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Thanks to Tom Donohue for inviting me to speak about the business of nanotechnology today, and to the Chamber for sponsoring this event. I regret not having heard all the speakers and panels that preceded this wrap-up keynote session, but of course I will be glad to answer all unanswered questions and clear up any remaining details that might have been omitted by others! Seriously, nanotechnology is a remarkable phenomenon, or set of phenomena, and one that deserves the attention of the Chamber of Commerce and its numerous stakeholders. Devoting a session like this to a discussion of the barriers that may be getting in the way of commercial applications on nanotechnology is very timely, and I am glad to be part of it.

I will start by explaining that I am an applied physicist with a professional interest in the atomic structure of matter. My own research included studies of exotic optical properties of materials, and it was clear when I was doing this work in the 1960's and 70's that there were many more possibilities for integrating optics with electronics than we could take advantage of with the materials then available. In those days we often joked that the laser was a solution looking for a problem, but we knew the real barrier to applications were the materials we were using. The properties of materials lie at the heart of many, if not most, of today's technology challenges from clean energy to personalized medicine. And much of what we call "nanotechnology" is devoted to the creation of new materials with unprecedented properties. Recent advances in so-called meta-materials whose properties derive from engineered nano-scale structures motivated me this summer to go back to research notes I made thirty years ago to see if some of those ideas could finally find applications. Nanotechnology is revolutionizing the creation and production of new materials with unprecedented functional properties.

Previous speakers have surely defined "nanotechnology" – at least I hope they have, because I'm not sure I can. There *is* a definition in use that serves to limit the scope of the term, but it has fuzzy boundaries. What I say when asked is that "nanotechnology" is a buzz-word that sweeps up new as well as old capabilities to manipulate – to engineer – matter at the level of atoms and molecules. All living cells "do" nanotechnology, and you might as well call biotechnology "wet" nanotechnology. And in the broadest sense, chemists have always been nanotechnologists. From my physicist's perspective what is new here is the instrumentation that allows us to image, manipulate, and simulate the behavior of any kind of matter atom by atom. This opens such a huge landscape of possibilities for invention that no attempt at a comprehensive classification of applications can be successful.

The wide scope of application of the new nano-capabilities has drawbacks, and it contributes to some of the barriers that are the subject of today's discussion. Frankly, I don't like the word "nanotechnology" because it projects an image of a coherent field of study that can be easily monitored, managed, and invested in – like high-temperature superconductivity, or vaccine development. Although we do have a Congressionally mandated National Nanotechnology Initiative, and my office administers a National Coordinating Office for it, the federal investment strategy for nanotechnology works from the bottom up. Based on advice from the scientific community, delivered through National Research Council reports, a variety of technical advisory panels, and agency scientists and program managers, we identify broad priority areas appropriate for federal funding. But we do not specify how much should be spent on each priority. We rely on the 25 agencies who participate in the NNI to request funds in their budgets for nano-work related to their missions. Some agencies have specific nanotechnology programs, and 13 agencies have identified funds for nanotechnology research. We publish an annual supplement to the President's budget proposal to Congress that rolls up the budgets from these agencies.

For your information, Five agencies comprise over 95 (96.6) percent of the President’s budget request for nanotechnology R&D. They are: NSF ($390M), DOD ($375 M), DOE ($331.5 M), NIH ($203 M), and NIST ($97 M). With the FY 2008 request, the NNI will have invested over $8 billion since its inception in FY 2001.

We know that the development of the countless applications of nano-capabilities requires investments in the basic sciences of chemistry and physics, as well as in the enabling fields of mathematics, computer science, and the more applied fields of electrical and mechanical engineering and materials science. All these fall under the general rubric of physical science and engineering, and that is the focus of the research component of the President's American Competitiveness Initiative and the recently passed and signed America COMPETES Act of 2007. The National Nanotechnology Initiative is a major beneficiary of the ACI.

But let me return to barriers. Thinking of nanotechnology as a single field is a serious conceptual barrier that we have to overcome in almost every conversation on this subject. Unfortunately the word has become a symbol of over-the-top expectations of miracle cures and products, and for some a label for reckless creation of potentially hazardous new materials. Sweeping so much activity under a single brand risks stigmatizing all of it for the excesses or issues related to smaller parts. But we have the brand, and we have to live with it.

If I had to pick a single issue to which the evolution of nanotechnology from laboratory phenomena to commercial applications is most sensitive, it would be *standards*. The frontier of nanotechnology is the creation of things made of atoms in configurations that have never been seen before. We have to be able to recognize these things and characterize them exactly in order to use them in products or to study their properties in interaction with other things, including the environment and human beings. Standards are almost synonymous with the technical ability to measure, and the science of nano-measurement has to grow up along with the nano-things that need to be measured. The key to standards development is NIST, and its current scale is a barrier to the commercialization of nano-products. I have said as often as I am given an opportunity to say it publicly that the National Institute of Standards and Technology is the most under-funded agency in the Executive branch of government. Its core mission of developing and promulgating standards is far and away its most important function, and it is a serious strategic error to burden NIST with technology transfer and technology assistance missions.

It should be obvious that health effects of nano-particles, for example, cannot be fruitfully studied in the absence of means to identify the specific kinds and properties of the particles. In the absence of established conventions for classifying, characterizing, and detecting nano-particles in quantitative terms, there can be no science of health effects of these new substances. It is important for the public to understand that what we call nanotechnology includes far more than the production and use of nano-particles, but the immediate public concern about nanotechnology is about the proliferation of new substances in the environment. If funding for research into environmental and health effects of nano-particles is to be more than a symbol of concern, then we must link such research strongly with the development of standards.

This public concern is a second potential barrier to the commercialization of products incorporating nanotechnology. It is not sufficiently well known that concerns about health and environmental effects have been a high profile issue throughout the entire history of these fields, and nearly every conference on nanotechnology "writ large" has devoted high profile sessions to nano-EHS. Research on these issues is a rapidly growing component of the NNI. The NNI infrastructure includes an interagency working group on Nanotechnology Environmental and Health Implications (NEHI) that has produced a list of research priorities on which it is soliciting public comment as we speak. It is important to continue to develop a community of scientists and technicians to maintain progress in this area, and this is not something that can happen overnight. In my view, proposals to devote a certain fraction of the nanotechnology research budget to EHS research are off the mark. What we need to do is fund as much EHS research as the state of the field allows. There is no law of nature that says the capacity of this emerging field of nano-EHS will grow at the same rate as nanotechnology research itself.

Do we need new agencies to handle the new challenges of health and environmental impacts of nano-products? I don't think so. I think the regulatory processes and authorities that we have now can work on nano-materials, but every new class of material requires agency expertise to develop appropriate regulations. Agencies that have significant EHS research include EPA, NIH (through NIEHS, the NCI Nanotechnology Characterization Laboratory and other research), NIOSH, NIST, and NSF. Without supporting research sponsored by NIST, NSF, and DOE the health and regulatory agencies cannot do their work effectively.

Public concern about the environmental and health impacts of nano-materials have to be taken very seriously. Advocates of nanotechnology do the field no favors when they respond to EHS concerns simply by pointing to all the wonderful benefits of nano-products, or to the economic importance of the field. The first response must be to express a sincere commitment to dealing responsibly with EHS issues.

The third barrier I want to mention briefly is the interdisciplinary nature of nanotechnology work. The problem is the difficulty of finding people and building teams who can cover the diverse fields of knowledge required to make progress. I hope this will be a temporary barrier, but I have no idea how long it might persist. Part of the problem is the generic one of access to men and women trained in the physical sciences. Increases in federal funding for university based research in these fields is almost certain to help. This is an objective of the American Competitiveness Initiative. Today most PhD's in these fields are awarded to foreign students, mostly from Asian countries. It is likely the U.S. will continue to be attractive to talented young graduate students and scientists from other countries. It is also likely, however, that the rapidly increasing opportunities for science careers in their countries of origin will alter the dynamics of this valuable segment of our workforce. Our visa and immigration policies are not optimal for encouraging these talented scientists and engineers to remain in the U.S. after receiving their degrees. Another component of the ACI is directed at immigration policies that make it easier for highly skilled technical workers to become long-term contributors to the American economy.

I have also heard concerns about the rigidity of curricula in our colleges and universities and "stove-piped" academic departments. The capabilities that define nanotechnology encompass a huge range of science. I was serious about living cells "doing" nanotechnology, and I expect increasing integration of bio-techniques with traditional materials processing in the development and manufacturing of nano-products. Nano-scientists need to be broadly trained themselves, but they also need to be prepared to work in teams of people with widely different skills. The length of time needed to acquire appropriate experience for effective research in nanotechnology might turn out to be a deterrent to young scientists choosing their career paths. In my experience, however, the excitement of a new field and new opportunities for discovery is a powerful incentive. And universities are creating new interdisciplinary and multidisciplinary institutes, centers and programs to increase their attractiveness for recruitment and for research funding. It is not surprising that the demands of a new field should grow faster than the supply of skilled labor. The combined effect of continued federal funding for nanotechnology and the intrinsic excitement of the field itself will certainly help with this part of the workforce problem.

The promise of nanotechnology, however it is defined, is very great, and it is appropriate for the Chamber of Commerce to take an interest in it. I know that interest will stimulate constructive responses from the many actors who need to work together to convert the excitement of this new field into products that will enhance the quality of our lives and the strength of our economy. Thank you.