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Nanotechnology Strategy and Grand Challenges in U.S

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Research and development opportunities at the nanoscale and projections of their societal outcomes have been integrated into a transforming strategy to yield the U.S. National Nanotechnology program announced in January 2000. This paper briefly outlines the motivation of this major investment, its preparation since 1996, current strategy and activities in 2001, and key challenges for the future.

The missing length scale in science and engineering

We know more about single atoms and molecules at one end, and on bulk behavior of materials and systems at the other end. We know less about the intermediate length scale - the nanoscale, which is the natural threshold where all living systems and man made systems work. This is the scale where the first level of organization of molecules and atoms in nanocrystals, nanotubes, nanobiomotors, etc. are established. Here, the basic properties and functions of material structures and systems are defined, and even more importantly can be changed as a function of organization of matter via 'weak' interactions (such as: hydrogen bonds, electrostatic dipole, van der Wall forces, various surface forces, electrofluidic forces, and DNA assembling) at the molecular and supramolecular levels. At this scale, there is a unity in the scientific treatment in various disciplines and for various areas of relevance. This length scale was underestimated and less explored until recently.

National Nanotechnology Initiative (NNI)

A planning activity at the national level to advance nanoscale science and engineering has been underway in the U.S. since November 1996 through an ad-hoc interagency Nanotechnology Group. Nanotechnology was perceived as a dormant opportunity with immense potential. We felt that there is a tremendous potential for scientific and technological progress, as well as a generality and a unity in concepts among disciplines and areas of relevance that would stimulate intellectual advancement and economic developments. First, we have established a vision that is focused on the novel system behavior and manufacturability at the nanoscale and less on the advantages of smallness itself. This vision is applicable to all disciplines, involves potential contributors from all areas of relevance, and aims to long-term objectives.

Seed research funding limited to specific objectives or areas of relevance has been provided on a continuous basis at NSF starting with the Nanoparticle Synthesis and Processing initiative (focus on chemical processing, 1991- 2001, $3-4 million per year) and the National Nanofabrication User Network (with the original focus on miniaturization in microelectronics, 1994-2003, $3-4 million per year). In 1997-1998, NSF sponsored a multidisciplinary program entitled "Partnership in Nanotechnology: Functional Nanostructures" (see http://www.nsf.gov/nano). The activities in U.S. and other countries were fragmented, nanotechnology had various definitions, and a unifying vision was emerging. The White House, National Science and Technology Council (NSTC) established the Interagency Working Group on Nanoscience, Engineering and Technology (IWGN) in October 1998, in order to develop a vision, a strategy and a plan of action for advancing nanotechnology [1-4]. After the NNI planning process was completed, NSTC has established the Subcommittee on Nanoscale Science, Engineering and Technology (NSET) in August 2000. NSET succeeds the Interagency Working Group on Nanoscience, Engineering, and Technology (IWGN) as the primary interagency coordination mechanism. Its goal is to work towards NNI implementation, facilitate interagency collaboration for nanoscale R&D, continue to improve the vision for nanotechnology, and provide a framework for establishing U.S. R&D priorities and budget. In October 2000, the U.S. Congress enacted the Federal nanotechnology investment portfolio of $422 for FY 2001. The FY 2002 Budget request by President Bush is approximately $519 million, a 23% increase starting with October 2001. The number of departments and independent agencies in NSET has increased from 6 in 2000 to 14 in August 2001. International developments partially stimulated by NNI have created an even broader impact than envisioned initially.

Transforming Strategy

The main goal of NNI is to fully take advantage of this new technology by a coordinated and timely investment in ideas, people and tools. NNI has risen the flag of nanotechnology on the top of R&D priorities, and has become a catalyst for R&D support in physical and biological sciences. A coherent approach has been developed for funding the critical areas of nanoscience and engineering, establishing a balanced and flexible infrastructure, educating and training the necessary workforce, promoting partnerships and avoiding unnecessary duplication of efforts. Key investment strategies are:

- *Focus on fundamental research*
- *Policy of inclusion and partnerships*
- *Recognize the importance of visionary, macroscale management measures*
- *Prepare the nanotechnology workforce*
- *Address broad humanity goals.*

2001 NNI plan of action

This investment of $422 million is still a small fraction (less than 0.5%) of the federal R&D budget of $90.8B in the same fiscal year. The main activities are:

- *Long-term fundamental nanoscience and engineering research*
- *Grand Challenges* – areas where potential breakthroughs could provide major, broad-based economic benefits, as well as dramatically improve the quality of life. The FY 2001 has identified 9 areas of Grand Challenges (NSTC, 2000). Nine areas for "grand challenges" are targeted by all participating funding agencies in the first year of NNI: nanostructured materials by design-stronger, lighter, harder, self-repairing, and safer; Nanoelectronics, optoelectronics, and magnetics; Advanced healthcare, therapeutics, and diagnostics; Nanoscale processes for environmental improvement; Efficient energy conversion and storage; Microcraft space exploration, and industrialization; Bionanosensors for communicable disease and biological threat detection; Applications to economical and safe transportation; and Applications to national security.
- *Centers and Networks of Excellence*
- *Research Infrastructure*
- *Ethical, Legal, and Societal Implications, and Workforce Education and Training*

Challenges for 2002 and beyond

It is estimated that in 2001 we are at the beginning of the development curve where the rate of discovery is increasing and we need about five years to get on the fast rising sector of the classical "S" curve. In addition to technical Grand Challenges, other challenges for the advancement of nanotechnology must be considered:

- *Interdisciplinarity and unity in research and education*
- *Timely education and training*
- *Nanoscale manufacturing*
- *Societal implications and continuing funding*
- *International challenges.*

Closing remarks

Nanoscale science and engineering R&D is mostly in a precompetitive phase. International collaboration in fundamental research, long-term technical challenges, metrology, education and studies on societal implications will play an important role in the affirmation and growth of the field. The U.S. NNI develops in this context. An increased number of companies act globally with significant flow of ideas, capital, and people. This trend will accelerate and will be the environment in which nanotechnology will develop. Priority goals may be envisioned for international collaboration in nanoscale research and education. Examples include understanding single molecules and operation of single cells, improving health and the human performance, simulation and measuring tools and nanosystems, assembling and manufacturing processes, highly efficient solar energy conversion and water desalinization for sustainable development.

References

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