Mr. Chairman and members of the committee, I appreciate the opportunity to give my thoughts on the future of science with perspectives from my own research. For nearly a century now the U.S. has provided scientific leadership to the rest of the world. We have done this as a nation by taking bold steps to develop the scientific foundations in new areas, by sticking with the task until it was ripe for commercialization, and then by getting out of the way and letting free enterprise take over. A case in point is the National Nanotechnology Initiative (NNI), which has received strong and continuing support over the past several years. The NNI took a fledgling but tremendously promising field and provided the resources to develop the basic science for giving that field a foundation for growth. That investment will pay off. Nanotechnology is now impacting industries ranging from information technology to health care,[1] and that impact will dramatically increase over the next several years, with the U.S. in the lead in most areas.

As I look into the future, I see several major scientific challenges that are looming, but at the head of that list is energy. Energy consumption is the only quantity that directly correlates to standard of living. The global consumption of energy is now in excess of the equivalent of 200 million barrels of oil per day (MBOE), and that demand will more than double by 2050.[1] Where will all that energy come from? Fossil fuels will not meet this demand by themselves, and so alternative energy sources will have to be developed. The late Rick Smalley called this the 'TeraWatt Challenge" (1 TeraWatt = 15 MBOE), meaning that any pathway we take must ultimately yield large energy dividends. I personally believe that solar energy is the only viable, long term solution (175,000 TeraWatts of solar energy impinge upon the earth every day and we only need to collect ~.03% of that to solve this problem!), but it is not the only alternative. Regardless of which pathway or pathways we take, the fundamental scientific challenges behind collecting, storing, and distributing energy in usable forms are daunting. Scientifically speaking, there are no low apples on this tree. Even if Congress decided to act now, U.S. scientists and engineers are going to have their work cut out for them if they are to solve this problem in time.

A second closely related challenge that we face involves getting our children engaged in science. The WWII and Sputnik generations of American scientists largely developed the information technologies and biomedical and chemical industries that provide for much of the U.S. economy today. The nanotech and biotech revolutions are, in large part, being developed by foreign-born scientists that immigrated to the U.S. for graduate school. Stan Williams, a leading nanotechnology researcher at Hewlett Packard, states that "Everybody in my lab over 40 is U.S. born. Everybody under 40 is Asian born." China, in particular, has constructed several state-of-the-art research universities over the past several years, and they are currently producing many more scientists and engineers than we are.[1,2] Asian countries, in general, are increasingly able to attract their own scientists back from the U.S. by providing them with exciting opportunities and significant resources. In addition, their need to meet the TeraWatt Challenge is becoming increasingly acute, and necessity is the mother of invention. If the U.S. is to maintain its competitive advantage as we move towards solving the scientific and engineering challenges of the 21st century, then we must take bold steps now to solve the underlying scientific and engineering challenges. We must also take strong steps towards encouraging and preparing our children to actively participate in developing this future by becoming the scientists and engineers who will make it happen.

Jim Heath, Caltech November, 2005

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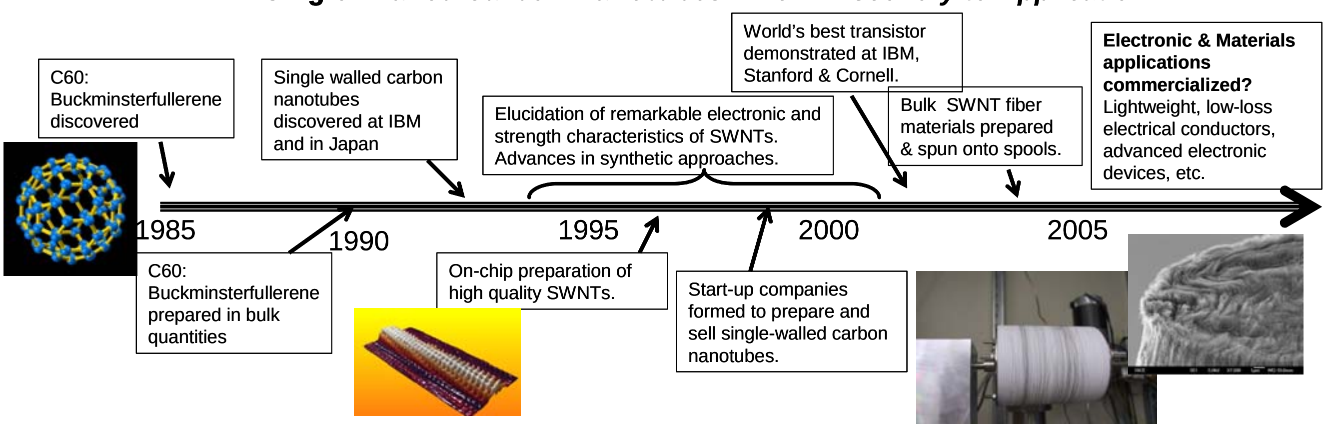
[1] Supplementary materials: Part I – Science-to-Technology Pathways; Part II: Energy Consumption; Part III: Production of Scientists in U.S. and Asia.
[2] National Science Board, Science and Engineering Indicators (2002 and 2004).

Supplementary Materials to Heath's Testimony to Senate Committee on Commerce, Science, and Transportation, November 19, 2005.

In this supplement I provide two examples of relatively modern discoveries, the, development of which was aided by the National Nanotechnology Initiative (NNI), and which will lead to a variety of commercial applications within the next decade or so. The point of these examples is to illustrate that even today, with all of the scientific and technological infrastructure that is in place in the U.S., the timeline between initial discovery and initial commercial application remains around 15-20 years. Both of the examples provided, single-walled carbon nanotubes and semiconductor nanowires, constitute the enabling discovery that can support a number of technologies. As a result both classes of materials have also received significant attention and federal investment worldwide.

As we move towards addressing the emerging problems of this century, it will be necessary for us to not only move boldly towards solving those problems, but to also stay the course and allow for the development of the critical scientific discoveries into viable technologies. With respect to the energy problem highlighted in my testimony, it is worth noting that many discoveries that have been supported by the NNI (including carbon nanotubes and nanowires) will likely play key roles in terms of developing the ultimate solutions.

Single-Walled Carbon Nanotubes: ***From Discovery to Application***



Single walled carbon nanotubes are currently being developed, within both academic and industrial settings, as

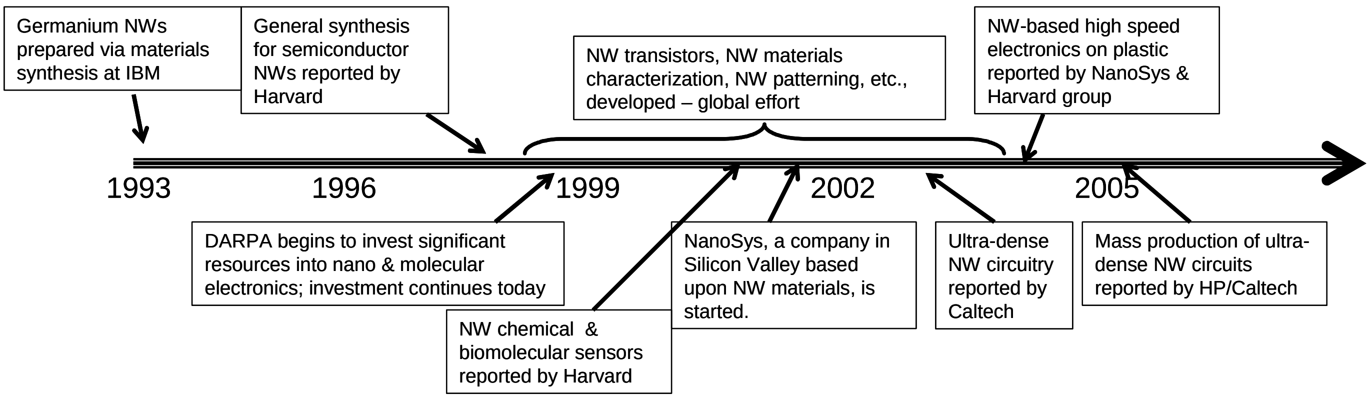
- lightweight electrical conductors ***(can impact the energy problem)***
- integral components in video monitors
- high speed, low power electronics devices
- chemical sensors for applications in many arenas including bioagent detection
- lightweight, ultra-strong structural materials (e.g. kevlar replacements).

The second example, that of semiconductor nanowires, is also characterized by an equally broad and diverse set of applications. Depending on the application, these materials are currently being investigated in both academic and commercial settings. Applications include

- High-speed electronic and optical devices that work on plastic substrates
- Adhesives with an unusual and enabling combination of properties
- BioSensors within chip-based tools for the early diagnosis of cancer and other diseases

- Electronic circuitry that significantly extends the Moore's Law scaling of electronic devices.
- Ultra-efficient thermoelectric devices (refrigerators and power-recovery devices) ***(can impact the energy problem)***

Semiconductor Nanowires (NWs): ***From Discovery to Application***



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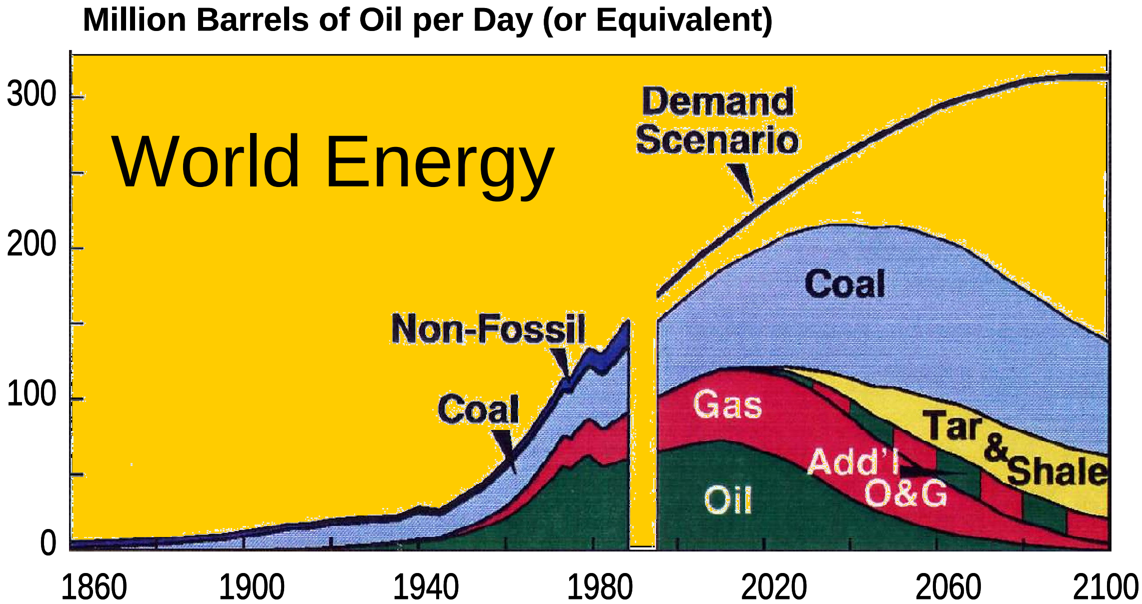
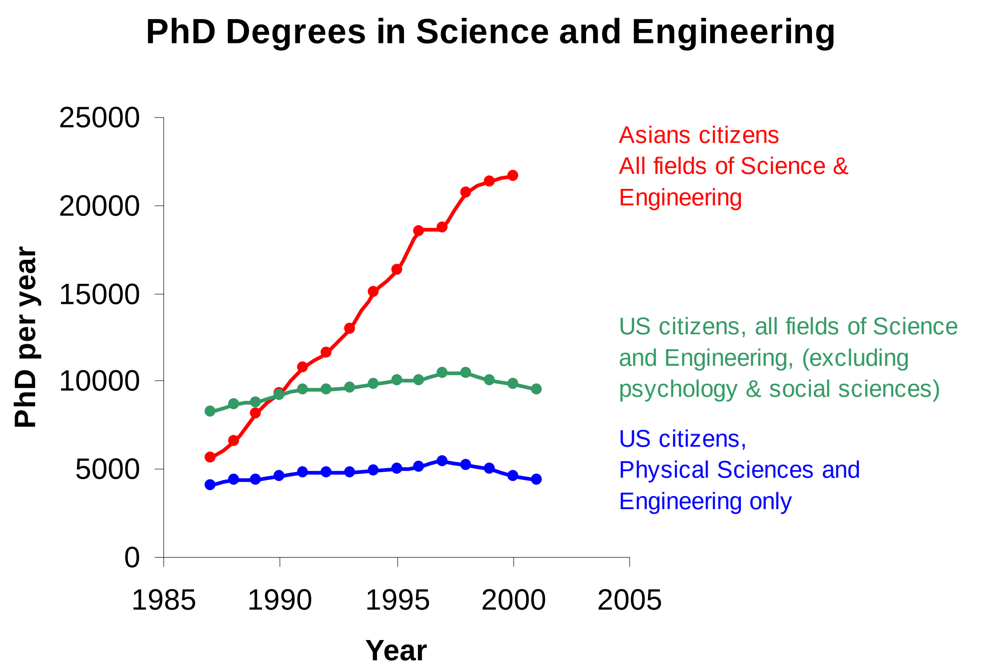
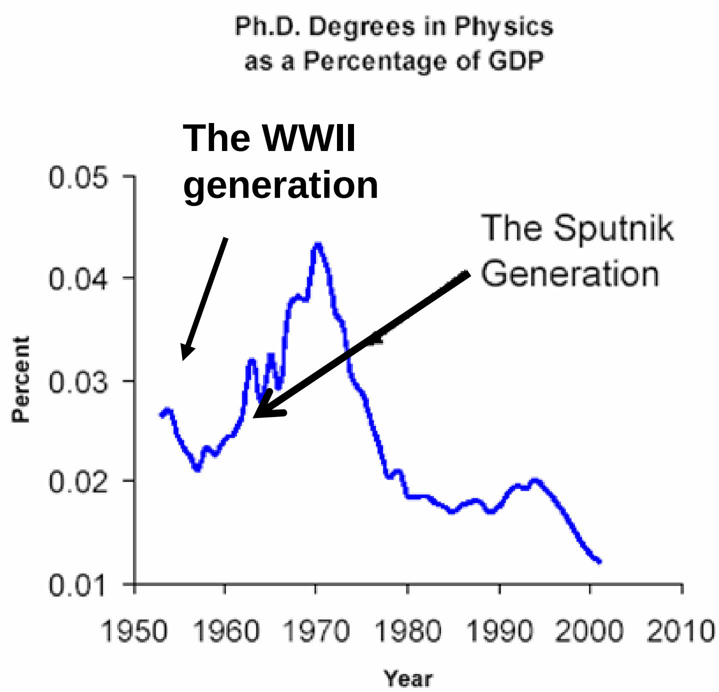


Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" Int'l Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).

Supplement III. Data on the Production of U.S. Scientists and Engineers with a comparison to Asia.



Source: Science and Engineering Indicators, National Science Board, 2002



GDP is expressed in constant 1996 dollars (in million)
Source: American Institute of Physics & National Science Board, Science and Engineering Indicators, 2002.