechnology Ethics and Legal Forum to facilitate a dialog on the ethical and legal aspects of nanotechnology with a cross-section of diverse individuals including myself. A series of milestones are being discussed to subsequently widen the scope of the forum and include others.

T.Harper: Well as most people know, Científica has a wide range of reports and white papers, many of which are freely available, helping to explain in simple understandable terms what nanotechnology is, and is not. We also run large scale academic and business focussed conferences such as TNT 2003 and the World NanoEconomic Congress, and we are working with several government studies on education right now.

J.Harrow: The only way to effectively participate in the important debates revolving around nanotechnology is to become educated about the field. This does NOT require a technical degree or any math or science skills, or the interest and ability to understand exactly "how it works" (although clearly some people will have those skills and knowledge.) But because nanotechnology does seem poised to "change everything," an open mind -- MANY open minds from domains technical and not -- are needed to assure that the hard questions are looked into, and that the public debate encompasses not only scientific issues, but also the very real and significant public policy issues that our learning to work like "Nature," demands.

Like many fields of study before it, but perhaps even more so, nanotechnology holds the potential for great good, and for great harm. Only by EACH of us becoming knowledgeable, in the areas and to the extent we're individually interested and able, can we assure that we'll end up in a society that we can, quite literally, live with.

In my particular case, that's exactly why I've been educating a broad spectrum of people about the coming nanotechnology revolution through my online technology journal, "The Harrow Technology Report" at www.TheHarrowGroup.com , and through a series of interactive multimedia consulting presentations that I bring to businesses and organizations, large and small, around the globe (see http://www.theharrowgroup.com/consulting.htm).

L.Liu: Organize workshops for educating layman about the impact of nanotechnology in everyday life.

C.Murphy: The philosophers I talk with here want to do consensus conferences with members of the public to address their knowledge (or lack thereof) and concerns re nanotech. Personally, I go out and give talks to middle and high schools about nanotechnology.

V.Pena: There has to be, and must be a debate at all levels of the economic, education and societal spectrum regarding the issues that will result from the cataclysmic changes that will be brought about by

  next page

nanotechnology. If my thesis stated in my first response is to be accepted,"... for the benefit of all mankind," it logically follows that debate should be allowed, encouraged, and accommodated from all corners of society. In this regard, I have made recommendations for such debate, and education, in planning the future events in two forums in which I am personally involved, the Nanotechnology Technical Advisory Group of the President's Council of Advisers in Science and Technology, and as Co-Chairman of the newly established Nanotechnology Committee of the Northern Virginia Technology Council.

O.Saxl: My organization devotes a considerable amount of time and effort to public information - we have produced a CD on 'What is Nanotechnology?'

B.Varga: We are launching a monthly series at The Tech Museum in Oakland where we will have large public meetings and expect to have a web forum also.

Advanced science training as a pre-requisite to making decisions IS NOT the issue, the issue is - will the nanotechnology knowledge base when converted to wealth be captured by a small minority or distributed to all the people - as all our taxes drive the R&D process. If democracy is to survive people in all sorts of organizations, not just scientific organizations, have to become aware of the issues and lobby and participate in all communication channels to assure a more fair and just future. (Thomas Jefferson said this - every generation has to create democracy anew, this IS NOT a new issue)

D.Wilson: I believe it is extremely difficult for anyone that lacks the proper scientific and technological background to effectively participate in this debate. Most criticism of nanotechnology is generally based more on emotion that fact. I will use the example of nuclear power. In general the public is against further development of nuclear power plants because of emotional issues surrounding radiation hazards. However, coal fired plants are deemed safe, when in fact the background radiation from burning coal (with traces of uranium) is higher that the background radiation from nuclear plants.
Having said this, I still think it is important for the public to bring to the surface any concerns and challenge developments that they might feel are unsafe. This will force the scientific community to address these concerns appropriately.

I believe corporations must seriously consider health and environmental responsibility when considering new technological breakthroughs. Our company certainly takes these concerns very seriously. There are industry initiatives such as Chemical Industry 2020 initiative and workshop, consisting of an assemblage of leading U.S. multi-national chemical companies working in concert with our government to identify key issues. Nanotechnologies, Inc. is an active participant in this initiative. However, it is equally important to recognize the limits of one's core competence, and work within those boundaries. We are not experts in the safety and handling skills required at mass material production level, therefore partnerships with companies such as Air Products and Chemicals are key to complimenting our internal core competencies with skills that we fundamentally lack

6. **Given that any technology poses some degree of risk to people and the environment, what do we need to do in order to avoid serious and unexpected harm arising from nanotechnology?**

M.Bogedal: Tough one…. First of all we have to stay alert and be on the forefront of the development. Then we have to answer in a proper way to any of the above mentioned problems.

  next page

A.S.Daar: Bans or moratoria on research, development and deployment can be counter-productive. Moratoria, for example, remove from public discourse the very subjects that need public engagement. Instead there should be governance mechanisms that both address risks and increase utility and whatever public good characteristics of nanotechnology as can be sustained. Decision-making should be accountable, transparent, responsive and inclusive. Scientists need to learn to work with non-scientists.

N.Gordon: Every change brings on uncertainty of some type and magnitude. As it is impossible to anticipate every risk in life, dialog, early warning signs and rapid reaction to minor accidents will ultimately drive new and improved regulations that keep up with technology advances.

Clearly there are health risks with ultrafine particles, toxic materials, biohazards, and certain production equipment. However, this is true for research and production at all dimensions – meters, micrometers, nanometers and picometers. Regulations and safety practices have been established over the years and must be respected, with violators facing the consequences.

In fact nanotech and MEMS could also be part of the solution. For example, in reaction to several incidents where under-inflated Ford Explorer tires had separated and resulted in deaths and a massive recall by Bridgestone/Firestone, Congress responded with the TREAD Act (Transportation Recall Enhancement, Accountability and Documentation) which established a tire monitoring standard. When the regulation will be in effect, all new vehicles will include a tire monitor (MEMS based) to meet the standard. See "Safety, energy efficiencies pressure tire makers to adopt MEMS monitors."

T.Harper: I have spent a lot of time recently with environmental groups to ensure that the studies we are putting in place really do address their concerns. Denying that there will ever be a problem as some groups have done, is counter productive and just plain wrong. However, given that we have a lot of experience, unfortunately, of unintended consequences of technology, whether it be PCBs or Cane toads, we do at least have a good idea of where to start looking for problems.

J.Harrow: Broad public understanding and knowledge, as we explored in the previous question, is paramount. It is this 'public openness' that will enable people to "hold the scientists' feet to the fire," so that they are accountable for not inappropriately letting this nanotech cat out of the bag. Several authors, such as Michael Creighton through "Prey," are providing some needed "scare tactics" to help average people understand the possible threats from this new world-of-the-tiny (although remember, such fiction novels are not necessarily factual as they strive to make an important point.) But threats are a real potential (although they won't have to follow those threats dealt with in fiction), and such threats must be dealt with in-advance!

On the other hand, these threats are NOT a reason to try to halt the scientific process (such censorship simply does not work in a global society, anyway.) Indeed, there are *many* sciences and their resulting technologies that "pose some degree of risk to people and the environment." The trick for nanotechnology, as with all fields, is to pursue the research with appropriate technological and societal cautions and safeguards.

L.Liu: Education

C.Murphy: Environmental chemists, toxicologists, pharmacologists, etc should get samples of stuff from the chemists/engineers/physicists and test the stuff properly. I have a small grant from NSF myself, with a guy in our pharmacy dept, called "Cytotoxicity of Nanoparticles" in which we will see if gold

next page

nanoparticles kill cells differently depending on nanoparticle size/shape etc; the grant starts Aug 1 I think.

V.Peña: This is another legitimate role for government in the evolution of nanotechnology, the development and passage of sensible, adaptable, and low economic cost laws to manage the environment as new scientific frontiers are approached and reached. However, Government should not overplay its role and stifle creativity and advancement of science. Nanotechnology can play an important role technologically in avoiding environmental disasters, as well as remediating existing environmental damages.

O.Saxl: Apply common sense. Test likely harmful substances in relation to human exposure.

B.Varga: Like virus / anti virus arms race, we can encourage nano people to think about and be creative about counters to nano threats. Frankly I think the threat in the next 5-10 years from Ebola, antibiotic immune TB, new forms of AIDS - possibly linked to rhinoviruses (common cold or flu) are much more of a threat than our current primitive nano. Or biothreats such as the novel poliovirus created in Australia for mice (later destroyed). I think the homeland defense folks and many companies are working on identification of threats.

D.Wilson: I believe there are multiple organizations that will have a responsibility in this task. Some of our nation's premier universities like Rice University have already taken a lead in this area by creating The Center for Biological and Environmental Nanotechnology. They are studying environmental issues associated with nanomaterials and ethical issues across the entire nanotechnology landscape. I believe the President's Council of Advisors on Science and Technology (PCAST) will also have a role in bringing issues to the legislators' attention for action. For example, my responsibility as a member of the Technical Advisory Group will be to identify issues before they result in any health or environmental impacts.

7. **Several leading researchers have predicted an unprecedented rapid development of extremely powerful technologies, and been proven correct. And the trend continues, upward. In your opinion, does this require the development of new ethics and/or regulations?**

G.Allen: I'm not sure it is the federal government's job to develop new ethics around nanotechnology, typically that is a function of society and the market place. Our Nation has been at the forefront of almost every important and transformative technology since the Industrial Revolution. I do NOT believe in any new or additional regulations that micromanage this new and exciting field. Rather, I believe the proper role of the federal government is to create the conducive conditions to provide all Americans with the opportunity to compete and succeed.

M.Bogedal: First of all we have to be able to understand and get all the news from the ones producing these powerful technologies and then try to communicate this as understandable as possible to every interested party. This can be a huge problem as e.g. one of the larger players in the nanotech field GE will not share what they are producing and develop in their research labs.

A.S.Daar: We must start by seriously funding open-minded scholars to study NE^3LSI. See also Governance in previous question.

  next page

N.Gordon: Ethical standards and regulations should be regularly reviewed and should evolve with the needs of society. Our society's norms have in the past permitted many things that would be unthinkable in today's standards. With regards to nanotechnology, we need to consider short-term issues such as safety concerns for nanotech researchers and the disposal of nanomaterials.

Regarding longer-term issues, we are not starting from scratch as industrial countries have decades of rules and guidelines that form a foundation to evolve nanotechnology. We should however adopt a sense of reason on ethics and regulations, as they must not needlessly constrain research and development. At stake is delaying brilliant scientists from finding possible cures and solutions for cancer, clean water, and cheap energy, among many others.

T.Harper: Any new technology can raise ethical and regulatory issues. The most important thing is that these issues are addressed on the basis of science, not hype or fear. Let's make sure we have the facts, and can distinguish science from science fiction otherwise any debate will be meaningless.

J.Harrow: That's an interesting question, because it seems that societal ethics and regulation always lag, sometimes dramatically, the technologies that seem to follow a double-accelerating curve of advancement (not only do some technologies' capabilities double continuously, but the RATE at which they double is itself doubling.) Yet humans, and by extension their societies and laws, tend to grow at a more linear, "plodding" rate. Nevertheless, societies' ethics and regulations DO respond to new developments. Not perfectly; not always "in time," but we (so far) have been pretty good about self-preservation.

The same, I believe, will occur with those changes needed to embrace nanotechnology. The more people know about this field, the more they will develop an ethic that encompasses the changes that nanotechnology will bring, and the better our legislators will be prepared to enact those regulations necessary to instantiate the new ethic. Think of the evolution of traffic laws and the resulting cultural changes. (For example, drunk driving, once seen by many in society as a "norm," has recently been accepted as the killer that it is. This changed society's once-light ethic towards such activities, led in part through public awareness brought about by organizations such as *Mothers Against Drunk Driving*.)

Similarly, our ethics and regulations will (have to) change to incorporate nanotechnology's new realities.

L.Liu: It is absolutely necessary to discuss the ethics and regulations just like any other emerging technology to ensure the positive use of the technology

C.Murphy: I am not sure whom you are referring to, and what technologies you are referring to. Nanotechnology is so broad - integrated circuits, drug delivery, sensors, catalysts, sunscreens are all applications - that I don't think "global" regulations will be as useful as application-specific regulations. The philosophers have definite and probably conflicting opinions about this!

V.Pena: I don't think that new ethics are required. Ethics, defined as "the basic principle of right action" is applicable whether creating nanorobots, or creating any other science and engineering based product. What is needed, however, is an International Convention recognizing the risks involved in moving into these new areas, and adoption of a code of ethics based on generally accepted scientific standards, and internationally accepted norms of conduct.

O.Saxl: Up till now, civilization has managed to self-regulate powerful technologies; eg the atom bomb, cloning, DDT, GM and I am sure will continue to do so.

next page

B.Varga: Yes, with the focus on openness - and not on closed. Unfortunately the current (U.S.) administration has moved to "trust us" and "you don't ask and we don't tell" and this is precisely the environment where abuses can occur.

D.Wilson: There is no question that totally new scientific developments must have serious and broad-based debate. Take for example the advances made in stem cell research. This has spawned intense debate on the bioethics around human cloning. It is imperative that regulations and procedures be established to prevent potential long-range consequences.

8. What risks do you expect from future nanotechnologies, including molecular manufacturing? What, if anything, are you planning to do to address public concerns about issues such as gray goo?

G.Allen: See answer to question # 5.

M.Bogedal: The risks from future nanotechnologies are that new products will come on the market and have not been tested properly. This happened to e.g. Lancome when putting a new creme with too tiny nanoparticles that went under the skin. Again we have to stay alert of any new developments in this area, being able to communicate this to the general public in a proper way.

A.S.Daar: The 'gray goo' scenario is an unrealistic proposition at present but it is a sexy idea that has found a sexy term, and will therefore be repeated often. We are creating a NE^3LSI Forum that will provide leadership in creating avenues for interaction between scientists, government, industry, the media and the general public. The Forum will serve as a touchstone for public engagement, as well as for actively pursuing research opportunities to examine the NE^3LSI.

N.Gordon: The Daily Mirror in the UK ran a story in May 2003 entitled "Grey Goo Science is Used in Skin Cream." In addition to the mention of suncare products from L'Oreal and Lancome that make use of nanotechnology, and a quote of concern from Prince Charles about speculation of nanotechnology turning the world into gray goo, what really fascinated me was the author's definition of nanotechnology - "Nanotechnology is a way of creating tiny machines 1/80,000th of the width of a hair". The article continues, "The gray goo scenario is the fear that millions of robots would reproduce unchecked, transforming every atom into a machine."

After reading the article, and as a responsible parent, I am now torn between using sunscreen to protect my children against harmful UV rays which at the same time places tiny robots on their skin and may seep through their pores and into their blood stream, or alternatively avoid sunscreen entirely and let them take their chances with the sun's UV rays.

Seriously though, I believe that scientific breakthroughs should be evaluated through publications in credible journals, peer reviews, and debates with informed parties. Consideration needs to be given to the "timing" of actual products, the "size" of possible risks, and the "likelihood" of possible risks

When so-called breakthroughs are conducted through journalistic sensationalism, press releases and movies, we are doing ourselves a disservice.

next page

T.Harper: Education is a key issue, and we are working with a variety of bodies on this very issue. The key is to separate the issues surrounding molecular manufacturing from those surrounding the effects of carious species of nanoparticles. We really need to concentrate our resources on the near term issues, based on what we can already do, rather than speculating about may happen providing a variety of elements of a technological house of card stack up correctly.

J.Harrow: Since nanotechnology is in its infancy, it's difficult-to-impossible to realistically define the threats that might develop. On the one hand, it's easy to conceive of the "gray goo" scenario, where nano-assemblers, devices that grab raw atoms or molecules and manufacture them into more nano-assemblers who then go off and do the same, might get out of hand and rape the environment to create a geometrically expanding "gray goo" of run-amok nano-assemblers. In part, it's the public debate that we explored above that will help scientists to consider ways to guard against such threats.

On the other hand, for a science so new and with such potential to affect things at their most basic level, I can conceive that new, previously unanticipated threats at all levels will become possible as we turn over each new nano-leaf. We'll never foresee them all, just as Madam Curie never imagined the harm that radium could cause (including her death), or as in the 1950s, shoe stores proudly announced how they used fluoroscopes to XRAY childrens' feet to assure a good shoe fit.

Damage was caused, but we learned. Society mourned the damages, but we moved forward. With nanotechnology, as with most every other field, damage will also be done (but hopefully in very limited areas due to the knowledge, oversight, and ethics we've been discussing), and we will learn. Thus has it always been so. Pragmatically, risk is part of the game, although we should (must) do everything practically possible to minimize the risks without killing the nanotech Golden Goose.

L.Liu: There is risk in every science and technology development. We cannot give up dreams. Dreams are the drive force advancing S & T development since its beginning.

C.Murphy: It sounds like from this question you are more worried about some kind of "nano-bot" that can run amuck and infect the world, is that correct? That sounds more like a nanotechnology + biotechnology thing to me as opposed to "straight" nanotechnology. To a chemist, "molecular manufacturing" happens all the time - chemical plants produce molecules that are drugs, used to make plastics, etc, and of course one can always consider living cells as marvelous factories that make all kinds of molecules (e.g. proteins). But certainly, if people are afraid of some sort of "dust" that will get out in the air and dissolve proteins, or something - scientists such as myself should not just ignore these fears in disgust, but try to figure out what basis there is or is not for such fears. Since most scientists are pretty narrowly trained, this is why having environmental/medical people for the chemists and engineers to talk to would be good. My involvement with the philosophers here is to help get the word out on this stuff to the public or at least the humanists.

V.Pena: If the proper conventions are in place, I don't see too much danger from future technologies. With regard to the issue of grey goo, the public certainly should be made aware of the risks, but so too should they be assured of the low probabilities of such occurrence given existing conventions and adherence to these.

O.Saxl: The main scientific bodies in the UK (RS, RAE etc) are actively monitoring developments, and are formulating ways of conducting open and honest debate with all stakeholders. We are part of that process.

next page

B.Varga: You have to separate the next 5-10 years (kind of knowable) from the following (totally unknown - at least to me). In the short run the threats are minimal, standard or engineered biothreats are much more dangerous potential. In the long run something like "*The Diamond Age*" or similar nano defenses like "*Moving Mars*" will have to be implemented.

(We are also conducting a) monthly series of public forums and dialogs at The Tech Museum in San Jose.

D.Wilson: I believe through forming strong alliances and partnerships between universities, corporations and government, that allow for collaboration and an open communication, the industry will be able to ease the public concerns about this technology.

9. How can the benefits of new technology, including nanotechnology, be made available to all people, not just an elite?

G.Allen: Generally, market demand will take care of those concerns.

M.Bogedal: When the SME's get to the nanotech area we have solved this.

A.S.Daar: Equity was one of the issues we identified in our *Mind the Gap* paper as a major issue confronting nanotechnology. We are currently surveying nanotech research in developing countries. This information will serve as a useful tool for advocacy regarding equity issues.

N.Gordon: My 4 year old son can log on to the Internet and figure out how to use most CD games. He is interested in new things, motivated to keep up with his older brothers and has an open mind for change. In this spirit, if someone wants to learn about nanotechnology, let him or her read nanotech-now, smalltimes, nanoapex and mainstream media that are providing increasing coverage on nanotechnology. The learning curve might be steep to understand nanotechnology and its benefits; however there are many quality sources of information available to people who want to invest the time.

T.Harper: Well a pair of nanocare pants is available at a variety of stores, and the extra $10 it will cost doesn't really put that into the elite category. A more important issue is how do the disadvantaged and people in the developing world get access to the quality of life benefits afforded by nanotechnology? You only have to look at HIV treatments to see how much of a divide can be created. We are looking at a variety of projects that will enable developing countries such as India to become producers rather than merely consumers, by developing nanotechnology based solution that address specific local needs, with the development of expertise which can then be re exported.

J.Harrow: Pragmatically, it seems to me that most new technologies have traditionally first been available to "the rich" or "elite" of a society. The products of new technologies, be they metal tools, the finest of swords, the first cars, and leading-edge experimental drugs, are often initially so expensive that those folks are the only ones able to afford them.

But one of the advantages of many of the technologies that we deal with today is how quickly they become inexpensive and so affordable by the many. Take computers, for an example -- today, they're affordable by most families in developed countries, while they were a very expensive luxury only a decade ago. I anticipate a similar trend in products derived from nanotechnology, especially since it's already begun! (Consider one of the first common nanotechnology products, the accelerometers in cars

  next page

that help determine when the airbag deploys; they and their related systems were initially very expensive, but are now commonplace in even inexpensive cars.) I suspect that the fruits of nanotechnology will follow a similar curve.

L.Liu: At the end, technology (will) impact our everyday life so it will be available to everyone!

Popular S & T education is imperative. Scientific America, for example is a good magazine for this purpose!

C.Murphy: By making the technical advances cheap enough, and "green" enough, for people even in developing countries to take advantage of it.

V.Peña: Nanotechnology is not going to be a novelty available only to the elites and not to the non-elites. By virtue of science, market forces and economics, nanotechnology will transcend all elements of society.

O.Saxl: Ask big business.

B.Varga: Well now that IS the problem - many people vote their ideology, prejudices, and programs and NOT their self interest. The professional classes can take care of themselves - how to reach people and help them promote their self-interests is the issue. I am a believer in free speech, education, dialog - and if you can explain why it is OK to promote the welfare state in Iraq at US Taxpayer expense but not fund health, education, and welfare programs in the US, then I can answer your question.

D.Wilson: I'm not sure this is really an issue. The advances that will eventually find their way into the marketplace and will by definition have broad-based impacts across all segments of the population otherwise they will not be commercially successful.

10. By necessity, government plays a role in many aspects of our lives. What role do you see government playing in the development of nanoscale technologies?

G.Allen: I see the government's role in Nanotechnology as a facilitator. Over the past two years I have teamed up with Senator Wyden and introduced S.189, the 21st Century Nanotechnology Research & Development Act. We held the first ever Congressional hearings on Nanotechnology last year. Our bill authorizes $4.7 billion in appropriations over 5 years for the coordination of an inter-agency and inter-disciplinary program to support long-term nanoscale research in the field of nanoscience and nanotechnology as part of the National Nanotechnology Research Program.

The legislation provides an organized, structured and collaborative approach to nanotechnology research ensuring America's leadership and economic competitiveness internationally in nanotechnology.

M.Bogedal: They are very important and essential to any nanotech developments in their country.

A.S.Daar:

- Funding research in science and technology
- Funding research in NE^3LSI

next page

- Work with the research community and other stakeholders, including the public, to bolster research and development and evaluate governance mechanisms to minimize risk and maximize benefits

N.Gordon: The market acceptance of nanotechnology is slower than expected. This is because nanomaterials and devices are part of a vertically integrated value chain that has multiple buying groups and various stages of approval. For example, ceramic nanomaterials have the potential to replace platinum in catalytic converters at a fraction of the price. Beyond the basic product criteria of the nanomaterial supplier for technical specifications, production ramp-up, intellectual property protection, etc; a catalytic converter manufacturer has to modify its product to accommodate the new nanomaterial; a car manufacturer has to refine its design for a future model year; and the regulatory agencies (EPA, DOT, etc) have to approve the new technology. All this moves according to the slow but methodical pace of large companies and regulatory bodies.

Governments could pay a role in helping pioneering nanotech companies increase their chance of surviving the long road to financial self-sufficiency by providing pre-commercialization funding. This could take many forms such as nanotech initiatives, and procurement set-asides for purchasing nanotech products and services. The NNI, DARPA and ATP are positive examples of government assistance.

T.Harper: Government is already playing a huge role by funding nanoscience, as it should. While the scientific community could always do with more funding, where I would like to see a greater role is in helping fund early stage companies, ones that just need a few hundred thousand, or maybe less, to either get a first product to market, or develop technology to the stage where other funding mechanisms become available.

J.Harrow: Government often holds the purse strings to encourage expensive research. As such, (and it is already beginning), government holds the power to get nanotechnology research off the ground and out into the marketplace. Admittedly, this is often a result of the government's desire to have the fruits of the research available for the military or other government programs, but many past government-fostered research programs have also yielded very direct benefit to the populous as well. Consider the old standby Teflon, or the GPS network, or in fact the Internet...

The trick, of course, is for the government to be able to encourage and fund such research, and standardize on effective safety protocols, without bureaucratically killing the necessary innovation. That's a hard and often very frustrating process, but it has yielded some fascinating results to date...

L.Liu: Government leads to make its policy strategically and put their own country in the global perspective. Government must work with the academia, industry and business to coordinate S & T policy to ensure the taxpayer’s money is well spent.

C.Murphy: Funding the basic research and environmental/health/social impacts; funding educational and outreach efforts on nanotech; start-up business $$

V.Peña: Government can and should play an important role in the development of nanoscale technologies, especially in the funding of high-risk (technical as well as economic) endeavors. Through funding for products for oceans, earth, and space exploration, for example, it can become the customer of first resort. The same can be said for Defense, Energy, Transportation and the Environment. Government can challenge educational institutions by raising the standards for education and in

  next page

establishing sensible laws to govern the evolution and use of nanotechnology. Finally, it can fund the retraining of the workforce dislocations that will result as the nanotechnology age arrives.

O.Saxl: To continue the role they are playing already - funding and promoting.

B.Varga: Very large in both the short term funding and in the long term regulation, policy, and all the laws and agencies interacting with major changes in all fields of human endeavor. A possible analogy is the impact of the national highway system in the scale of impacts on our society - ranging from the political to the sexual.

D.Wilson: The government must be the chief advocate for early stage technology advances. New products and technologies will rapidly emerge from many academic and private company initiatives. These efforts are without doubt, critical to the future of the U.S. economy and national security and will certainly receive a significant amount of attention. Allowing critical intellectual property to exit the United States as a consequence of neglect at the formative stages of this industry will likely have severe downstream impacts in later years and we are starting to see this as an emerging and possibly concerning trend. Nanotechnology is not a short-term industry, and thus needs an appropriate level of support and critical nurturing to allow the many positive returns that I firmly believe will be there for the public good.

11. What role can nanoscale technologies play in any given country's growth within the global economy?

G.Allen: What has me so heartened about nanotechnology are the potential benefits; the new applications and technologies that have not yet been imagined. It reminds me of the observations by DeToqueville in the early 1830s, that in America the only things that haven't been accomplished are those that have yet to be attempted. We are only limited by our ingenuity and imagination.

I see the potential of nanotechnology to affect almost every aspect of the global economy, from computers and electronics devices, to healthcare and pharmaceuticals, to agriculture, energy and our national defense. I believe Nanoscience will be the foundation of many of the revolutionary advances and discoveries in the decades to come and will soon occupy a major portion of the global economy. However, I am careful and do not want to overhype the nanotech, there is still much work to be done as this field is still very much in the research and development phases.

M.Bogedal: Some, or if "lucky" (clever!!) a lot, but any economy will not share the same growth.

A.S.Daar: Several developing nations including China, Brazil, South Africa, India and South Korea are investing in nanotechnology R&D. As some groups in rich developed nations call for moratoria on nanotechnology, they are endangering the role that these countries could play in the global economy of nanotechnology.

N.Gordon: I believe that each country and region needs to consider its own nanotech opportunities on a case-by-case basis. On one hand, nanotechnology offers the creation of revolutionary technologies, new companies, jobs of the future, and exports of products and services. On the other hand, some countries and regions have already established focused nanotech hubs with insurmountable leads in certain industrial applications, in which it would be impossible for other regions to compete.

next page

One place for planners to start is by evaluating its local needs and know-how for a nanotech initiative. By solving a local problem it may be possible to create marketable applications, which in turn could evolve into commercial benefits. For example, a country which has high arsenic concentrations in its drinking water may consider a nano initiative and allocate funds to develop arsenic removal solutions, solicit a local multi-disciplinary team along with leading international experts, invest in required infrastructure and education to complement the team, commercialize the resulting technology for local needs, and then export to other markets.

T.Harper: Much of what we are seeing in current industrial applications is all about reducing costs, improving efficiency, boosting margins, increasing market share, or to sum all that up, increasing competitiveness. Being competitive in a global economy is absolutely crucial to national economies, just look how entire industries have shifted the geographic location in the last thirty years. While many medium and small business still have as similar view of nanotechnology to the general public, grey goo and nanobots, there are some real competitive advantages to be gained, right now. Governments that understand that, and educate the business community will have a significant advantage in the coming decades.

J.Harrow: I suspect that nanotechnology, over the long term, will confer an unprecedented "competitive advantage" to those countries who first master the related technologies. So much so that being the first country to successfully develop the fruits of nanotechnology could tip the traditional international trade balance. It's that fundamental, and that significant. To take just one example, consider the economic position of a country that had developed safe and effective nanomachines that could be injected into the body and target and destroy only cancer cells. Or the ability to create perfect gem-quality diamonds 'from the bottom-up'. Or the ability to perfectly copy and reproduce raw materials or manufactured goods that "used" to be the major export of a country... The list could be endless, when considering the potential to do things Nature's way, and it behooves every country to pay attention.

L.Liu: Refer to the recent Deutsche bank report on the market studies, which was also discussed in my report at www.nanoworld.jp/apnw

C.Murphy: For science and technology to advance in general, you need three things: people, ideas, and tools. Money is only the means to get those things. People with good ideas and the right tools can make a lot happen. If governments can encourage people, ideas and tools to flourish in nanoscale technologies, this will lead to a boosting economy as companies get going in nano.

V.Peña: Quite simply, nanoscale technologies can raise the standard of living economically and socially, within the global economy. As products are developed at an economic scale, that country's standing in the global economy will rise, as an exporter of nanoproducts, and from that acquired wealth become a consumer and importer of otherwise scarce goods in its own country.

O.Saxl: It is the basis of new products; so design and manufacturing companies will need to plan for the utilization and adoption of nanotechnologies in the future.

B.Varga: Large when you look 10 years out, small in the short run - takes times to ramp.

D.Wilson: Advances will be at the forefront of future global competitiveness fueling many countries' GDP and national defense and economic progress. We already sense a race between the nations in funding nanotechnology research. Ultimately, each nation will chose to support specific nanotechnology-based programs that are critical to the future of that country's growth. In effect, we

  next page

might ultimately see regions that will develop expertise in various facets of nanotechnology: biotechnology, microelectronics, defense and energetics, etc.

12. If you could sit down with the leaders of every country and talk to them about the development of nanotechnology, what issues would you focus on?

G.Allen: Training, standardization/metrology and commercialization; as scientist move forward in this field providing effective education and training for researchers to gain the multidisciplinary focus and skills necessary to understand the true culture of nanoscale science, engineering and technology will be paramount to future development. Additionally, I think as researchers from across the globe collaborate and foster partnerships with each other it will be important for them to all be working from the same metrics or standardization in measurements to assure reliability and quality control.

Lastly, in terms of commercialization, there is a big push to move much of the research in this area to commercialized products. Already, according to the National Science Foundation, there are more than 1,700 companies in 34 nations pursuing nanotechnology's commercial potential. I would urge other government leaders, to the greatest extend possible, to support those efforts, encourage collaboration and overcome many of the barriers and challenges to technology/commercial development.

M.Bogedal: I will at first try to let them be able to get the drift of what nanotechnology is and what it will bring to society. Then I would focus on well-known industrial strengths for this country and try to tell them what nanotechnology could bring to this. Then I would tell them to educate more nano-engineers.

A.S.Daar: See nanotechnology as a possible new wave of technologies for human development. Look at the economic potential. Keep an open mind. Be informed of developments. Be aware of risk potential. Think for yourself after getting reliable information.

N.Gordon: Most political systems place a high priority on short-term deliverables since their parties and leaders may not be in power for subsequent terms to see the benefits of long-term actions. Unfortunately, the current state of nanotechnology is not in line with many political milestones.

The worst mistake is to do nothing, as their countries could miss out on the nanotechnology revolution. Alternatively, if investments are made entirely in education and research, without consideration for commercialization and industry support, the country or region could end up as a farm system where talent and licenses migrate to well positioned and creatively funded industrial nanotech hubs being developed in other countries and regions.

T.Harper: I will be doing exactly that as the World NanoEconomic Congress moves around the globe over the coming year. At this stage, I am content to listen, and try to understand the issues where nanotechnology could really make a difference.

J.Harrow: Safety, safety, and safety. And within those boundaries, moving nanotechnology forward as quickly as feasible. And of trying to prepare for sane ways of introducing the resultant technologies and products in ways that don't destructively destabilize the world scene.

Nanotechnology holds the power for incredible good, and for incredible harm. Even more so than the atomic bomb. Let's be sure that we all -- ALL of us -- do it "right!"

next page

L.Liu: Global Coordination and Cooperation in every related issue in nanotech R & D and commercialization.

C.Murphy: Training of people. At the graduate level, we need broadly-trained scientists that know some engineering with emphasis on nanoscale science and fabrication, engineers that know a lot of basic science re nano, and all techy people need to think their nano-work through, from lab to society. Especially in engineering, a huge fraction of US PhD degrees go to citizens of other countries, esp. China and India. After Sept 11, 2001 it got a lot harder to get these students here - and US labs were starving for students since US students in general do not go into science and engineering like they used to.

V.Peña: I would focus on three issues:
The human capital issues of

a. Education
b. Displaced Workforce Retraining and the economic and societal issue
c. Minimal interference of laws and regulations to allow for the safe, economic, and forward thinking evolution of nanotechnology.

O.Saxl: Economics, sustainability; opportunities and threats.

B.Varga: Education, training, resources - and standard SWOT (*) analysis for countries and regions within countries. The major threat is that the inequality in power and access to information and other resources will even further split the interests of classes and regions.

D.Wilson: As we have already discussed, the major issues are attracting more science and engineering university students, continuous focus and support to emerging interesting technologies that are critical to our nation's economic growth, programs that support start-ups and emerging companies, and in general an education of the public to the potential benefits of nanotechnology especially in countering the negative PR that the public has been exposed.

(*) SWOT = strengths, weaknesses, opportunities, threats

IN CLOSING:

Soon we'll begin a series of commentaries on these answers, and post them to a future issue. "Commentators" will include those that participated in the interview, and those we ask in the future. Each will have a unique viewpoint, set of ethics, values, and goals. They will agree on many things, and disagree on many more. They will *also* be passionate about their missions, and leaders in their field. And they will continue to talk and enable debate; debate which will be needed for the days ahead, as nanotechnology takes its first halting steps, and enters the nanoage.

next page

BIOS:

George Allen

Senator (R.-Va.). Member of the Commerce, Science and Transportation Committee, and the Small Business and Entrepreneurship Committee. Coauthor with Ron Wyden (D.-Ore.) of S.189 -- 21st Century Nanotechnology Research and Development Act. Senate Committee Approves Nanotech R&D Bill. Official Bio.

Morten Bogedal

CEO, Nordic Nanotech, a nanotechnology portal for the Nordic region. Nordic Nanotech's objective is to impart and disseminate knowledge regarding nanotechnology and related technologies to the Scandinavian countries. This imparting of knowledge is considered particularly useful for certain branches of the industry, the scientific research and the authorities but also to the public in general. Through its role as an information bank Nordic Nanotech acts as an intermediary between various interest groups, as an active partner in the implementing of projects and as a forum for critical discussions.

A.S. Daar

D.Phil (Oxon), FRCP (Lon), FRC, FRCS Ed. Professor of Public Health Sciences and of Surgery at the University of Toronto, where he is also Director of the Program in Applied Ethics and Biotechnology at

next page

the University of Toronto Joint Centre for Bioethics. Official Bio. Co-author of *Mind The Gap: Science and ethics in nanotechnology*. (requires free registration) [Anisa Mnyusiwalla, Abdallah S. Daar and Peter A. Singer 2003 Nanotechnology 14 R9-R13. 13 Feb 2003]

Neil Gordon

Partner-Nanotechnology with Sygertech and specializes in the commercialization of nanotechnology and MEMS. He is on the Advisory Board of the Nanotechnology Opportunity Report and the World Nanoeconomic Congress, was Judge for the SmallTimes Company of the Year 2002, Panelist at the NASA Global Nano Investments Forum, and is regularly interviewed as a leading nanotechnology industry analyst. He developed the InfoCast Nanotechnology Bootcamp course "Building the Business Case for Nanotechnology R&D and Products at Your Company". Neil is also the President of the Canadian NanoBusiness Alliance, a nanotechnology trade association with affiliated organizations in the US and Europe. He has established the Canadian Nanotech SWAT Team, which was formed to create a Canadian National Nanotechnology Initiative. He co-organized the Canadian Institutes of Health Research Nanoscience Workshop, the Canada/Europe/US (CANEUS) Micro/Nano Space Conference, and the Canadian Nanomaterials Crossroads Conference. Interview.

Tim Harper

Founder & President of CMP Cientifica, and the Co Author of the Nanotechnology Opportunity Report™, described by NASA as "the defining report in the field of nanotechnology." Tim is also the Founder and Executive Director of European NanoBusiness Association and an advisor to the US NanoBusiness Alliance. He also contributes a weekly column to the Institute of Physics Nanotechweb site and writes a regular column for Tornado Insider magazine. Official Bio.

next page

Jeffrey R. Harrow

Author *The Harrow Technology Report*, and Principal at ***The Harrow Group***. Jeff has been the chief technologist for the Corporate Strategy Groups of both Compaq and Digital Equipment Corporation. Jeff has numerous patents issued and on file in the areas of network management and user interface technology, and he is a commercial pilot. He brings these and other technological interests together to help people "look beyond the comfortable and obvious," so that they don't become road-kill by the side of the Information Highway. Official Bio.

Lerwen Liu

President ABACUS Partners Official Bio. Dr. Liu has worked in nanotechnology in Japan, Australia and Europe. She has visited a comprehensive list of nanotechnology institutes, industries and governments in the Asia Pacific region, Europe and the United States, promoting nanotechnology global policies. She is a frequently invited speaker on global trends in nanotechnology to audiences across the globe. Dr. Liu consults with high-level policy makers all over the world on government and industry nanotechnology programs and R&D planning. She has been particularly interested in promoting nanotechnology development in the Asian Pacific countries including Japan, China, Taiwan, Korea, Singapore and Australia. She also has been consulted by Asian governments on the planning of nanotechnology R&D strategies. Her contribution to global nanotechnology development is recognized worldwide.

Cathy Murphy (1)

next page

Guy F. Lipscomb Professor of Chemistry, Department of Chemistry and Biochemistry, University of South Carolina. Research Areas: Inorganic chemistry, materials science, physical biochemistry, optical properties of semiconductor clusters, luminescent probes of DNA wrapping and bending, inorganic coordination compounds for optical sensing. Official Bio.

Vic Peña (1)

Co-Founder and CEO nanoTitan, Incorporated, a design and development software provider to the nanotechnology industry. He is responsible for the Business and Financial Operations, Business Development, Marketing and Sales for the company. He has been instrumental in the start-up phase of the company, and in its early and continuing presence in the nanotechnology industry. He is Co-Chairman of the Northern Virginia Technology Council's Nanotechnology Committee, and a founding member of the Initiative for Nanotechnology in Virginia, INanoVA.

Ottilia Saxl

Ion European Board. Founding Director, The Institute of Nanotechnology. Responsibility: "To ensure the growth and development of a new learned Institute (a registered charity) whose objective is to act as a focus for information exchange, education, training and research in the field of nanotechnology." Managing Owner, The Technology Transfer Centre

Bo Varga

next page

Principal and Strategic Consultant for the The Strategic Synergy Group."...focuses on team building and business building in the nanotech domain, including executive & senior recruiting, technical & marketing consulting, and funds raising via our investor network. We have particular value add in development, funding, manufacturing, & marketing in Asia-Pacific, through joint ventures & strategic alliances." Interview with Bo Varga, Chair, Steering Committee, nanoSIG.

Dennis Wilson (1)

Chief Technology Officer, Chairman of the Board and Founder Nanotechnologies Inc. Official Bio. Dennis has more than 30 years of experience in industry, government, and university research. He has eight years of technology management experience as founder and president of Applied Sciences, Inc. He has also served as director of special projects at the Institute for Advanced Technology. He was a professor in the Mechanical Engineering Department at The University of Texas, and has over 50 technical publications.

(1) NTAG - Nanotechnology Technical Advisory Group

Named by the President's Council of Advisors on Science and Technology (PCAST)

“The NTAG is composed of leading experts in nanotechnology representing a range of disciplines, and was established to serve as a source of technical facts and information needed to assist the Council in the area of nanotechnology, particularly in reviewing current U.S. government-sponsored nanotech research and funding efforts. As part of NTAG, PCAST has formed three Task Forces in the following areas: Materials/Electronics/Photonics; Energy/Environment; and Biology/Medicine/Societal Issues.” From White House Names NanoBusiness Alliance's Executive Director to Nanotechnology Advisory Panel.

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In our next issue we will cover nanotechnology as it applies to medicine, and the changes we may see in society and business as a result.