Testimony of Da Hsuan Feng for the U.S. House of Representatives Hearing on "*Nanotechnology Research in the 21st Century: Economic, Intellectual, and Workforce Issues*"

This testimony by Da Hsuan Feng (Vice President of Research at The University of Texas at Dallas) comprises (A) Overview of the Research and Development Activities of the NanoTech Institute and (B) Responses to Addressed Questions.

Dear Congressional members: It is indeed an honor and privilege for me to be here today to deliver this testimony. As you know, my colleague, Professor Ray Baughman, UTD's NanoTech Institute director was invited to be here, but had the prior obligation of serving on a National Science Foundation panel today.

We in the Metroplex are very fortunate to have Congressional members, such as yourselves, who have lead in promoting nanotechnology in the region and the nation. Countries around the world have followed the lead of our nation in making investment in nanotechnology a national priority.

In human history, whenever a fundamentally new type of material emerged, a new economy was born. This certainly happened during the Stone, Iron, Bronze, and Plastic Ages. Instead of pertaining to a single material, nanotechnology provides the opportunity to so fundamentally change virtually any material that a groundswell of new businesses will arise. Those countries and companies that do not lead in the development and application of nanotechnology are at great risk of becoming noncompetitive. Recent avalanching advances in the ability to manipulate materials at the sub-microscopic scale means that the materials of the future can have properties that were only imagined in the past. Taking an example from biology, nature has long been manipulating virus and cells at the submicroscopic level. This ability of nature to operate at a very small scale eventually cascaded to the diverse functionality of higher organisms. However, it took approximately 600 million years after the formation of the Earth for nature to achieve the single cell, and less than a million years afterwards to develop the first organism. Materials made possible by nanotechnology will include those having some of the capabilities of biological systems, like the ability to appropriately change properties in response to the environment and to self-repair. This vision of taking nature's nanosize building blocks to build manmade materials, first proposed by the legendary Richard Feynman some 44 years ago, is the fundamental guiding principle of this now exploding field of nanotechnology.

A. Overview of the NanoTech Institute at The University of Texas at Dallas

The NanoTech Institute of The University of Texas at Dallas was founded merely two years ago. We did this by strategically hiring some of the best people in the world to propel our activities in this arena. The Institute is led by its Director, Dr. Ray Baughman, its Deputy Director, Dr. Anvar Zakhidov, and Dr. Alan MacDiarmid, a Nobel laureate in Chemistry in 2000 and holder of the James Von Ehr Distinguished Chair in Science and Technology. I am extremely pleased to say that by working as a team, which includes senior management of UTD, the various Schools within the university, and the technological and economic planning communities in North Texas, the Institute has grown rapidly to include more than 60 people from all over the world. We are inspiring and educating students of all ages for the work force and creating knowledge and technologies that will generate new businesses and job growth. Physicists, chemists, biologists, ceramicists, metallurgists, and mathematicians are teaming with engineers to solve problems. We are eliminating boundaries that interfere with the transition from science to technology, and from technology to product. The NanoTech Institute has an atmosphere of excitement, fun, and creativity that inspires – researchers from 8^{th} graders to senior citizens work in our laboratories in the quest for new basic understanding and new technologies.

Finding and effectively utilizing new energy sources without damaging the environment is one of the primary challenges of our Nation and the World. For this reason, the Nanotech Institute has identified NanoEnergetics as an area of focus. We are using carbon nanotube fibers for the

(a) transformation of electrical energy to mechanical energy in nanotube artificial muscles,
(b) reversible transformation of electrical energy to chemical energy in supercapacitor and battery fibers that can be woven into electronic textiles,
(c) transformation of mechanical energy to elastic energy and thermal energy in super-tough carbon nanotube composite fibers, and
(d) transformation of waste thermal energy into electrical energy in electrochemical thermal energy harvesting devices.

While every category deserves a full and detailed description, within the time constraint, I will merely underscore that one important aspect is the assembly of nanofibers into high performance fibers that can be used in building devices. All known bulk synthesis methods produce carbon single walled nanotubes as impure soot. An important challenge is to develop practical technologies for transforming this soot into continuous fibers that have useful properties for important applications, such as converting waste thermal and mechanical energy to electricity, mechanical energy absorption in safety harnesses, and energy storage in textiles for the soldier. By using a novel spinning apparatus, spinning solutions, and spinning coagulants, the scientists in UTD's NanoTech Institute have spun nanotube fibers with record lengths, tensile strengths, and energy-to-break (toughness). No known fibers of any type are nearly as tough. The landmark importance of the advance (published in *Nature* and reported in *Science*) was indicated by news coverage from around the world (Wall Street Journal, New York Times, US Today, China Peoples Daily, Discover Magazine, NBC and ABC television, Voice of America, *Science*, Physics Today, C&E News, etc.).

Mr. Chairman, in the late seventies, I was privileged to spend a year as a visiting professor in the Niels Bohr Institute in University of Copenhagen, then one of the world centers of nuclear science research. At the NBI, led by the two Nobel laureates, there was great scientific excitement there, and great works and discoveries were performed routinely by scientists from all over the world. It was quite an intellectual atmosphere. I am therefore extremely pleased to observe a similar intensity of intellectual excitement about a new and fast paced field of science and technology, permeating in UTD's NanoTech Institute.

B. Questions and Responses

- How significant of an impact will nanotechnology have on U.S. economic growth and job creation in the coming decades? In what industry areas will the impact be most dramatic? What challenges exist that may slow or limit the growth and influence of nanotechnology?

Mr. Chairman, in the long term, I believe that most products will depend upon nanotechnology, from products for detecting and treating cancer, to smaller and faster computers, to improved sensors for home land security, and to the skins of our most advanced aircraft. Anytime fundamentally new materials with exciting properties are created, new businesses can result. Nanotechnology is generic, avalanching abilities in manipulating and self-assembling of the nanoscale are creating fundamentally new materials of all kinds – from metals, semiconductors, and superconductors to plastics. An economy base on new materials and devices can simply mean to carry out traditional tasks more efficiently, or more often then not, carry out tasks which were previously impossible. Also, it can mean having materials that are multifunctional, like nanotube fibers fabricated at UTD's NanoTech Institute, which might eventually be used in a soldier's uniform as both a power source and for antiballistic protection. Nanotechnology can also provide intelligent materials, like the NanoTech Institutes nanotube sheets, which can detect the composition of the fuel mixture in an engine and automatically open or close a valve – all without the need for an external power source. Mr. Chairman, advances in nanotechnology will likely impact virtually all industries, from materials, clothing, aerospace, communications, biotechnology, and computing industries to industries that not yet even been conceived. As for any new area, there are a host of challenges that must be solved. One is the high cost of producing materials on laboratory scales. Materials producers are wary of risking money on improving and upscaling material production until customers are clearly identified, and users are wary of investing money on evaluating the materials in their products until they can be guaranteed low material cost. Cradle-grave assurance of material and product safety is another important issue for nanotechnology-based materials, but probably no more than for other materials and chemicals.

- What in your experience are the best practices to help facilitate the transfer of basic research results to industry? To what extent has the Institute partnered with industry on nanotechnology research and development challenges, and how can such collaborations be made more effective?

The evolution of nanotechnology advances into new economies is still at the early phase, but there are already noteworthy successes, like the commercialization of remarkable biomedical test kits, multiwalled nanotubes as conducting additives for plastics, and nanofiber coated textiles for ordinary clothing (jeans). Overcoming the barriers between early technological breakthroughs and products is always challenging, and targeted governmental funding can make the difference between a shelved technology and a commercial success. Two years ago, at a nanotechnology conference in Richardson, Texas, Jack Kilby, one of the scientific giants of the 20th century from Texas Instruments and the year 2000 Nobel laureate for discovering the integrated circuit (IC) said that, and I paraphrase, "if it was not from the military, the IC may still be on the shelf today." In a sense, the discoveries of nanotechnology are similar to the IC discoveries in the early days. Achieving commercial application may or may not be straightforward, depending upon the technology. The best practice is for universities to partner early on with the most appropriate companies. Throwing early technology results over a fence to industry generally doesn't work, so finding ways to facilitate the partnering of industry and universities is critical. UTD is partnering with a host of companies in the area of flexible light-emitting displays, and is partnering with industry on federally funded work in the nanotube area.

- Has federal support for your research been effective at helping the Institute achieve its goals? How might Congress strengthen the structure, funding levels, and focus of the National Nanotechnology Initiative?

The successes achieved by UTD's NanoTech Institute research programs would not have existed were it not for the support of various Federal agencies as well as the visionary leadership of statesmen such as you. The same is true for virtually all of the major nanotechnology efforts in universities that are ongoing in our country today. Continuation and strengthening of this support is critical for our nations maintaining and increasing its leadership position. Industrial managers, especially in large companies, are often forced to focus on next year's product, so that the research commitment to revolutionary products is severely weakened. Targeted funding like that of the NIST ATP program can help industry take risks that are in the longer term interest of our economy and the companies, and facilitate partnering between industry and universities. Programs for small businesses, like the SBIR program, are critical, and increases in phase I funding levels could provide the industrial focus that enables success.

- Is the U.S. education system currently producing an adequate number of people with the skills needed to conduct research in nanotechnology and to work in industry on the commercialization of nanotechnology applications? What is the longer-term outlook for the nanotechnology workforce, and what changes, if any, should be made to the current education system to ensure these workforce needs are met?

Mr. Chairman, I do not think I am exaggerating that many of our research universities are among the best in the world. However, the number of Americans obtaining PhDs have not grown with our population and with the increasing needs of our industry. Indeed, our Nation's intellectual and economic growth has long been closely linked to our ability to absorb the best and the brightest from all corners of the globe. Innovations carried out in American university laboratories are powered by students, postdocs, and faculty members from across the United States and from all regions of the Earth, and many of these individuals join American industry to forge the products of the future. The NanoTech Institute of UTD is but a microcosm of this trend. For example, in the NanoTech Institute's laboratories, you will find nearly around the clock, American students, postdocs and faculty members working hand-in-hand with their colleagues from Russia, Uzbekistan, China, Korea, Philippines, Brazil, India, Germany, Ireland, Spain, Australia, and other countries. Mr. Chairman, in the wake of The War on Terror, a situation has arisen because of the serious limitation of visas issued in countries that are becoming the world's technical powers. At the most obvious level, the ability of international scientists to attend scientific conferences in the United States has become problematic. Often even invited speakers are unable to receive a visa in time. Unless this visa problem is corrected, I fear that major international conferences will be rarely held in our country, so our students, technologists, and industries will lose rapid access to information. The brain drain of the past has been to enrich America, and I fear that present visa crisis is now closing our borders to many of the best and brightest from around the word. We are in danger of no longer being a "technology" melting pot. (See Nature **426**, 5 (2003)). At the same time as we are seriously restricting visas for these countries, important American companies are creating major research laboratories in China and India. Business is usually done with those you know, often through face-to-face interactions, and I further fear that the visa problem will eventually decrease our ability to conduct commercial interactions with rapidly developing economies around the world. Mr. Chairman, the visa issue is beginning to effectively isolate American science and technology and decrease our ability to attract the brightest and most productive scientists to our shores. Unless, solutions are found we could be jeopardizing both our economic progress and security built on leadership in nanotechnology and many other fields.

In the final analysis, Mr. Chairman, the chronic shortage of scientists and engineers facing our Nation require long term and sustainable solution by the Federal Government. There is no replacement other then to truly excite our students in the K-12 levels in science and mathematics, and the only way we can achieve that is to greatly enhance the number of skilled teachers at those levels.

In summary, Mr. Chairman, nanotechnology is a fast changing field. I think everyone would agree with me that not so long ago, North Texas was not known for its nanotechnology efforts. Now, we are on the national and international radar screen. Your assistance and understanding of all the issues surrounding the region's ability to maintain a healthy scientific and economic landscape will be critical to our future.