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Extended Written Remarks:

Chairman Wyden, Senator Allen, members of the subcommittee, I thank you for allowing me – on behalf of Hewlett-Packard Company – the opportunity to testify before you on the topic of nanotechnology.

Few words have generated as much hype and controversy over the past few years as 'nanotechnology'. On the one hand, some enthusiasts have established a quasi-religion based on the belief that nanotechnology will generate infinite wealth and life-spans for all humans. On the other, alarmists fear that nanotechnology will somehow end life as we know it, either by poisoning the environment or releasing some type of self-replicating nanobot that conquers the earth. Neither scenario is realistic, and both have been propagated by people who are good communicators but actually have no relevant scientific experience in the nanosciences.

This knowledge gap exists primarily because most scientists actually working in the field are either unable to communicate what they are doing to lay audiences or think they are too busy to try. I am afraid that many scientists are guilty of believing that the public in general and policy makers in particular are incapable of understanding science, and that their work should be supported simply because it is important and beautiful. This patronizing attitude has not served the citizens of the US or American scientists. It is certainly true that policy makers do not have the time to understand the full details of the research in any field of scientific endeavor, just as most scientist have no clue about the intricacies of the legislative process. However, we owe it to each other and to the American public to engage in meaningful dialog. Our two communities may not understand the details of what the other does, but we should each appreciate what the other has to contribute to the overall benefit of society.

I will attempt to provide you with some of that appreciation today by providing a high-level description and a series of analogies, each of which is certainly flawed but taken together I hope they provide you with a picture that you can utilize in your deliberations. Nanotechnology is particularly frustrating to describe. It is not one thing, and it is certainly not all things. I have been told by public relations experts that I need to simplify the field and provide a single rallying point upon which policy makers can focus. However, this would do a grave injustice to the field and I think in the long run it is an insult to your intelligence. Therefore, let me attempt to describe what nanotechnology has to offer by delving into some of the complexity.

First, one needs to appreciate the smallness of a nanometer. Consider shrinking yourself down in all three dimensions by a factor of 1000 – you would become the size of a fairly small ant. Now take that ant and shrink it down by a factor of 1000 – it would be about the size of a single red blood cell, which are the smallest cells in your body. Finally, shrink that red blood cell by a factor of 1000 – that is the size of a nanometer, essentially the width of a few atoms. When thinking explicitly about this as a fundamental building block, Richard Feynman was truly prescient when he said there is 'plenty of room at the bottom'.

Nanoscience, the study of structures that are a few nanometers in size, is the field where hundreds of years of advances in the fields of physics, chemistry and biology have come together in just the past decade. Each discipline naturally and separately evolved toward this common goal through a series of intellectual advances, instrument developments and experimental discoveries. A significant fraction of the Nobel prizes in physics, chemistry and medicine in the past 10 years have been awarded for research discoveries at the nanoscale. Now that all three disciplines have arrived at this same goal, each has realized that it can learn much from the others, so that the field of nanoscience has transcended traditional academic boundaries. Engineers have been very quick to adapt the insights gained at the nanoscale, and in many cases have actually been the leaders in recognizing the trans-disciplinary synergies available. Material science, bio-engineering and electrical engineering are all rapidly becoming components of a nano-engineering super-discipline. The unifying issue for engineering is that the intrinsic properties of matter, such as color, chemical reactivity, and electrical resistivity, depend on size and shape only at the nanoscale. Thus, nano-engineered systems have the broadest possible range of properties that can be designed, which in turn means that building anything with control down to the nanometer scale will enable them to be produced in the most efficient possible manner. Thus, nanotechnology can and will be applied to everything made by human beings – it will allow us to dramatically improve nearly everything that we currently make, and it will enable us to create an entire range of new materials, medicines and devices that we cannot even conceive of today. Human cleverness is at a premium – which means high value added products and high wages for companies and countries that dominate nanotechnology.

With that said, we must realize that nanotechnology is a collection of new tools available to a broad range of scientists and engineers – it is not a complete solution to any problem. For the next several decades, there will be very few cases in which an entire product is the result of nanotechnology, but more and more we will find that the crucial or enabling component of a system is engineered at the nanometer scale. A current example of this is the giant magneto-resistance, or GMR, read head currently found in hard disk drives for computers – the recent dramatic increase in storage capacity of disk drives is directly attributable to the fact that GMR heads have components that are nano-engineered. The value of the read heads alone is fairly small, but they enable a multi-billion dollar per year industry. Indeed, Matthias Werner of Deutsche Bank has estimated that the total value of nanotechnology-enabled products will be $116 billion in 2002, and will increase dramatically in the near future. Thus, as we think about increasing support for the US Nanotechnology Initiative, we must not neglect other disciplines that will also be contributing necessary components to complete solutions. As in all things, a balanced approach is essential.

- What are the recent advances in nano science and engineering?

There have been so many recent advances in the nano sciences and engineering in recent past I could take up all my time just listing them. Let me give just three examples that illustrate the breadth and scope of what is possible in the present, the near future, and the longer term.

During the past couple of years, a significant number of new nanocomposite materials have come into the market place. These materials are engineered to combine properties that natural materials have never displayed, such as hardness and toughness. Naturally hard materials such as diamond shatter easily, whereas naturally tough materials like wood are easy to scratch or dent. However, by mixing hard and tough materials at the nanoscale, new composite materials can be made with levels of the two properties never seen before. In the past year, General Motors has introduced a polymer-clay nanocomposite material that is used for a dealer installed optional running board on their SUVs and pickup trucks. This material is not only harder and tougher, but it is also lighter and more easily recycled than other reinforced plastics, and GM plans to utilize it in more and more components of their vehicles as economies of scale make it cheaper. In this one example, we see that a nanotechnology can help the fuel economy, the safety, the maintenance cost, and the ecological impact of our transportation system. In the future, nanocomposites will become increasingly sophisticated and truly smart, with the ability to adapt to new environments and even to self-repair.

One of the most significant nanoscience discovories of the past couple of years that came out of Stanford, Harvard and UCLA is that nanowires, especially carbon nanotubes and semiconductor wires, can be used as extraordinarily sensitive detectors of light and of chemical and biological agents. In this case, the nanowires have such a small diameter that any change on the surface of the nanowire has a dramatic effect on its electrical conductivity. There is already a significant activity in the US and abroad to build sensors based on this discovery. These sensors can be used for medical diagnostics to detect and report extremely small amounts of pathogens for the early detection of disease such as a known cancer or even a new bacterial or viral infection not previously known. Prof. James Heath of UCLA has proposed a vision in which a laboratory on a chip with nanosensors could help investigators go from a new 'bug to drug' in 24 hours. However, probably their most pressing near term application will be for security applications for the detection of explosives, chemical warfare agents and biological threats. Given an appropriate level of support, it should be possible to begin deploying such sensors in sensitive areas within two to three years. Given economies of scale, it should be possible on the five to ten year time frame to cheaply manufacture such sensors in the hundreds of millions to billions of units to provide continuous monitoring our public buildings, post offices, transportation networks and other institutions vulnerable to terrorist attack.

I will also mention that on a longer time frame, recent discoveries and announcements in the area of nanoelectronic memory and logic circuits promise to extend the dramatic improvements in performance for cost that we have seen over the past 40 years. These advances promise to extend the economic benefits of the electronics industry that the US has enjoyed for several decades, and also continue the efficiency with which we conduct our business and government affairs. We will see a wide variety of new products emerging, but most important of all we will see our electronic tools become much easier and intuitive to use.

- What is the significance of and potential for the development and deployment of nanotechnology?

From these examples, we can see that nanotechnology has the potential to greatly improve the properties of nearly everything that humans currently make, and will lead to the creation of new medicines, materials and devices that will substantially improve the health, wealth and security of American and global citizens.

- Is the Federal Government adequately investing in nanotechnology (i.e. perspective on the National Nanotechnology Initiative)?

Given the starting point of the NNI in the year 2000 and budgetary realities, I think the current funding for nanotechnology is appropriate. It would be a mistake to put too much money earmarked for nanotechnology too quickly into the research community, since it could not adjust and efficiently absorb that funding . However, current experiences show that the number of excellent proposals for research funding in nanoscience and engineering far outstrips the available funds, and thus the ramp-up must be steep, approximately 30% per year, and sustained for at least the next five years. A National Nanotechnology Program will allow for continuous monitoring and feedback to make sure that the best ideas are funded. Also, increases in nanotechnology support must be consistent with an overall increase in the total physical science and engineering base in agencies such as the National Science Foundation, the

Department of Energy, and the Department of Defense.

As a nation, we have neglected our investments in physical sciences and engineering over the past decade. We have forgotten that these have been the drivers for our current level of material well being. The analogy is that physical science and engineering have been orchards, and we have been busily harvesting the fruits of those orchards for the past 20 years. However, we as a nation have forgotten that if we want to continue to harvest from such orchards, we must continually be planting new trees. As a fraction of GNP, our investments in basic research in the physical sciences and engineering have declined nearly 30% over the past decdade. This state of affairs has convinced American young people that there is no future for them in these disciplines, even though the potential in these areas is great.

- As an expert and a leader in this field what are your concerns in the nanotechnology area?

My primary concern is that we in the United States will not have enough of the best researchers to be the leaders in this crucial area. Currently, the US is supplying approximately 25% of the global federal funding for nanotechnology. Other countries are determined to keep pace and even surpass our efforts. Even though Japan has experienced significant economic problems, they make certain that their NNI meets or exceeds the funding levels approved in the US. The European community is doing the same. Korea, Singapore, Taiwan and China are pouring a much higher percentage of their economy into research in this area, and when considering the local purchasing power of currencies, the PRC has the largest NNI in the world in terms of the number of researchers they intend to support. Another significant part of the NNIs of all other nations is that they have set aside significant funds to recruit senior and talented researchers from other countries, and for the most part they are targeting the US. The primary requirement for federal support of basic research, from a large corporation point of view, is the training of the people needed in our corporate research and development labs to invent the new products that secure our futures. We are going to have to be smarter and more efficient going forward – we need cooperation among government at all levels, national labs, and corporate R&D facilities.

I also have some secondary concerns for the future health of the US R&D enterprise.

Largely as a result of the lack of federal funding for research, American Universities have become extremely aggressive in their attempts to raise funding from large corporations. Severe disagreements have arisen because of conflicting interpretations of the Bayh-Dole act. Large US based corporations have become so disheartened and disgusted with the situation they are now working with foreign universities, especially the elite institutions in France, Russia and China, which are more than willing to offer extremely favorable intellectual property terms.

The situation with respect to corporate partnering with US National Labs is not much better. In this case, inconsistent policies, the long time lines to negotiate relationships, and constantly shifting government priorities often make it too difficult for companies to partner with National Labs. Again, there is an international market place. National Labs in other countries are aggressively courting American companies. Perhaps the major example of this is Center for Innovation in Micro and Nano Technologies, or Minatec, in Grenoble, France, which provides access to facilities and a source of students for companies that locate research labs on their campus.

The most important problem of all is that we have lost sight of the fact that government and corporate funds spent on research are not expenditures or luxuries that can be cut at a whim, they are essential investments to the long term viability of an enterprise. We have neglected those investments for a long time now. The prosperity of the 1990's was prepared by the investements of the 1960's, when the US federal goverment was investing 2% of GNP on R&D. That investment has paid off many fold over the decades, but because we became wealthy, we forgot that we needed to keep investing to stay wealthy. The impatience of corporate boards and institutional investors have placed too strong a focus on short term results with too little long-term investment. A significant factor in the current economic situation, especially in the high tech sector, is that we do not have enough new and compelling products and services to generate customer demand. The internet bubble was a failed experiment to substitute clever business plans for new goods.

- How should and could government-industry collaboration enhance research and development in the nanotechnology area?

The US government has several roles to play to insure that America leads the world in nanotechnology. The first is to invest sufficiently in the basic research enterprise, which produces the scientists and engineers who will invent the future. The second is to act as an early adopter of new technologies, especially in the areas where technological advantage enhances our security. Finally, government should consider a new role, that of mediator to bring together academic, corporate and national research labs so they can work together and the nation can share in the benefits of their discoveries.