Change Required for the National Nanotechnology Initiative as Commercialization Eclipses Discovery

Testimony before the Senate Committee on Commerce, Science, and Transportation
Matthew M. Nordan, President, Lux Research Inc., April 24, 2008

The National Nanotechnology Initiative (NNI) is a great success; it has not only funded prodigious fundamental research, but has also catalyzed a virtuous cycle of innovation manifested in corporate R&D and venture capital. The landscape is different today than when the NNI commenced in 2001, however. Nanotech's discovery phase has given way to commercialization – tens of billions of dollars worth of products now incorporate nanotech – and other nations are eroding the U.S.'s dominant position. As the NNI is reauthorized, its focus should shift to application development and manufacturing scale-up – and its approach to environmental, health, and safety (EHS) issues must be overhauled.

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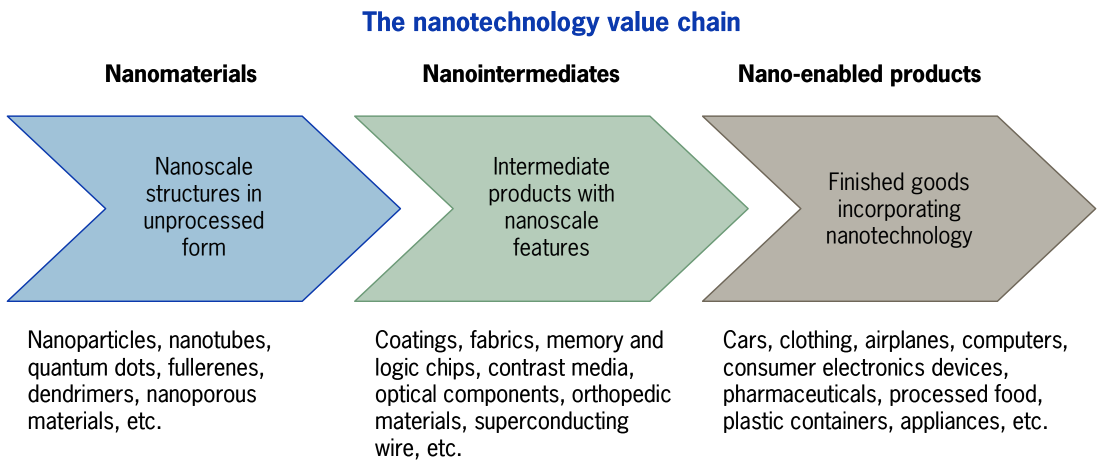
The NNI Has Catalyzed a Virtuous Cycle of Innovation

Nanotechnology is the purposeful engineering of matter at scales of less than 100 nanometers (nm) to achieve size-dependent properties and functions. Nanotech is not a new industry or market, but rather an enabling set of technologies that impact a wide variety of industries through a nanotech value chain. This value chain starts with nanomaterials like carbon nanotubes and dendrimers, which are incorporated into intermediate products like memory chips and drug delivery systems, which are in turn used to make enhanced final goods like mobile phones and cancer therapies (see Figure 1). Lux Research projects that new, emerging nanotechnology applications will affect nearly every type of manufactured product through the middle of the next decade, becoming incorporated into 15% of global manufacturing output totaling $2.6 trillion in 2014 (see Figures 2 and 3).[1]

Introduced in 2001 and signed into law in 2003, the U.S. National Nanotechnology Initiative is the federal government's coordinating program for publicly-funded nanotechnology research, which has inspired similar efforts in countries worldwide from Germany to

Fig. 1: Nanotech Adds Value across Industry Value Chains in Three Stages



Source: 2007 Lux Research reference study "The Nanotech Report, 5th Edition"

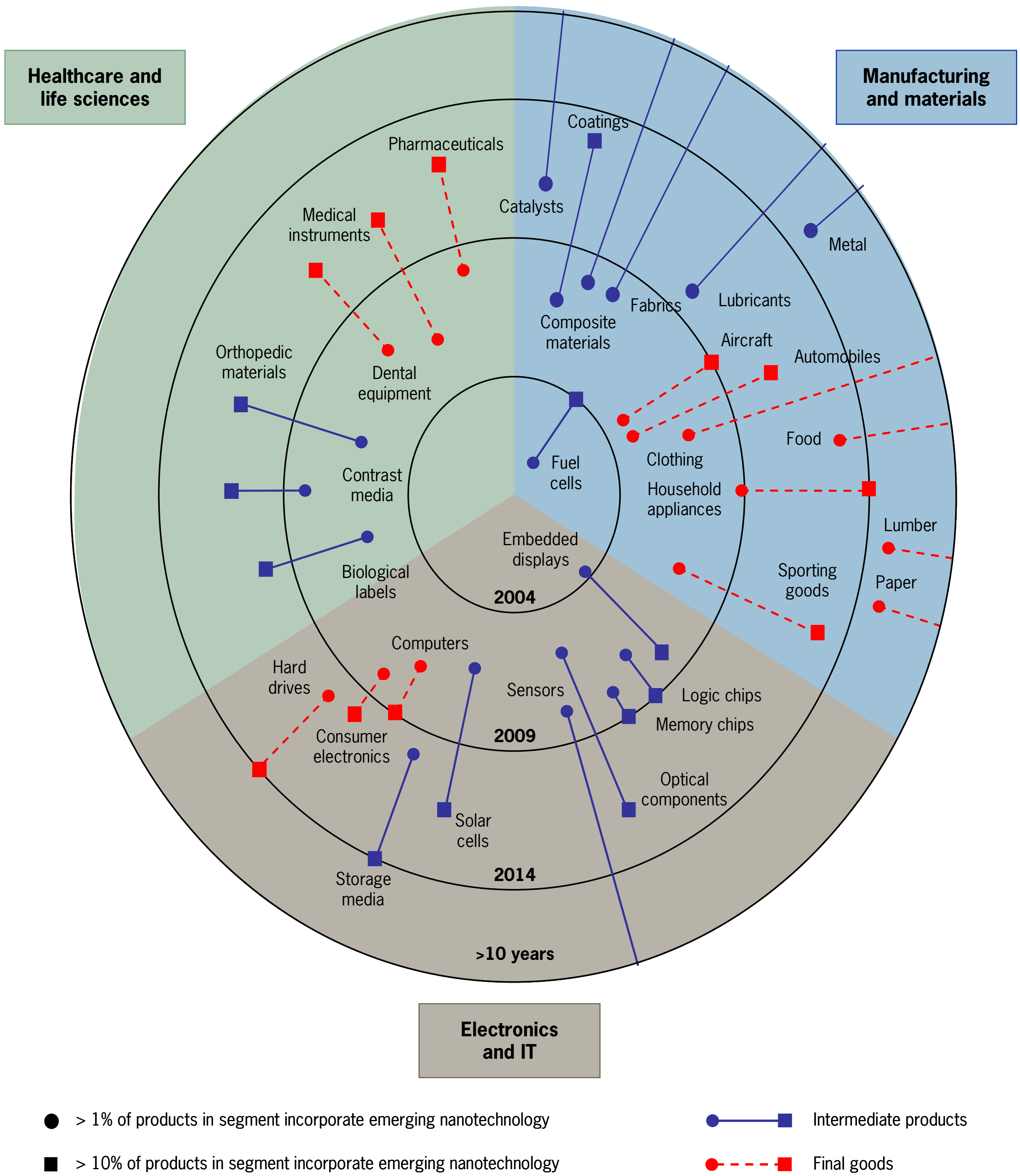
South Korea. By the core measure of scientific output, the NNI has been a great success – U.S. scientists have published 55,661 journal articles on nanoscale science and engineering since 2001, 27% of the world's total. But in addition to this, the very presence of the NNI has catalyzed a virtuous cycle of innovation, manifested in:

- **Corporate R&D spending.** Large U.S. corporations from GE to Motorola spent $2.4 billion in nanotechnology R&D in 2007, up 22% from 2006 and 557% from 2000, the year before the NNI's introduction. The 2007 figure was 23% higher than U.S. government nanotechnology funding at the federal and state level combined.[2] These efforts include in-house research like GE's Nanotechnology Advanced Technology Program, broad collaborations like Cabot Corporation's Fine Particle Network, and joint ventures like DA Nanomaterials, created by DuPont and Air Products. Without the NNI as a widely-publicized focusing mechanism for nanotechnology research, it's unlikely that this intense corporate focus on nanoscale science and engineering would have materialized.

- **Venture capital (VC) funding.** Venture capitalists are always on the lookout for compelling investment themes, as well as non-dilutive sources of financing that can help sustain the companies they invest in through notoriously rocky early stages. The NNI has provided both, serving as a validator that has helped open VCs' wallets to materials science investments in a fashion never before seen. In 2007 VC firms put $632 million into U.S.-based nanotech start-ups in 2007, more than four times the figure in the year before the NNI was initiated (see Figure 4).[3]

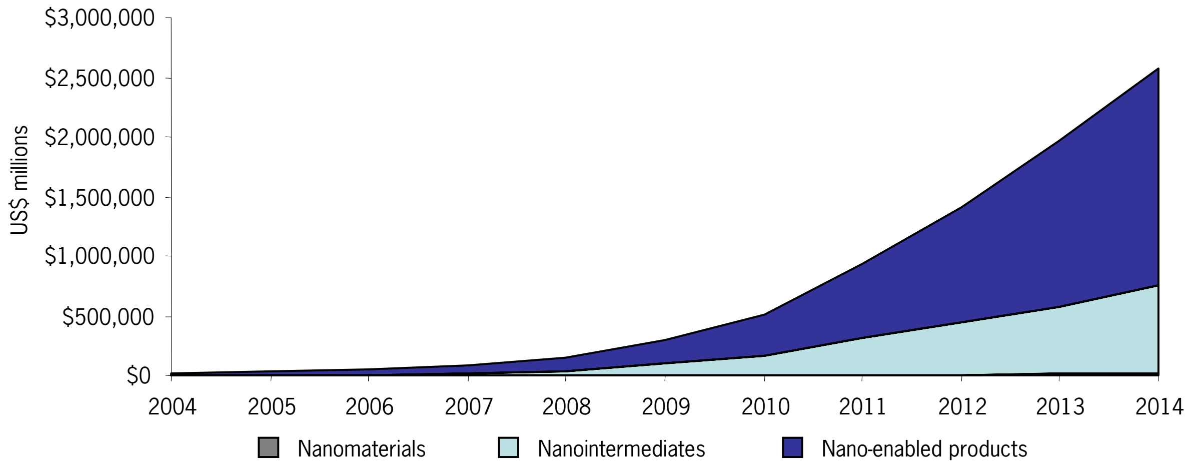
- **New companies and new jobs.** Consider A123Systems, which uses nanostructured lithium iron phosphate electrodes to make advanced batteries now being evaluated for use in electric vehicles like GM's Chevy Volt. In the mid-1990s, the Arsenal complex in the city of Watertown, Massachusetts was 750,000 square feet of empty, crumbling space. Now, A123Systems is its

Fig. 2: Product Categories Are Incorporating Emerging Nanotechnology at Different Rates



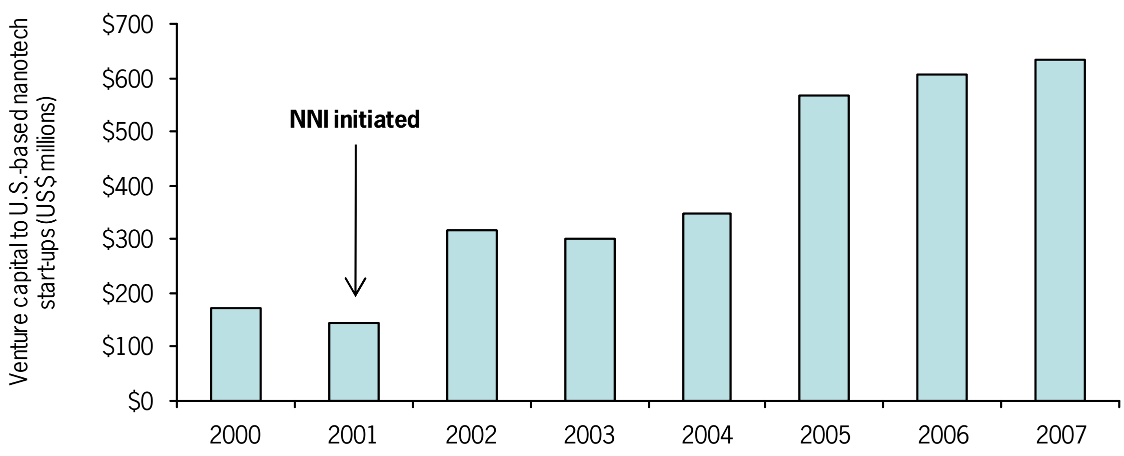
Source: 2007 Lux Research reference study "The Nanotech Report, 5th Edition"

Fig. 3: Global Sales of Products Incorporating Emerging Nanotechnology, by Value Chain Stage, 2004 to 2014



Source: 2007 Lux Research reference study "The Nanotech Report, 5th Edition"

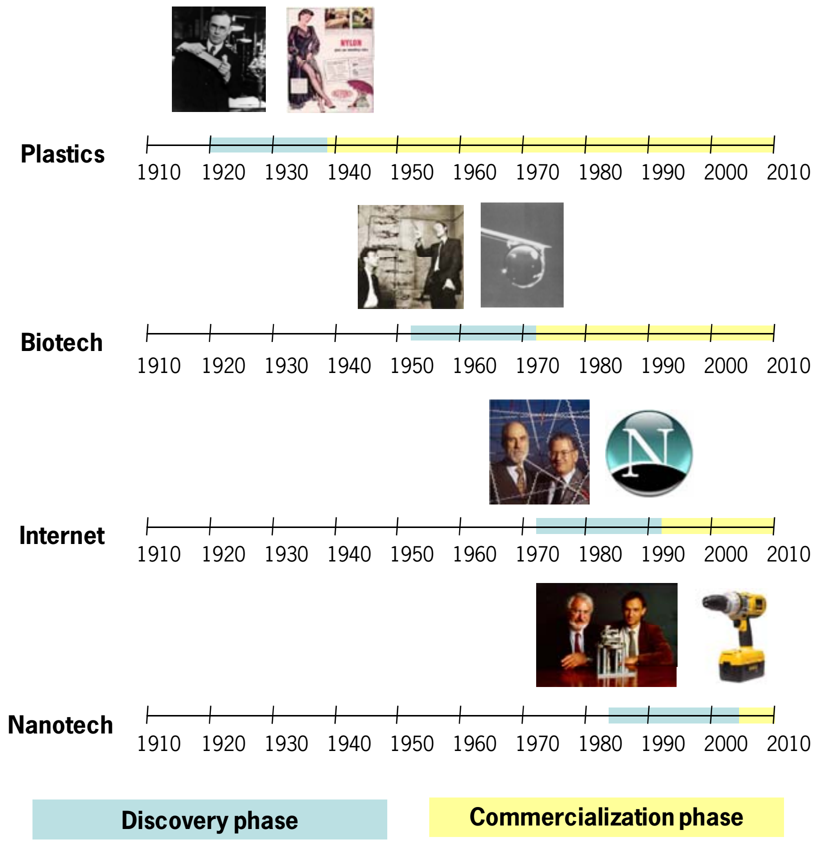
Fig. 4: The NNI Sparked Venture Capital Interest in Nanotechnology



Source: March 2008 Lux Research report "How Venture Capitalists Are Misplaying Nanotech"

biggest tenant, commercializing battery devices based on research by Yet-Ming Chiang at MIT – precisely the type of research that the NNI funds. In just four years, A123 has gone from a few dozen employees to more than 1,000 – and helped to shift the center of battery innovation from east Asia to the United States.

Fig. 5: Nanotech's Shift from Discovery to Commercialization Follows a Familiar Pattern



Source: 2007 Lux Research reference study "The Nanotech Report, 5th Edition"

The Nanotech Landscape Is Very Different Today than When the NNI Launched

When the NNI took shape in 2001, nanotechnology activity focused on early-stage laboratory research with little commercial impact, and the U.S. was alone in the world in having a nationwide coordinating program for nanotech. Today, both factors have changed. Nanotechnology has shifted from its discovery phase into its commercialization phase – and at the same time, the dominant competitive position of the United States has been eroded by other nations.

Nanotech Commercialization is Eclipsing Discovery

In the last seven years, emerging nanotechnology has increasingly become a fact of life and of business, as the technology has shifted from an era of *discovery* to one of *commercialization*. In this fashion, nanotechnology follows the example of other world-changing technologies like polymer science and biotechnology. For these emerging technologies, everything starts with the discovery phase – a period of basic research and application development – which has a characteristic time span, give or take a bit, of about 20 years. It's then that a tipping point gets reached, triggering the commercialization phase – where the technology's long-term impact is manifested (see Figure 5).

For instance, plastics' discovery phase started in the 1920s, when scientist Wallace Corrothers at DuPont began work on synthesizing nylon. In 1937, he was issued his patent on the material. Two years afterward – about 20 years after discovery began – American women bought 64 million pairs of nylon stockings; once the commercialization threshold was reached, it took off fast. In biotechnology, James Watson and Francis Crick characterized DNA in 1953, and 20 years later, right on cue, Stanley Cohen and Robert Boyer applied genetic engineering techniques to synthesize insulin for the first time. Genentech, the first biotech start-up, was founded in 1976, and commercialization has since skyrocketed: In 2006, revenues of publicly-traded biotech companies topped $65 billion. In information technology, Vint Cerf and Robert Kahn proposed the Internet protocol in 1974. The number of Internet users grew gradually to the single-digit millions up through 1993, but began to skyrocket in about 1994, the year Netscape's browser was released – reinventing communication and commerce in the process.

Nanotech's discovery phase started in the mid-1980s with the invention of scanning probe microscopes that enabled scientists to visualize matter at the nanoscale for the first time. Innovations have reached the market in electronics, as A123Systems' nanostructured battery electrodes appeared on store shelves in Black & Decker's Dewalt line of power tools; in healthcare, as nanoparticulate drug reformulations like Abbott's cholesterol drug Tricor have found their way into doctors' repertoire; and in materials and manufacturing, as PPG's coatings have improved the performance of millions of automobiles. According to our research, approximately $88 billion in manufacturing output worldwide incorporated emerging nanotechnology in 2007.

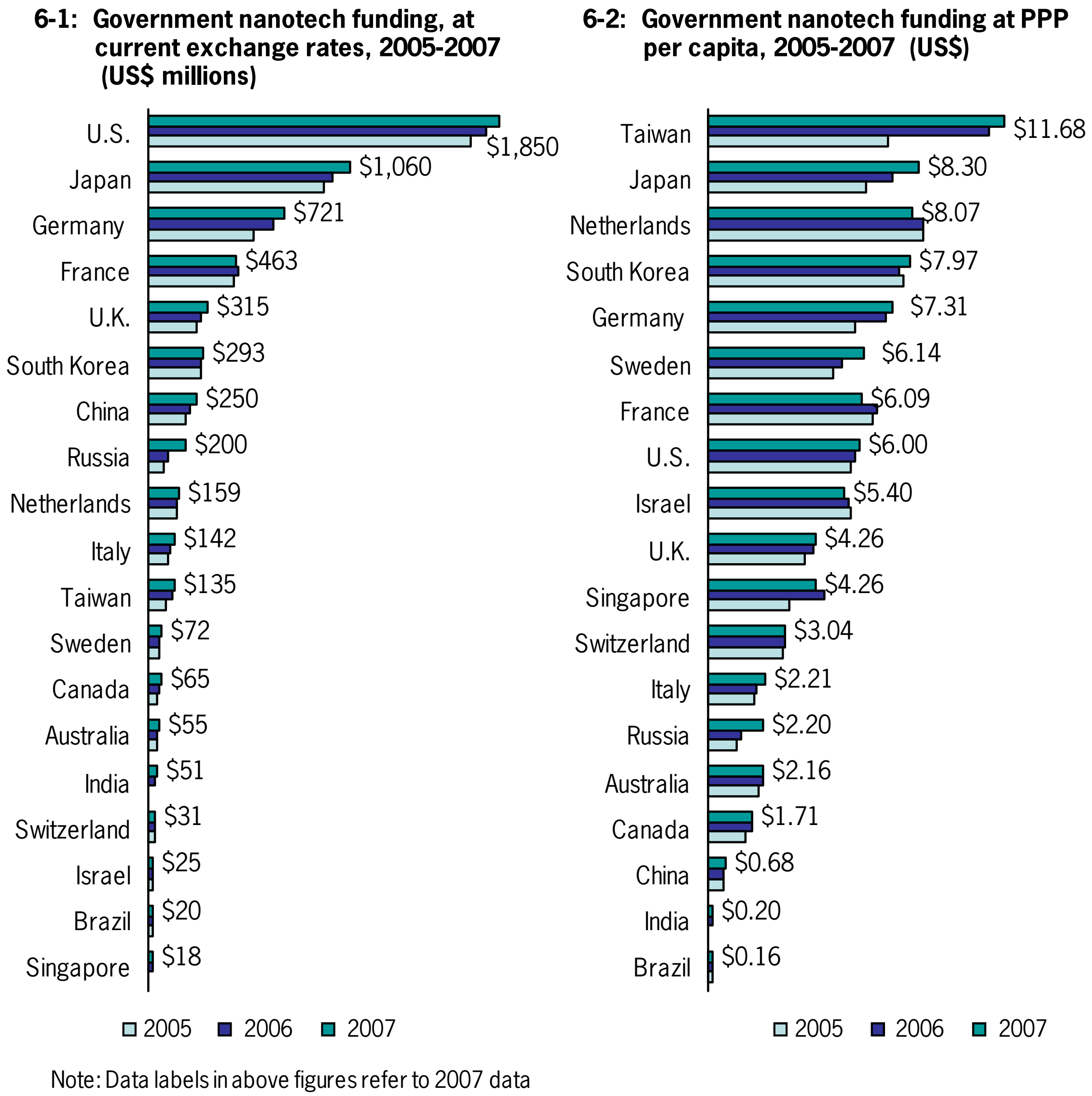
The Dominant Position of the U.S. Is Being Eroded

Each year, Lux Research conducts an annual assessment of international competitiveness in nanotechnology, ranking 19 nations worldwide on their nanotechnology activity and technology commercialization strength. On an absolute basis, the U.S. remains the world leader in nanotech. Two factors, however, should give U.S. policymakers pause:

- **The U.S. does *not* lead on a relative basis.** Relative to our population and the size of our economy, the U.S. pales in comparison to other countries when it comes to nanotechnology activity. For example, when government funding is considered on an absolute basis, the U.S. topped the charts in 2007. However, when the same figures are considered on a per capita basis at purchasing power parity, the U.S. takes eighth place, with funding half that of Taiwan, and behind Germany, Sweden, and France (see Figure 6).[4]

- **Other countries are catching up.** Since we began performing our international competitiveness rankings in 2005, the position of the U.S. has remained static while other countries have vaulted upwards in their nanotechnology activity (see Figure 7). For example, nanotech funding is growing in the EU at twice the rate in the United States, putting the EU on track to claim the mantle of nanotechnology leadership due to a renewed focus on nanoscale science and engineering in the 7th Framework Programme for research. Russia recently funded a state nanotechnology corporation with $5 billion of public financing. And scientists in China published nearly as many scientific journal articles on nanoscale science and engineering in 2007 as those in the U.S. did, at 7,282 to 7,528 (see Figure 8). While the quality of these

Fig. 6: U.S. Government Nanotech Funding Lags Other Nations on a Relative Basis



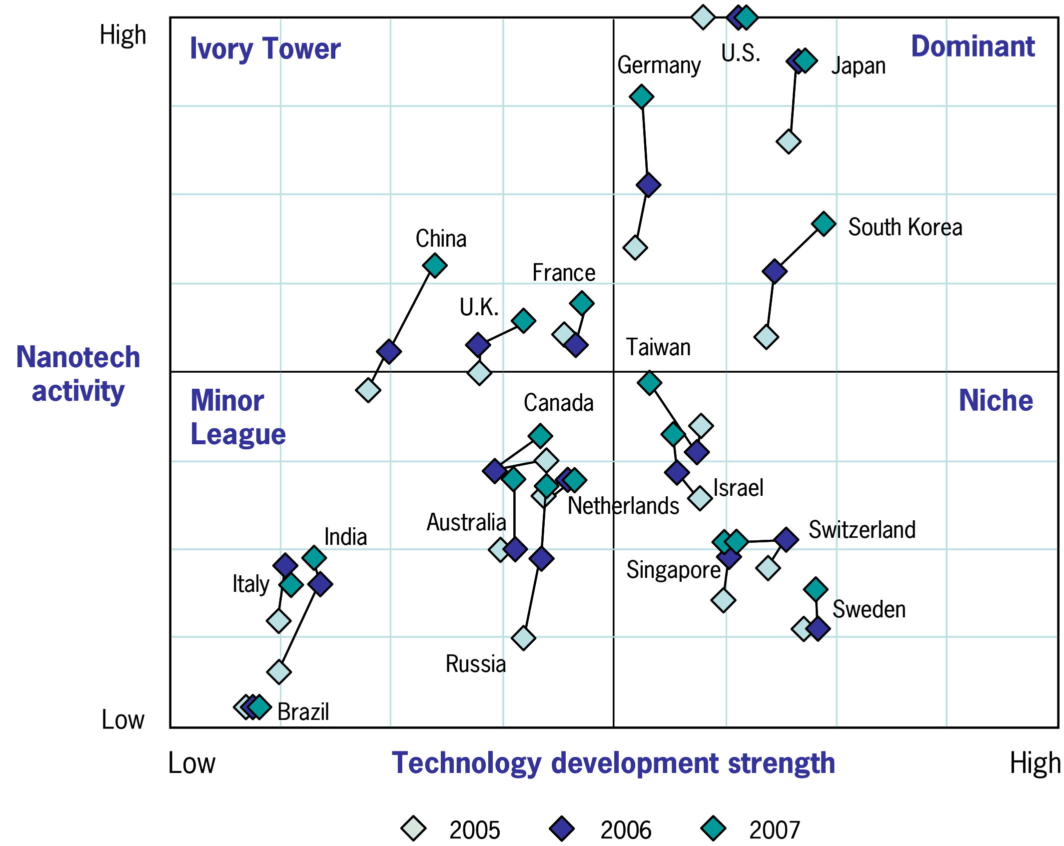
Source: December 2007 Lux Research report "International Activity Drives Nanotechnology Forward"

publications has been suspect in the past, the citation rate of nanotech journal articles from China – a measure of their quality – has doubled in the last decade.[5]

A Commercially-Dominated Landscape Requires Change to Unlock the NNI's Value

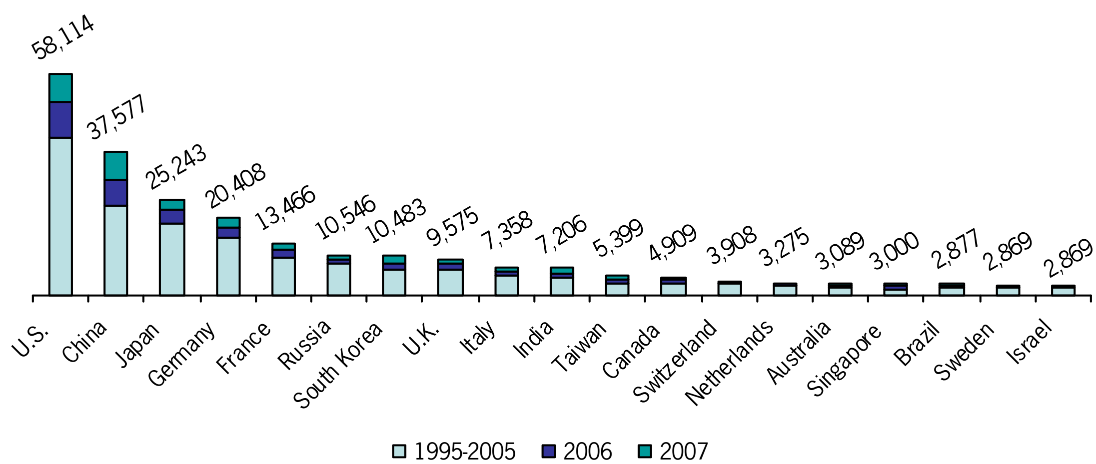
Clearly, the NNI should be reauthorized. But in the context of growing nanotech commercialization and increased international competitiveness, the onus is on Congress to eliminate roadblocks to

Fig. 7: Other Nations Are Gaining on the U.S. in Nanotechnology



Source: December 2007 Lux Research report "International Activity Drives Nanotechnology Forward"

Fig. 8: Journal Articles on Nanoscale Sciences and Engineering Topics, 1995 to 2007



*2007 data as of December 10, 2007

Source: December 2007 Lux Research report "International Activity Drives Nanotechnology Forward" market introduction for nanotechnology applications. Most of these changes are not specific to nanotech, although a few key ones are.

Nanotech's Pervasiveness Means that Most Required Changes are General

Many of the changes that will help transition NNI-funded research to market have nothing to do with nanotechnology specifically, but address broader issues in technology commercialization. Given nanotechnology's diversity, and the breadth of product categories that it touches, this is to be expected: As goes technology in general, so goes nanotech. These changes include:

- **Attracting U.S. students to science and engineering, and retaining foreign ones.** Funding for nanotechnology R&D will amount to nothing without a steady stream of trained scientists and engineers entering the workforce. The U.S. should strengthen programs designed to inspire students with wonder for the physical sciences in K–12 and undergraduate education to nurture homegrown talent. But it should also reconsider the effect of visa tightening on the inflow of foreign science and technology graduate students, and expands H1-B visa programs to allow students that have earned advanced degrees in science and engineering in the U.S. to remain here – rather than repatriating taking with them the skills they acquired in the U.S. The lesson of A123Systems is instructive: Had Yet Ming-Chiang returned to his native country, its 1,000 employees would likely be in Taiwan.
- **Reducing the cost of doing business for start-ups seeking public markets.** Start-up companies looking to make initial public offerings (IPOs) on the public markets face immense administrative costs to comply with regulations such as Sarbanes-Oxley. Easing these burdens will unshackle them. It's important to note that of the 14 nanotech start-ups that have gone public, most have done so on foreign exchanges where the cost of doing business is lower.
- **Introducing financial mechanisms to encourage collaboration between small and large firms.** Nanotechnology commercialization has followed a pattern similar to biotech, in which small, innovative companies develop breakthrough technologies that incumbent corporations bring to market: Silver nanoparticle antimicrobial company Nucryst Pharmaceuticals relied on wound care dressing maker Smith & Nephew to get to market, while A123Systems found its partner in Black & Decker. Congress can grease the wheels of nanotechnology commercialization by creating financial mechanisms that help small firms to collaborate effectively with large ones. One example of such a measure would be enabling small companies to transfer their net operating losses to their corporate partners – allowing those partners to reap the tax benefits of research investments, which the loss-making smaller companies can't claim.

A Few Nanotech-Specific Changes Are Necessary

In addition to these general reforms, a smaller number of changes specific to nanotech are also required. There are two specific actions we think Congress should take now:

- **Shift some of NNI's focus to application development and manufacturing scale-up.** A reauthorized NNI should focus on not just on basic research, but also on precompetitive R&D into nanomaterials application development and manufacturing scale-up. Currently the technical challenges that are limiting nanotech commercialization are not as much in synthesizing nanomaterials or understanding their fundamental properties as in learning how to integrate them into products and manufacturing them economically in large volumes. The Department of Energy's Nanomanufacturing initiative, run out of its Industrial Technology Program, is a model case study – it aims to introduce shared Nanomanufacturing centers as pilot facilities on the model of the NNI's existing user centers for nanoscale analytical equipment.

- **Take a completely different approach to environmental, health, and safety (EHS) issues.** In our work with companies looking to take advantage of nanotech innovation, the single concern that comes up more than any other is potential EHS risks of nanomaterials. While it's of course incumbent on companies developing nano-enabled products to test their own products to ensure safety, there's an important role for government to play in resolving these concerns – by funding basic research on nanomaterials EHS risk that no individual firm can afford, and by establishing clear regulatory guidelines for companies working with nanomaterials.

  On the first point, the NNI should be generously funding basic research on the EHS risks of nanomaterials – just as NNI-funded research on nanoscience has supported deployment of real-world nanotech applications, the results of NNI-funded EHS work would help companies complete their own EHS evaluations. Unfortunately, funding levels remain too low to have the desired impact, and, even more critically, the NNI has never effectively addressed EHS issues surrounding nanotech with a comprehensive, interagency plan for required EHS research. The Nanotechnology Environmental and Health Implications (NEHI) Working Group report on EHS issues has not filled this gap – it fails to prioritize specific materials and applications for research, avoiding the tradeoffs that are inherent in any meaningful strategy – and the EPA's internal review of its own nanomaterials EHS activities, by definition, does not cross agencies. This lack of coordination is hampering development, and must change. The best way to move forward on this front would be to execute the nanomaterials EHS strategy by the National Academies' Board on Environmental Studies and Toxicology – Congress has already appropriated funds for this study, but the work has not yet been started.

  Second, ambiguity surrounding how nanomaterials will be regulated must be dispelled. It's still often not clear how current regulations apply to nanoparticles or whether and when agencies will issue new ones – leaving firms that work with nanomaterials confused about how to plan for regulatory rulings. The companies we speak with are actually eager for appropriate regulatory guidance about nanomaterials, to ensure a level playing field and to help them guarantee the safety of workers, consumers, and the environment. While companies are generally pleased about how the EPA, for example, has communicated with them so far, they're also frustrated by how slow those agencies have been to set specific guidance, as witnessed by the glacial pace of the EPA's voluntary Nanoscale Materials Stewardship Program. Seven years after the NNI's launch, it's still unclear to most commercial entities when and how the materials they work with will be treated under the EPA's Toxic Substances Control Act – forming a real commercialization gating factor.

At Lux Research, we applaud the efforts that have taken place so far under the National Nanotechnology Initiative, which have made the U.S. a world leader in nanotechnology and are bringing real economic benefits to our nation. We're confident that a renewed NNI, with adjustments like those outlined above, will increase these benefits – and enable nanotechnology to help address the challenges the country faces in combating disease, moving toward energy independence, and sustaining economic growth.

Endnotes

1 Source: October 2004 Lux Research report "Sizing Nanotechnology's Value Chain."

2 Source: 2007 Lux Research reference study "The Nanotech Report, 5th Edition."

3 Source: March 2008 Lux Research report "How Venture Capitalists Are Misplaying Nanotech."

4 Source: December 2007 Lux Research report "International Activity Drives Nanotechnology Forward."

5 Source: Science Citation Index as of December 10, 2007; search terms (country), (year), and (quantum dot OR nanostruc* OR nanopartic* OR nanotub* OR fulleren* OR nanomaterial* OR nanofib* OR nanotech* OR nanocryst* OR nanocomposit* OR nanohorn* OR nanowir* OR nanobel* OR nanopor* OR dendrimer* OR nanolith* OR nanoimp* OR nano-imp* OR dip-pen).