Texas NANOTECHNOLOGY Initiative®

Sweating the Small Stuff

Nanotechnology and Texas' Economic Future

A report on Texas' bid to become the center of the nanotechnology industry—and the ways that industry, academia, and the legislature can support this effort.

Developed by the Texas Nanotechnology Initiative

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About the Texas Nanotechnology Initiative®

The Texas Nanotechnology Initiative (TNI) is a consortium comprising the industrial, university, government, and investor communities. The members' common goal is to position Texas as a world leader in the discovery, development, and commercialization of nanotechnology. The organization does this by bringing the necessary constituents together—research, business development plans, and funding—to create the right environment for rapid commercialization.

Executive Summary

Most Texans would agree that size matters and might admit to a preoccupation with the "bigness" of things. But when it comes to the state's economic future, the size that matters is small—nanosized, between the size of an atom and a cellular protein.

Nanotechnology is a wide-ranging discipline that has often been the victim of hyperbole. At its core, though, the field stands to revolutionize manufacturing processes, enabling us to make better products faster, cleaner, and cheaper than we can today.

Many consider Texas the birthplace of nanotechnology, and today, the state is an acknowledged world leader in nanotechnology research and development. It's the only state with three Nobel laureates leading active research in nanotechnology. All of the major universities in Texas—and many of the minor ones—have thriving nanotechnology programs. Since 1997, 12 start-up nanotech companies have set up shop in the state.

Yet Texas is not alone in its quest to own the nanotechnology market. California, Boston, and the combined New York/New Jersey region have all put significant state investment and existing infrastructure muscle into growing their nanotechnology programs. And they have been quite successful, each ranking higher than Texas in a 2002 review of nanotechnology's top regions.[1]

This report outlines Texas's strengths as a nanotech leader. More importantly, it calls on Texas industry leaders, academics, and legislators to champion Texas nanotechnology. For nanotechnology to be the next "big" thing in Texas, all the constituencies that stand to benefit must work together.

- We must pool and share resources—equipment, personnel, and business and technical know-how.
- We must improve science and engineering education at all levels.
- We must create a research and business climate that values and supports innovation.
- We must set priorities—and find new ways to fund them in a time of budget shortfalls.
- We must talk about Texas's strengths in nanotechnology, calling attention to our state's impressive mix of cutting-edge university research, well-positioned start-ups, enthusiastic business communities and investors, and world-renowned industrial infrastructure.

[1] "Ranking Small Tech's Top Regions." *Small Times*, March/April 2002: 20-37.

Business leaders, academics, and legislators can help sustain the new technology development that will drive nanotechnology in Texas in five "pillar" areas.

Leadership: Create twenty new chaired professorships in science and engineering through government funds and private-sector/industrial matching contributions, with the aim of doubling the number of strong nanotechnology researchers in the state.

Infrastructure: Encourage donations from industry to universities and develop state-sponsored mechanisms to assist universities in making major equipment purchases, in order to provide and maintain the state-of-the-art equipment that supports and attracts cutting-edge research.

Partnerships: Sow the seeds of downstream innovation by improving technology transfer programs; tying state-sponsored research funding to industrial matching funds; and developing curricula to educate young scientists in intellectual property and commercialization.

Workforce: Study the demands of academia and industry and implement science and engineering curricula in K-12 schools and at the university level to ensure that high-tech workers are born, raised, and ultimately stay in Texas.

Focus: Organize Texas science and engineering thrusts around a common, visionary "Grand Challenge." The application of nanotechnology to energy stands not just to place nanotech in context—as a key tool for solving a global need—but to leverage existing Texas infrastructure while repositioning the state as an energy innovator.

I. What Is Nanotechnology?

The Science, the Technology, and the Hype

A general definition of nanotechnology might read as follows: the manipulation of matter on an absurdly small size scale (anywhere from 1-100 nanometers) to create structures, devices, and systems that display novel functions and properties because of their size (see Table 1). But in practice, this simple definition leads to tremendous variability in what can—or should—constitute nanotechnology and underlying studies in nanoscience.

Table 1: How small is nano? Some comparative sizes are shown here. The shaded areas indicate sizes typically considered within the sphere of nanotechnology.

Object	Size in nm
Grain of sand	1,000,000
Width of human hair	150,000
Red blood cell	10,000
E. coli bacteria cell	1,000
Semiconductor circuit	150
Human protein	10
Hydrogen atom	0.1

Some define nanotechnology broadly. Rice University's Dr. Richard Smalley, a pioneer of nanotechnology, states that nanotechnology is "stuff that does stuff" on the nanometer size-scale. Another camp defines the field in terms of the tools and techniques used to investigate it, such as the specific microscopy techniques essential to observing and manipulating phenomena in the range between 1-100 nm. Others focus on the peculiar properties that can be designed by varying the size of a structure or device. And then there are the purists, who define nanotechnology as the process of manipulating "individual atoms and molecules to build structures to complex, atomic specifications"[2]—placing molecules "just so" to solve an engineering problem.

Given these various, often contradictory definitions, it's no surprise that the public and the press is confused about nanotechnology. For every research scientist committed to the painstaking characterization of a nanomaterial, there's someone

[2] *The Coming Era of Nanotechnology*, K. Eric Drexler, Anchor Books, 1986.

else envisioning a world run by self-assembling, autonomous nanobots. In the popular press, nanotechnology is simultaneously heralded as the next "big" thing and criticized as underdeveloped and overhyped. Both characterizations are valid. The challenge for researchers, entrepreneurs, and investors is separating opportunity from hyperbole.

The Essence of Nanotechnology

The general definition of nanotechnology presented earlier attempts to tie together the competing sub-definitions of the word to convey the essence of the discipline. First, nanotechnology happens at a certain size scale. Second, it involves the intentional manipulation of matter at this size scale to achieve a desired effect, typically a change in a particular property. Simply put, the laws of physics that prevail at very small dimensions are different than those we deal with in the every day world. Familiar Newtonian mechanics, such as gravity or inertia, yield at the nanoscale to the more esoteric effects of quantum mechanics. The tech in nanotech refers to our emerging ability to exploit these raw physical phenomena to engineer new and useful materials and devices.

The essence of nanotechnology is the application of engineering principles to the molecular-scale world. Instead of looking at molecules as something to be discovered or synthesized, nanotechnologists view molecular-scale matter as building blocks for solving engineering problems. Like any engineer, nanotechnologists build their systems specifically to exploit particular properties in the component parts. But unlike a macroscale engineer, nanotechnologists can't use traditional manufacturing tools to grab a component and solder it in place. Instead, they must rely on the sophisticated tools of chemistry to fashion their products.

Biology is frequently held up as an example of nanotechnology. Undoubtedly, the nanoscale products of chemistry and biology possess a sophisticated organization that has been optimized to perform complicated tasks. Proteins, for instance, are nanoscale compounds. They are assembled from individual molecules that are placed together by other biological tools. They exhibit novel characteristics that include mechanical behavior (such as "crawling," propeller- and hinge-like motion, and the ability to transport other molecules), changed electrical properties, and the ability to regulate their own, or other proteins', replication or destruction. But what's lacking is intention. Proteins have through the trial and error of natural selection come to play certain biological roles. Nanotechnology puts that intention foremost, using the tools of chemistry, biology, materials science, and physics to solve problems.

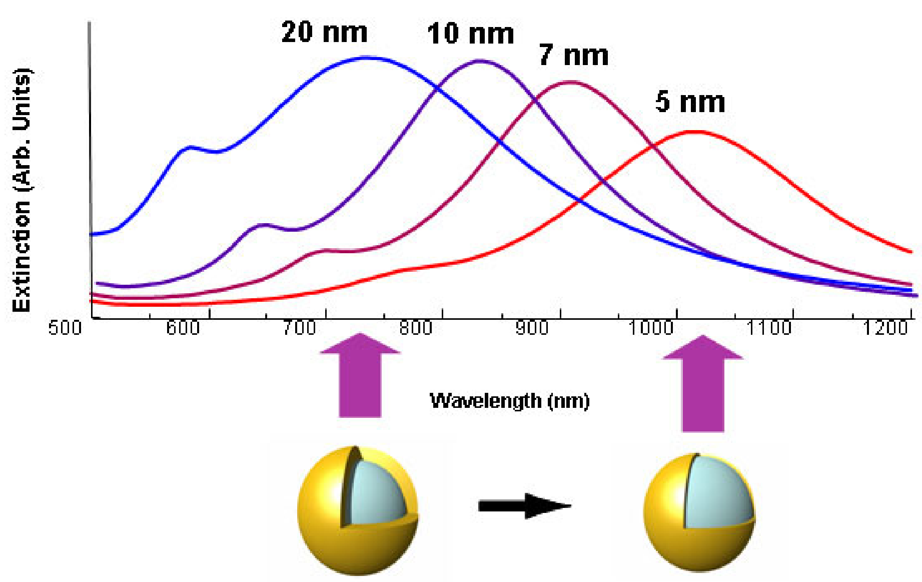
Rational drug design, a close analog to nanotechnology, has for decades approached disease-causing or -inhibiting proteins as design problems. Scientists use experimental data, microscopy, and computational studies to model a target molecule (the active site of a disease-causing protein, or a target compound that binds to an active site to initiate or inhibit disease-causing activity). They then use the tools of biochemistry to engineer compounds—drugs—that will selectively bind to the target. Nanotechnology extends this molecular-level engineering focus beyond the field of biochemistry into other organic and inorganic materials for applications as diverse as electronics, bioengineering, and energy.

Nanotechnology Applied: The Gold Nanoshell

The gold nanoshell developed at Rice and licensed by Houston-based Nanospectra Biosciences perfectly embodies the essential nanotechnology definition—an engineered system comprising unique properties tunable by size. Gold nanoshell technology builds on the properties of gold colloids, which reflect a brilliant red color when exposed to light. This property has been exploited in consumer-related medical products such as home pregnancy tests.

Gold nanoshells consist of two components: a dielectric core, such as silica, surrounded by an ultra-thin layer of gold colloid. Varying the relative size of the core and the outer gold colloid layer impacts the optical properties of the nanoshell. In fact, gold nanoshells can be specifically tuned to either absorb or scatter light at a certain wavelength. Figure 2 shows how two nanoshells with the same size core can have completely different absorption properties based on a 15 nm difference in the gold layer's thickness; in this case, the thicker layer (20 nm) absorbs in visible range (emitting a red color) while the thinner layer (5 nm) absorbs in the near-infrared range (a range is invisible to our eyes).

Figure 2.



The near-infrared range, in particular, is crucial because blood and tissue only minimally absorb this light. In other words, light from a near-infrared laser passes safely through the human body. Such light would be absorbed, though, by gold nanoshells tuned to the near-infrared wavelength. Engineer these nanoshells to bind to tumor cells and shine an infrared laser at the area, and the nanoshells would absorb the light and selectively ”cook” the cells to which they are bound. A difference of just a few nanometers makes the difference between nanoshells that have a pretty color and those with the potential to even the odds in humanity's war against cancer.

The Promise of Nanotechnology

Nanotechnology is the fastest growing technology field in the United States, with the National Nanotechnology Initiative receiving $710 million in the 2003 federal budget, 17% more than 2002. Mihail Roco, who chairs the initiative, estimates that nanotechnology-related business will have a $1 trillion annual global market before the next decade is out. Why all the interest? The answer lies in the definition—in the complete shift in manufacturing perspective afforded by the field. Nanotechnology promises to create better products containing enhanced properties or completely new ones. The manufacturing process will be fast. And the techniques—once optimized—will be inexpensive compared to traditional manufacturing practices with very little waste or environmental impact.

All promises aside, nanotechnology ***is*** real and impacting our lives. Today, average consumers can buy clothing nanoengineered to offer exceptional stain-resistance or moisture-wicking properties. They can slather on more effective (and less unsightly) sunscreens containing nanoengineered zinc oxide particles. They also benefit from the somewhat less tangible but undoubtedly more significant impacts brought about by the implementation of nanoscale innovations in a range of industries (see Figure 3), including

- **Information technology and computing**, which in 2002 saw the development of molecular-scale, electronically configurable logic circuitry in this industry's quest to meet the performance demands dictated by Moore's Law.
- **Healthcare**, where nanoparticles and nanostructured devices have been incorporated into wound dressings, explored as therapeutic delivery agents, used as diagnostics in the clinic and in the lab, and deployed as crucial drug discovery tools during early-stage R&D.
- **Aerospace**, where nanostructured plastics, composites, and other engineered materials are being tested for use in aircraft, space flight, and defense.

More so than most other endeavors, nanotechnology must draw on the combined knowledge and skills of scientists from a variety of disciplines. Physicists, chemists, biologists, materials scientists, engineers—all have something to offer, whether it be characterizing the fundamental properties of a nanoengineered component or directing the construction of that component *en masse*. Discoveries in one discipline will ultimately ripple into others. While the ability to make lighter, stronger materials has clear implications for the aerospace, automotive, and other transportation industries, the materials engineering advances needed to foster this change may come from a completely different sector, such as textiles. Similarly, the next paradigm in computer processing may spring from biology rather than physics. Inevitably, just as matter behaves differently on the nanoscale, scientists working in nanotechnology will need to embrace new ways of working together if they are to bring the products of this new discipline to market.

Figure 3: The trillion dollar market for nanotechnology comprises advances in a variety of fields. (Source: Presentation by Mihail Roco, chair of the National Nanotechnology Initiative, January 2002.)

Sector	Nano's estimated market impact
Materials	$340 billion/yr in 10 years
Electronics	$300 billion/yr in 10-15 years for semiconductor industry alone (global integrated circuits will add to this figure)
Pharmaceuticals	$180 billion/yr in 10-15 years, when over half of production will depend on nanotech
Petroleum and chemical processing	$100 billion/yr in 10-15 years
Healthcare	$31 billion/yr in tools and technology development in 10 years
Sustainability (energy and environment)	$150 billion/yr in 10 years
Enabling technologies and tools	$22 billion/yr in 10 years

II. Texas Nanotechnology Assets

It could be argued that Texas is the birthplace of nanotechnology. It is home to Rice University, where the fullerene form of carbon—which inspired the first nanoscale science—was discovered in 1985. It's the only state where three Nobel Laureates are running active research groups in nanotechnology: Dr. Richard Smalley and Dr. Robert Curl at Rice University and Dr. Alan G. MacDiarmid at the University of Texas at Dallas. Texas also claims the first company in the world dedicated exclusively to molecular nanotechnology: Richardson-based Zyvex Corporation, which put up its shingle in 1997 and is now offering a range of nanomanipulation tools and microfabrication techniques born out of its seminal mission.

Texas as a region is a nanotechnology powerhouse, boasting a wealth of research activities in nanoscale science that have spawned some of the field's most promising start-ups. Of the 12 nanotechnology start-ups in the state, nearly half are technology transfers from university research, and two were lured to Texas by the siren song of lower operating costs and access to formidable institutional resources, such as the Texas Medical Center (the largest in the world) and Austin's renowned “technopolis” city planning model. In addition to these institutional infrastructure resources, Texas is home to NASA’s Johnson Space Center and a range of corporate juggernauts in industries that could stand to support and benefit from fledgling nanotechnology innovations. Taken together, it’s not surprising that in 2002, Texas ranked as one of the top five “small tech” regions in the country according to *Small Times*, nanotechnology’s leading trade publication.

Yet history and habit will not be enough to keep nanotechnology in Texas. Competing regions, including California, New York, Pennsylvania, Illinois, and New Jersey, are supporting high-tech business development, launching programs to improve science education, and committing millions of dollars to fund nanotechnology research. Such programs are the crucial fuel for any new field. They provide the innovative ideas, commercialization expertise, and workforce talent upon which industry thrives. To seize the opportunity afforded by nanotechnology, Texas will need to leverage its assets. It will need to identify, categorize, and analyze both its strengths and its weaknesses. And it will need to stake a claim, laying out an objective where Texas—and Texas alone—can uniquely take the lead.

Research and R&D Activity

Texas’s preeminence in nanotechnology began in 1985 when a group of researchers at Rice University in Houston discovered buckminsterfullerene, the carbon form that launched the field of nanoscale science. By 1996, when Smalley, his Rice colleague Dr. Robert Curl, and the British researcher Dr. Harold W. Kroto had received the Nobel Prize for their discovery, Rice had already established, three years earlier, its Center for Nanoscale Science and Technology (CNST), the first university center dedicated to this research. One year after the Nobel was awarded, Rice completed construction on Dell Butcher Hall, an 86,000 square foot facility designed to support further innovation in nanotechnology. Today, over 40% of Rice’s science and engineering faculty are members of the CNST—82 researchers, more than any other university program in the United States.

Rice is one of three nanotechology research hubs in Texas, which are in turn part of a Texas-based community of nano know-how that encompasses institutions of every stripe—from educational behemoths like the University of Texas at Austin to regional schools like Prairie View A&M and the University of North Texas. In all, 12 Texas universities have laboratories and facilities, collaborative arrangements, or research centers dedicated to nanotechnology (see Appendix A).

Highlights of Texas R&D activities follow:

- **University alliances**: Vice presidents of research at four Texas universities—UT Arlington, UT Austin, UT Dallas, and Rice University—formed the Strategic Partnership for Research in Nanotechnology (SPRING) in April 2002. SPRING fosters multi-campus research collaboration, coordinates knowledge-sharing through joint programs and conferences, and promotes the development of joint facilities and infrastructure. Together, SPRING grabbed $6 million in federal funding in 2002 to create an inter-institutional "virtual lab." A similar program, Nano at the Border, builds a consortium around nanotechnology within the UT system; it was formed in January 2003 by provosts at UT Arlington, UT Austin, UT Brownsville, UT Dallas, and UT Pan Am.

- **Fabrication unites**: Two initiatives focused on the fabrication of next-generation materials are uniting research programs at universities across Texas. The University of Texas at Austin, home to the Center for Nano- and Molecular Science and Technology (CNM), announced in October 2002 the inception of the Integrated Nano Manufacturing Program (INMP). Eighteen CNM faculty members are heading up the initiative, but the program will involve all 58 CNM faculty and researchers based throughout the University of Texas system, including UT Arlington and UT Dallas. The other collaborative effort is run out of Texas A&M, which was named in June 2002 to lead a NASA University Research, Engineering, and Technology Institute (URETI). The Texas Institute for Intelligent Bio-Nano Materials and Structures for Aerospace Vehicles encompasses researchers at Texas A&M, Prairie View A&M, Rice, Texas Southern University, the University of Houston, and UT Arlington.

- **The north Texas nano-hub**: In early 2001, a $2.5 million grant from nanotechnology entrepreneur Jim Von Ehr propelled the University of Texas at Dallas into nanotechnology research. The university's NanoTech Institute has attracted a Nobel laureate, Alan G. MacDiarmid, to lead its research efforts and has sequestered several million dollars in federal funding. In 2003, the institution is planning to raise the research profile of the north Texas region, calling for legislative and business support to fund 25 chaired professorships in UT system. The positions would be spread over nine science and engineering disciplines, including nanotechnology.

- **Exploring both sides of nano**: Rice added a second nanotech research center to its portfolio in September 2001. The Center for Biological and Environmental Nanotechnology is one of six $10.5 million Nanoscale Science and Engineering Centers established by the National Science Foundation, and the first center in the world to explore both the utility and potential impact of applying nanotechnology to the life sciences.

Industry/Start-Up Activity

The eclectic mix of nanotechnology-oriented enterprises in Texas portends the broad impact nanotechnology is poised to make on modern manufacturing and product development. Texas nanotechnology companies are engineering advanced nano-therapies for treating cancer and HIV disease; leading the world in carbon nanotube processing; incorporating nanostructures into an array of materials and devices; and developing next-generation tools, materials, services, and strategies for working effectively and productively at the nanoscale.

Leading the charge in Texas has been Richardson-based Zyvex Corporation. Founded in 1997 as the first molecular nanotechnology company in the United States, Zyvex spent five years pursuing the biggest idea in small tech: construction of a molecular assembler. Today, the company is leveraging its foundational R&D to deliver materials, tools, and structures that enable adaptable, affordable, and molecularly precise manufacturing.

Fifteen nanotechnology-oriented start-ups currently operate in Texas, many with the mandate of commercializing intellectual property transferred from university research (see Appendix B). At the end of 2002, 250 people were employed in Texas nanotechnology firms, up 200% from the previous year. Such growth is typical of start-up industries. But more importantly, sustainable start-up industries have a tendency to quickly outpace their more traditional industrial counterparts. Witness job growth from 1996-2001 in Massachusetts, where biotechnology jobs outpaced overall industrial job growth by a factor of 10.[3]

Highlights of Texas industrial activities follow:

- **Bringing home funding:** Zyvex pulled in the biggest federal money by a Texas nanotechnology company in October 2001, when it received a $25 million, five-year grant from the NIST Advanced Technology Program to produce and commercialize low-cost assemblers for micro- and nanoscale components and subsystems. In 2002, Texas nanotechnology start-ups secured nearly $1.5 million in federal Small Business Innovation Research (SBIR) program funding. The recipients were Applied Nanotech, which will partner with Northrop Grumman Systems Corporation in the development of nanotube-based radio frequency arrays; Zyvex, which will develop a new holder for transmission electron microscopes; and Quantum Logic Devices, which will develop an instrumental technique for direct base sequencing of DNA.

- **Location, location, location**: Citing lower operating costs and access to key infrastructure resources, two nanotechnology start-ups moved their operations to Texas in 2001 and 2002. Quantum Logic Device transferred from North Carolina to Austin in October 2001, citing a desire to be closer to the semiconductor and electronics expertise in Austin's "Silicon Hills." CSixty, which owns the rights to nearly all the intellectual property associated with fullerene drugs, relocated in the summer of 2002 from Toronto to Houston in order to be closer to collaborators at the MD Anderson Cancer Center.

- **World leader in carbon nanotube processing**: Houston added another chemical processing plant to its landscape in 2002, but this plant is refining a new type of manufacturing process rather than crude oil. The pilot plant at Carbon Nanotechnologies, Inc., produces single-walled carbon nanotubes at a capacity 10-100 times greater than previous bench-scale units. Increased capacity is

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[3] Source: MassBiotech 2010: Achieving Global Leadership in the Life-Sciences Economy, 2002.

enabling CNI to explore other production avenues, such as the utilization of different feedstocks, and deliver more customer-friendly nanotube products, such as the BuckyPearl nanotube pellets developed in September 2002.

Infrastructure and Business Support

Texas is home to some of the world's most respected research institutions and possesses a diverse industrial infrastructure that stands to benefit from many of the promises of nanotechnology. Not surprisingly, regional business groups throughout the state have begun educating their communities about nanotechnology and promoting their regions' particular strengths. In 2002, the Arlington Chamber of Commerce established a nanotechnology incubator; the North Texas Technology Council brought UT Dallas together with Canadian research teams to explore potential collaborations; and numerous meetings and gatherings specifically focused on nanotechnology were sponsored by groups in all of the state's major metropolitan centers.

Statewide, the Texas Nanotechnology Initiative is working to coordinate the efforts of these business groups and generate synergies among nanoplayers in industry, academia, government, and the investment community. The consortium, founded in 2000, now includes nearly 40 member organizations and boasts a distinguished board of directors from companies, venture capital firms, and universities around the state. In 2002, the TNI raised the profile of Texas nanotechnology efforts by sponsoring the country's first nanotechnology conference focused specifically on commercialization, NanoVentures 2002, which drew 400 attendees from around the world to Dallas.

Highlights of Texas infrastructure and business support activities follow:

- **The right types of industry**: Between Austin, Houston, and the Dallas/Ft. Worth metroplex, Texas harbors three of the primary industries that stand to benefit most from nanotechnology—energy, semiconductor manufacturing, and telecommunications. Houston has been called the U.S. energy headquarters as home to 5,000 energy-related establishments involved in every segment of the petroleum industry. Austin's Clean Energy Initiative launched an aggressive campaign in 2002, leveraging the existing "technolopolis" planning model that has sustained the area's semiconductor expertise, which ranks second behind California.[4] The Dallas area has a strong telecom presence within its concentrated "Telecom Corridor" in Richardson.

- **The doctors are in**: The medical implications of nanotechnology are tremendous. Consider the Blount Laboratory at the UT Southwestern Medical Center in Dallas. This lab has been exploring the mechanism of action behind mechanosensitive channels, cellular gateways tuned to "sense" changes in membrane surface

[4] Source: Cyberstates 2002, American Electronics Association.

tension. Now, it is collaborating with the U.S. Air Force to determine whether these cellular tools could be employed as sensors within an engineered nanoscale system. In addition to fostering innovative research, Texas offers nine world-class institutions where nano-therapies could be developed and tested. Houston's Texas Medical Center is the largest concentration of medical facilities in the world—a unique medical cluster of 42 institutions employing over 61,000 people and servicing 5.4 million patients in 2000. In the past five years, this "Texas-sized" medical center has attracted over $2.2 billion in research grants.

- **Successful tech transfer and enthusiastic venture support**: UT Austin's IC^2 Institute and affiliated Austin Technology Incubator (ATI) are model tech transfer programs, graduating to date some 65 companies that contribute nearly $280 million in annual sales regionally. Largely through the efforts of the ATI and the Rice Alliance in Houston, nanotechnology tech transfers currently account for one-third of Texas's nanotechnology start-ups. Texas also houses the third largest venture capital community in the country, which has to date invested $45 million in support of the state's early nanotechnology enterprises.

- **An ongoing mission**: NASA's Johnson's Space Center continues to explore the final frontier while simultaneously contributing over $2 billion to the Texas economy in 2001.[5] But cost-effective space flight will require next-generation materials. Hence the JSC's Carbon Nanotube Project, which is investigating bulk production methods to make nanotubes easier and cheaper to deploy.

III. Texas Nanotechnology Weaknesses/Competitive Analysis

Texas had the advantage of an early start in nanotechnology research. But it has already seen its lead erode compared to other regions. In the first ranking of "small tech" centers by *Small Times* in 2002, Texas was ranked in the top five, but just barely. Texas placed fifth behind Northern and Southern California, Boston, and New York City/New Jersey. Of course, *Small Times* considers nanotechnology a subset of a broader industrial collective that includes microsystems and MEMS. Nevertheless, the ranking reveals some of the weaknesses in Texas's nanotechnology portfolio.

Minimal state government support

To date, the Texas legislature has invested just $500,000 in nanotechnology (see "Comparative Nanotechnology Spending"). Compare this to California, which in 2000 and 2001 dedicated $400 million over five years to establish four high-tech research centers in the University of California system, one of which is the UCLA/UCSB California Nanosystems Institute. New York, which placed fourth in the *Small Times* ranking, ponied up in 2002 more than $150 million in public and

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[5] Source: Clear Lake Economic Development Foundation.

private sector support for a Center of Excellence in Nanoelectronics at the University at Albany.

As a measure of return on such investments, three of the top five nanotechnology breakthroughs in 2002[6] were made by New York companies or research groups. One of these was shared with a California group supported by the California NanoSystems Institute; California company Nanosys received credit for a fourth breakthrough. The fifth went to Princeton (New Jersey, incidentally, invested $2 million to establish a Bell Labs nanotech center in July, and plans to put forward another $3.5 million toward a second center in the fall of 2003). Obviously, Texas research groups made none of the breakthroughs cited.

Comparative Nanotechnology Spending[7]

	Texas	CA	NY	MA	UK	Ger	Korea	Japan
Gross State/ Domestic Product	$768B	$1.36T	$755B	$239B	$1.36T	$1.94T	$765B	$3.15T
State Budget	$58B	$98.9B	$89.6B	$12.5B	NA	NA	NA	NA
Population	21.3M	34.5M	19.0M	6.3M	59.6M	83.0M	47.9M	127M
Workforce	10.3M	17.1M	8.9M	3.2M	29.2M	40.5M	22.0M	68.0M
Gov't Nano Funding	$0.5M	$100M	$100M	NA	~$50m	NA	$160m	$650m
Geographic Area (square kilometers)	681,000	425,600	128,900	21,500	244,800	357.000	98,500	377,800
Nano Funding per Capita	$0.02	$2.90	$5.26	NA	$0.84	NA	$3.34	$5.16

NA = Not available or not applicable

Limited synergy with large corporations

Texas is home to hundreds of large corporations in sectors that stand to benefit from nanotechnology. Many, such as Texas Instruments, Raytheon, Motorola, and 3M, are conducting internal research in nanotechnology. Yet none of these companies has partnered significantly with Texas-based research centers or start-up companies. This puts Texas at a disadvantage. In California, for instance, state funding for the UC tech centers is contingent on matching funds from industry. Big players like Sun Microsystems and Oracle are supporting work at the California NanoSystems

6 Source: Forbes/Wolfe Nanotech Report, Vol. 1, No. 10 (December 2002).
7 Source: Nanotechnology Foundation of Texas. Data are generally for 1999 except for "Nano Funding," which are 2001 data for states and 2002 data for foreign governments.

Institute, and the center's collaboration with HP has proved immensely important for both players. Such efforts prove that corporate backing drives research and often steers it toward commercialization, creating jobs, building investment opportunities, and growing local economies.

Workforce deficit

Texas currently ranks second nationally in the number of high-tech jobs.[8] But in-state talent to fill these jobs is meager. Currently, Texas K-8 students rank at or just under the national average in science and math, and only an estimated 5% of Texas high school graduates complete calculus, chemistry, and physics courses that would prepare them for university science and engineering tracks. But the problems are not just on the secondary level. For the past decade, Texas has graduated about the same number of engineers from its public universities—3000. To support a new industry, particularly one as scientifically rigorous as nanotechnology, Texas will need to improve its science education at all levels.

Inadequate coordination and communication

Regions like Silicon Valley have a built-in edge over Texas. Their historic success has led to a confluence of resources that promotes further economic development: cutting-edge R&D; a highly educated and motivated workforce; savvy entrepreneurs; and committed funding resources. Such resources exist in Texas, but they are scattered over a wide geographic area. Austin, for instance, has entrepreneurial spirit and a talented workforce, but lacks the R&D innovation in nano that's present in Houston. Dallas has a tremendous drive to build itself into a nano powerhouse, but lacks a critical mass in any single area to make an effective case. And Houston has the research know-how, but little experiencing in transferring research to the marketplace.

What's needed is better coordination of Texas resources to tap into each region's key strengths. In addition, the regions should work together to draw additional talent to the state—finding and keeping not just top researchers in the field, but serial entrepreneurs and other experts that can build and lead successful nanoventures.

IV. Marshalling Texas Resources

Nanotechnology has the potential to revolutionize many industries and, inevitably, may impact just about every facet of our lives. But in the short-term, regions are discovering that nanotechnology's multidisciplinary make-up makes it impossible for one place to be all things to nanotechnology. Regions are instead marshalling their resources around a core set of objectives, preferably ones that leverage existing regional strengths and infrastructure. Silicon Valley, for instance, sees the

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[8] Source: American Electronics Association.

intersection of nanotechnology, biotechnology, and information technology as a logical extension of its historic expertise and has rallied industrial juggernauts like HP, Sun Microsystems, and Oracle to investing in critical R&D programs in the state.

Rallying around a cause does more than energize participants and build momentum. It actually can catapult a technology over the key chasm in the high-tech product lifecycle, as identified in Geoffrey Moore's seminal books on high-tech marketing. On one side of the divide stand the somewhat easy-to-reach customers of the early market: the techies and visionaries that are drawn to early technology concepts and products. On the other side stand the more pragmatic, yet decidedly more lucrative customers of the mainstream market. These customers won't be swayed by testimonies from a visionary—they require performance and proof-of-concept and will only support "whole products" that offer immediate utility.

Nanotechnology is more a concept than a product. But nevertheless, it is standing at the edge of the chasm in Texas. Visionaries and techies have embraced it, but this interest won't be enough for the field to thrive in the state. Success depends on the technology crossing over to a more mainstream market that stands to directly benefit from the technology and can hence see the value in committing resources to its development.

As mentioned earlier, Texas universities and start-up companies have taken early leads in a number of fields, including nanomaterials; nanomanufacturing; and life science nanotechnology applications. These fields offer short-term deliverables, generating products and revenue within the next five years that will draw well-deserved attention to Texas as a center for nanotechnology innovation. In addition, though, Texas is home to a critical mass of energy companies, which in the next few decades will be in need of revolutionary advances that may only be possible through research at the nanoscale. The Texas Nanotechnology Initiative sees a tremendous opportunity for Texas to leverage its solid nanotechnology R&D to solve one what will undoubtedly be the most pressing issue facing the world this century: the inevitable loss of fossil fuels as an energy source.

Energy

From the refineries in Houston to Austin's clean energy push, Texas is without a doubt the leader in energy production in the United States. Conversely, it is also a leader in consumption. Though home to just seven percent of the U.S. population, Texas accounts for about 12 percent of the nation's total energy consumption. Within 40 years, Texas may need to import more than 80 percent of its energy in order to meet demand, an import level that would leave state and local economies economically and politically vulnerable.[9]

[9] Source: Austin Clean Energy Initiative, 2002.

Nationally, continuing U.S. dependence on fossil fuels has a destabilizing effect on foreign policy. It also has a destabilizing impact on the environment. Global warming arguments aside, 95% of the energy produced in the world today comes from burning carbon, which pumps carbon dioxide into the atmosphere in unprecedented quantities. Calls to invest in renewable energy, which today accounts for just one percent of the world energy supply, are insufficient. Even a doubling or tripling of this popular energy supply will not result in the breakthrough needed to wean the country from fossil fuels. A different path will be needed to alter the nation's energy future—one that has to involve new technologies.

Nanotechnology may provide a way. It's already helping make traditional energy production faster, cheaper, and more efficient. For instance, new catalyst nanomaterials are already being used to efficiently extract oil from tar-sand deposits in Canada, Venezuela, and the United States. Recent nanotechnology-based processes are also being deployed to convert coal into liquid hydrocarbons; by 2005, China plans to use this method to produce 50,000 barrels of liquid fuel per day. Nanotechnology innovations in fuel cells and solar cells may render these devices more efficient, while high-strength materials could result in more cost-effective wind and hydroelectric power and even in more powerful drill bits and sensing tools for oil exploration and production.

More importantly, the unique molecular-scale view of the world afforded by nanotechnology may allow for revolutionary discoveries—a different energy path leading to clean, abundant, low-cost, CO_2-free energy sources. The technical challenges faced in energy are ultimately engineering problems. How can we harvest the energy available in space or residing deep in the Earth's crust? How can we store and redistribute the energy collected at low cost? Nanotechnology may offer the tools for tackling these problems, and Texas, with its historic expertise in energy combined with its diverse research thrusts in nanotechnology, would be the ideal place to base these R&D efforts. In fact, the University of Texas at Dallas had begun an aggressive research program in the application of nanotechnology to energy. The university's NanoTech Institute is investigating ways to more efficiently harvest electricity from thermal, mechanical, and solar sources; to develop artificial muscles for energy conversion; to create more effective energy storage devices; and to create super-tough, conductive fibers.

Nanomaterials and Nanomanufacturing

Texas is home to Carbon Nanotechnologies, Inc., the world leader in carbon nanotube production. Several key firms in the state are also involved in producing nanomaterials and developing applications for them, as are research groups at Rice, UT Austin, and UT Dallas. In addition, well-funded, collaborative nanomanufacturing facilities—exploring different mechanisms and underlying technologies—have been established throughout the state.

Undoubtedly, Texas's leadership in both of these areas will be a crucial benefit to the state. Both technologies are critical enablers for nanotechnology applications.

Without cutting-edge, next-generation materials and the facilities to produce products at the nanoscale, nanotechnology application development inevitably will stall. Yet a statewide focus on enabling technologies does carry a risk. Texas may become known merely as the place to get materials or develop nanoscale components while the real work—the applications of these materials and components—occurs in the labs that request the getting and developing. Texas should take care to press its early advantage in nanomaterials and nanomaufacturing to attract companies in need of these services to Texas. Simultaneously, however, it should push a more imaginative vision for nanotechnology that will drive more broad-based discovery and innovation.

Nano/Bio

Texas has made a notable start in the application of nanotechnology to biological and medical problems, and the state possesses renowned resources to support continued R&D. Nanospectra Biosciences and CSixty both have therapies in clinical trials at the Texas Medical Center in Houston, and Austin-based Nanotechnologies, Inc. has made successful overtures to pharmaceutical companies interested in applying the company's silver nanoparticles as antibacterial agents.

More uniquely, Texas has become a focal point for discussions of the societal and environmental impacts of nanotechnology. Calls by the activist ETC Group in 2002 for a worldwide moratorium on nanotechnology research put the spotlight on Rice University's year-old Center for Biological and Environmental Nanotechnology (CBEN)—the only center in the United States dedicated to the study of nanotechnology in these areas. CBEN has stated its intent to foster and support research into potential toxicological and environmental impacts of nanomaterials and other nano-products and has initiated a dialogue with the Food and Drug Administration and the National Institute of Occupational Safety and Health about sources of funding for such research. Through the efforts of CBEN, Texas stands to play a crucial role in the long-term, global success and acceptance of nanotechnology and its products.

V. Building Nanotechnology's Future in Texas

In these economically uncertain times, major funding initiatives must result in tangible, sustainable outcomes. Nanotechnology investments do pay off. New York/New Jersey, the region ranked fourth to Texas's fifth in the 2002 *Small Times* ranking of "small-tech" centers, made investments totaling $155 million in nanotechnology-related endeavors last year and is already reaping benefits in R&D, nationwide exposure, and industry relocation and investment—in other words, more jobs contributing to robust economic growth.

The State of Texas, Governor Perry, and Texas industrial leaders have a tremendous opportunity to take the lead in nanotechnology. To capitalize on the state's existing resources, the Texas Nanotechnology Initiative recommends support and funding in five "pillar" areas that sustain new technology development: leadership; infrastructure; partnerships; workforce; and focus.

Leadership

Texas has a strong lead with its three Nobel laureates and nearly 200 researchers statewide actively involved in nanotechnology research. Strong researchers bring in top students, draw funding and infrastructure to their universities, and generate prestige. To retain its position, Texas must recruit and retain more "superstars"—aiming, if possible, to double the number of strong researchers in the state. This will help Texas compete with the research clusters centered in other regions, such as California and Boston.

Recommendation:

- Chaired professorships are a valuable tool for recruiting top faculty. The Texas Nanotechnology Initiative supports efforts by the State of Texas to create chaired professorships statewide in science and engineering over the next year. The organization will assist in garnering private-sector and industrial contributions to match state funds 1-1, up to $1 million per chair.

Infrastructure

As home to the first academic nanotech center and the first molecular nanotechnology start up company, Texas has set the pace in nanotechnology R&D. But it could easily be overtaken without improvement in the state's science and engineering infrastructure. Lacking the critical, but often expensive instrumentation necessary for research in this area, many Texas researchers have been forced to travel elsewhere in the country to do their work.

The Strategic Partnership for Research in Nanotechnology (SPRING) has as its primary mandate the creation of infrastructure and equipment hubs to support specific, regional research efforts and to serve as a magnet for statewide, national, and international research teams seeking access to state-of-the-art facilities. In 2002, SPRING secured $6 million in federal support; in 2003, it is seeking to double this number. But more investment is needed for Texas to see real benefit, both in terms of research output and usage revenue.

Recommendations:

- Develop a state-sponsored funding mechanism for infrastructure purchases. The Texas Nanotechnology Initiative would be willing to broker the development of a matching system that would provide state, federal, and industrial matching funds to labs that invest in qualified equipment. Texas should investigate programs adopted in other states; Florida, for instance, collects a sales tax on equipment purchases that goes into an "innovation fund" for further infrastructure investment.

- Encourage technology companies and equipment manufacturers to donate equipment, both within the primary hubs and throughout the state. The expansion of nanotechnology statewide is inevitable, but could be fostered now by equipment donations to universities seeking to establish early-stage nanotechnology programs or to train undergraduate students better in science and engineering.

Partnerships

Technology hotbeds like Silicon Valley are defined by relationships and fluidity among academia, industry, and business groups. Tech transfer is encouraged, corporations participate and invest in university and start-up R&D, and investors and regional business groups play an active role in encouraging and supporting technology development. Texas needs to better nurture this type of environment if nanotechnology—or any other new technology—is to thrive within in its borders.

Recommendations:

- Appoint a state-sponsored temporary commission to study "best practices" for university technology transfer that could be implemented statewide by Texas universities.

- Implement gubernatorial mandates requiring state-funded programs in science and engineering technology development to garner matching funds from industrial partners. Such programs force academic institutions to look outside their walls at the industrial implications of their research, which can benefit both university research programs and industrial business development.

- Develop entrepreneurial education programs for upper-level undergraduate and graduate students to teach young scientists about intellectual property and commercialization. The TNI would be willing to bring business school faculty together with science and engineering faculty to define and implement such courses of study.

Workforce

New technology chooses to locate in areas possessing a workforce that can sustain ongoing research and development. Nationally, the current focus on fact-based education is leaving K-12 students poorly prepared for university level science and engineering coursework. Texas needs good scientists and engineers: It should take steps to educate its students in these fields and to retain graduates to work in-state.

Currently, several groups statewide are aiming to improve both secondary- and university-level programs. The Center for Biological and Environmental Nanotechnology has as one of its mandates the development of K-12 outreach efforts for training teachers in science and providing ways for them to integrate nanotechnology into core science curricula. The Nano at the Border program also has the goal of targeting secondary science education in South Texas. In addition, the Texas State Technical College is working with industry and graduate-level university programs to pinpoint workforce training needs that can be implemented in community college programs.

Yet these efforts lack coordination. State sponsorship could give these efforts much-needed scope.

Recommendations:

- Create a state-sponsored temporary commission to study 1) what universities require incoming science and engineering students to know and understand about these disciplines and 2) what industry requires in terms of new hires. The commission's work would help identify the measure of success for science and engineering education, which could then be used to develop and implement specific programs to improve secondary science education and university programs.

- Develop internship programs that give qualified undergraduates and graduate students the opportunity to work in key nanotechnology firms and industrial partners. The Texas Nanotechnology Initiative is willing to coordinate the development of these programs through its industrial and academic connections.

Focus

Focus ultimately provides momentum to any new technology development. A well-organized mandate attracts leadership, builds infrastructure, motivates partnerships, and inspires a workforce. The declaration of a "Grand Challenge," accompanied by an appropriate expenditure of funding and an ambitious yet attainable end-date, would provide direction for Texas's existing resources and industry. It would also place nanotechnology in context—as one important tool for solving an urgent global need.

It should be noted that while a grand challenge in the energy field would serve as an important channel for infrastructure, research talent, and other resources, it would not preclude development in other important areas of nanotechnology. Rather, other fields would benefit from increased infrastructure investment associated with the grand challenge. In short, the grand challenge serves to organize Texas efforts, but does not intend to limit or stifle research activities.

The potential impact of issuing a grand challenge cannot be underestimated. A comparison is President Kennedy's famous challenge in the 1960s—to put a man on the moon and bring him safely home before the end of that decade. The resources and intellectual talent committed to that endeavor clearly benefited Texas and still contribute to economic development in the state. Coincidentally, Kennedy chose Rice University as the place to recap the impact of his challenge one year after its delivery, calling Houston "the furthest outpost on the new frontier of science and space." Will Rice and Texas again figure in the next grand challenge to face our nation?

Recommendations:

- Declaration of a "Grand Challenge" that leverages Texas's unique strengths and assets. The Texas Nanotechnology Initiative notes that the state's most vocal proponents of nanotechnology—Richard Smalley at Rice and Jim Von Ehr at Zyvex—have spoken broadly on the need for a state- or nationally sponsored program in energy. Such a mandate is a natural fit for Texas, given its current industrial infrastructure and early lead in nanotechnology. It also provides a tremendous public relations opportunity, enabling Texas to enhance its image as an energy innovator.

- Support the "Grand Challenge" and other broad-based R&D by establishing multidisclinary, cross-campus research centers within Texas universities and medical programs. The Texas Nanotechnology Initiative would urge the State of Texas to consider the program established within the University of California system as a potential model.

VI. Conclusion

The biggest problems of our time may be solved by our ability to understand and harness the smallest of interactions—nanoscale science that Texas researchers have explored for over a decade. This state has launched the discoveries that have propelled nanotechnology into the consciousness of entrepreneurs, investors, businesses, and the public. We have the opportunity to leverage our new tech expertise into the areas where we have traditionally excelled. And our bid is a strong one, so strong that even the most admired of tech centers, Silicon Valley, has expressed nervousness about its ability to compete.[10]

Scientists, business leaders, and the Texas state government can help strengthen Texas's lead. We can think creatively about how to bolster scientific enterprise—through better education initiatives, better technology commercialization pathways, and better entrepreneurial support. We can find ways to boost research funding, as budgets allow. Most importantly, we can begin talking about Texas as a leader in nanotechnology, with assets and expertise found nowhere else. Our willingness and ability to articulate a vision for nanotechnology will determine our economic future. And the Texas Nanotechnology Initiative is committed to ensuring that the future is a bright one.

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[10] A news story in the Feb. 7, 2003 online edition of *Small Times* reports that, despite the Valley's historic resources, it "may not know what to do with the competition." See "Pity by the Bay: Valley Frets Over Other Areas' Newfound Fortunes" at www.smalltimes.com/document_display.cfm?document_id=5468.

Appendix A: Nanotechnology at Texas Universities

Rice University (www.rice.edu)

Number of faculty actively engaged in nanotechnology research: 84

Total funding for nanotechnology research (in 2002): $16 million (excludes faculty nine month salaries)

Key research areas:

- Nanomaterial synthesis (single-walled carbon nanotubes, metal nanoshells, semiconductor nanocrystals, nanostructured porous media)
- Bulk composite creation (nanotube and nanoparticle reinforced polymers)
- Physics at the nanoscale (electron transport, ultra-cold, nanoelectronics, quantum effects)
- Medical applications (cancer therapy, tissue replacement)
- Environmental engineering applications (filtration, catalysis)

Center-based activities:

- Center for Nanoscale Science and Technology, established 1993 (cnst.rice.edu)
- Center for Biological and Environmental Nanotechnology, established 2001 (www.ruf.rice.edu/~cben/)
- Rice Quantum Institute, established 1985 (rqi.rice.edu)

Research facilities:

- Shared Equipment Authority: 20 state-of-the-art nanotechnology characterization systems distributed across campus, available for outside use
- Carbon Nanotechnology Laboratory: Includes HiPco single-walled carbon nanotube synthesis apparatus

Nationally/internationally recognized faculty:

- Richard Smalley (chemistry, physics): 1996 Nobel Laureate.
- Robert Curl (chemistry): 1996 Nobel Laureate.
- Neal Lane (physics): Senior Fellow, James A. Baker III Institute for Public Policy; Presidential science advisor and Director of the White House Office of Science and Technology Policy (1998-2001); Director, National Science Foundation (1993-1998).
- Vicki Colvin (chemistry): Alfred P. Sloan Fellow, Beckman Young Investigator; National Science Foundation Faculty Early Career Development (CAREER) awardee; named in 2000 one of the "Top 20 Scientists to Watch" by Discover
- James Tour (chemistry): Research in molecular electronics designated as one of the top chemistry achievements in 2001 by *Chemical and Engineering News*.

- Andrew Barron (chemistry and materials science): Fellow of the Royal Society of Chemistry.
- Naomi Halas (electrical and computer engineering, chemistry): Recipient of "Cancer Innovator" Award from the Congressionally Directed Medical Research Programs of the U. S. Department of Defense.
- Randy Hulet (physics): American Physical Society's I.I. Rabi Prize (1995); National Science Foundation Presidential Young Investigators Award.

Tech transfers:

- Carbon Nanotechnologies, Inc. (www.cnanotech.com)
- Nanospectra Biosciences, Inc. (www.nanospectra.com)
- Oxane Materials, Inc.

Achievements in 2002:

- "Structure-Assigned Optical Spectra of Single-Walled Carbon Nanotubes." *Science* 2002 Nov. 29; 298: 2361-2366 (lead group: Smalley)
- "Band Gap Fluorescence from Individual Single-Walled Carbon Nanotubes." *Science* 2002 July 26; 297: 593-596 (lead group: Weisman)
- "Formation and propagation of matter-wave soliton trains." *Nature* 2002 May 9; 417: 150-153 (lead group: Hulet)
- ISI Citation Rankings for nanotechnology (1990-2000)
  - Rice #3 ranked in world for citations
  - Smalley #1 cited author; two Rice authors in top ten
  - Three Rice papers in top 25

NanoTech Institute at the University of Texas at Dallas (www.utdallas.edu/dept/chemistry/nanotech/)

Number of faculty actively engaged in nanotechnology research: 10

Total funding for nanotechnology research (in 2002): ~$6 million (excludes faculty 9 month salaries)

Key research areas:

- Carbon nanotube science and engineering (targeted synthesis; fibers for supercapacitors, artificial muscles, and electronic textiles; biological molecule composites)
- Nano-energy (nanostructured hybrid composite membranes; thermal energy harvesting; nanoscale polymeric photocells; thermal conductivity studies)
- Advanced photonic materials (organic LEDs and photonic band-gap crystals)

Research facilities:

- Lab capabilities in thermal and elemental analysis, microscopy, spectroscopy, study of physical and magnetic properties from cryogenic temperatures
- Carbon nanotubes synthesis (advanced arc-discharge and CVD)

Nationally/internationally recognized faculty:

- Alan G. MacDiarmid (chemistry, physics): 2000 Nobel Laureate; James Von Ehr Distinguished Chair in Science & Technology
- Ray H. Baughman (chemistry): Director, UTD NanoTech Institute
- Anvar A. Zakhidov (physics, chemistry): Associate Director, UTD NanoTech Institute.
- John P. Ferraris (chemistry): Professor and Head, Chemistry Department.

Achievements in 2002:

- "Carbon Nanotubes—The Route Towards Application," R. H. Baughman, A. A. Zakhidov, and W. A. de Heer, *Science* 297, 787-792.
- "Charge Induced Anisotropic Distortions of Semiconducting and Metallic Carbon Nanotubes," *Phys. Rev. Lett.*, 89: 045503. (lead group: Baughman)
- "Controlled Assembly of Carbon Nanotubes by Designed Amphiphilic Peptide Helices," *J. Am. Chem. Soc.* 125**:** 1770-1777. (lead group: Draper)
- "Tunable, Gap-State Lasing in Switchable Directions for Opal Photonic Crystals," *Advanced Functional Materials*, 12: 21-26 (lead group: Zakhidov)
- "Evidence for Braggariton Excitations in Opal Photonic Crystals Infiltrated with Highly Polarizable Dyes," *Applied Physics Letters,* 80: 3491. (lead group: Zakhidov)

Other Texas universities with active nanotechnology research programs:

- Southern Methodist University (www.smu.edu/)

- Texas A&M University
  - Institute for Intelligent Bio-Nano Materials and Structures for Aerospace Vehicles (tiims.tamu.edu/)
  - NanoLab (faculty.physics.tamu.edu/teizer/)

- University of Houston (/www.uh.edu)

- University of North Texas
  - Laboratory for Electronic Materials and Devices (www.mtsc.unt.edu/lemd/)

- University of Texas at Arlington
  - Institute for Nanoscale Science and Engineering Research and Teaching (INSERT) (www.uta.edu/engineering/nano/)

- University of Texas at Austin
  - Center for Nano and Molecular Science and Technology within the Texas Materials Institute (http://www.utexas.edu/academic/tmi)

- University of Texas Southwestern Medical Center at Dallas (www3.utsouthwestern.edu/blountlab/)

Appendix B: Texas Nanotechnology Companies

Applied Nanotech, Inc. (www.appliednanotech.net)

Headquarters: 3006 Longhorn Blvd., Suite 107 Austin, Texas 78758
Phone: 512-339-5021
Key contact: Zvi Yaniv (email: zyaniv@appliednanotech.net)

Industry/nanotechnology category:	Nanomaterials; nanoelectronics; bulk and structural composites; photonics
Corporate history:	Subsidiary of SI Diamond Technology, Inc., a public company (SIDT.OB)
Employees:	20 full-time (as of Jan. 2003)
Revenues:	$1.5 million (FY 2002)
Science/Product/Service:	▪ Single- and multi-wall carbon nanotubes (CNTs) and their use in field emission displays, diode and triode type electron sources, x-ray equipment, etc. ▪ Nano-material fabrication (silicon nanocrystals, carbon nanotubes, nanowires, carbon nanotube composites, magnetic carbon nanotubes). ▪ Sensor applications of CNTs (hydrogen, humidity, ammonia, etc.) ▪ Nano-electronic devices (vacuum nano-transistors, ultra-capacitors, microwave matrix sources)
Stage of development:	Shipping product
Intellectual property	Almost 100 patents issued. Portfolio controls the field of electron emission from carbon nanotubes.
Strategic partners/customers:	Mitsui & Co. Ltd; Oxford Instruments, MediRad, NASA, Lawrence Livermore National Labs, Missile Defense Agency, Northrop Grumman, BMDO, two large display manufacturers in Japan
Investment history:	▪ IPO 1993 ▪ ~$10 million in licensing agreements ▪ $2 million in SBIR I and II programs

Goals:

- Increasing revenues to become self-sufficient by the end of 2003 by continuing to ship innovative products
- Becoming the dominant licensor of the intellectual property related to electron emission from CNTs

Management:

- Dr. Zvi Yaniv, President and CEO
- Marc Eller, Chairman
- Tracy Vaught, Chief Financial Officer
- Dr. Richard Fink, VP Engineering
- Key staff: Dr. Igor Pavlovski, Leif Thuesen, Dr. Dongsheng Mao

Carbon Nanotechnologies, Inc. (www.cnanotech.com)

Headquarters: 16200 Park Row, Houston, Texas 77084
Phone: 281-492-5707
Key contact: Daniel T. Colbert (email: colbert@cnanotech.com)

Industry/nanotechnology category:	Nanomaterials
Corporate history:	Founded in 2000 as a Rice University tech transfer by Richard E. Smalley, Daniel T. Colbert, Ken Smith, and Bob G. Gower.
Employees:	25 full-time (as of Jan. 2003)
Revenues:	N/A
Science/Product/Service:	Single-wall carbon nanotubes (SWNTs)
Stage of development:	Early commercialization
Intellectual property:	About 100 patents (mainly pending) covering production of SWNTs, enabling technologies, and end uses.
Goals:	▪ Generate sales contract to sell out first commercial plant ▪ Sustain position as the leading supplier of SWNTs ▪ Realize the multi-billion dollar potential value of SWNT markets
Management:	▪ Richard E. Smalley, Chairman ▪ Bob Gower, CEO and President ▪ Ray McLaughlin, CFO and EVP ▪ Ron Liotta, Senior VP ▪ VPs: Dan Colbert, Ken Smith, Ken McElrath, David Robinson

Molecular Imprints (www.molecularimprints.com)

Headquarters: 1807-C W. Braker Lane, Austin, Texas 78758
Phone: 512-334-1204
Key contact: Norman E. Schumaker (email: nschumaker@militho.com)

Industry/nanotechnology category:	Nano-enabling tools
Corporate history:	Founded in 2001 as a UT Austin tech transfer by S. V. Sreenivasan, C. G. Willson, and N. E. Schumaker.
Employees:	27 full-time (as of Jan. 2003)
Revenues:	$1.4 million (FY 2002)
Science/Product/Service:	Imprint tools (Imprio 100) for sub-100 nm patterning
Stage of development:	Shipping product
Intellectual property	Thirty-five issued and pending patents
Strategic partners/customers:	University of Texas at Austin, Motorola, KLA-Tencor, Lam Research, Photronics, Dupont Photomasks, Brewer Sciences
Investment history:	▪ $12 million raised from Alloy Ventures, Draper Fischer Jurvertson, Asset Management, Huntington Ventures, Motorola Ventures, KT Venture Group, Lam Research ▪ Two DARPA contract awards
Management:	▪ Norman E. Schumaker, President & CEO ▪ S. V. Sreenivasan, CTO ▪ M. P.C. Watts, VP Engineering ▪ R. D. Voisin, VP, Business Development ▪ P. Rotella, VP, Manufacturing ▪ P. E. Johnsen, Director, Finance & Administration

Xidex Corporation (www.xidex.com)

Headquarters: 8906 Wall Street, Suite 105, Austin, Texas 78754
Phone: 512-339-0608
Key contact: Paul F. McClure (email: pfm@xidex.com) or Vladimir Mancevski (vam@xidex.com)

Industry/nanotechnology category:	Nanomaterials; nano-enabling tools; nanoelectronics; life sciences
Corporate history:	Founded in 1997 by Paul McClure and Vladimir Mancevski
Employees:	Not disclosed
Revenues:	Not disclosed
Science/Product/Service:	Research, development, production, and marketing of innovative products that integrate nanosystems, microsystems, and macrosystems across dimensional scales. ▪ NanoCaliper™ Critical-Dimension Atomic Force Microscope (CD-AFM): Critical CD metrology tool for large-scale MEMS and NEMS manufacturing. Scheduled for market introduction in 2005. ▪ Aligned carbon nanotube growth for use as tips in scanning probe microscopes (CD-AFM, AFM, MFM, STM), filaments for scanning electron microscopes, field emitters, and molecular electronic devices. ▪ Nuclear magnetic resonance force microscope (NMRFM) development to make possible, for the first time, sub-optical resolution imaging of cellular functions at room temperature.
Stage of development:	Product development
Intellectual property	▪ One issued patent (CNT manufacturing methodology) ▪ Three pending patents (motion sensing, force sensing, and NanoCaliper™ CD-AFM technology)
Investment history:	▪ International SEMATECH funded a joint development agreement with Xidex in the prototyping of the NanoCaliper™ CD-AFM ▪ Contract R&D support (SBIR I and II) from the National Science Foundation, the Army Research Office, and the National Institute of Standards and Technology

Goals:	▪ Partner with equity investors and strategic partners for development and market entry of the NanoCaliper™ CD-AFM. ▪ Build strategic alliances driven by market opportunities in semiconductor metrology, biological and medical imaging, and micromechanical and microelectronic devices.
Management:	▪ Dr. Paul McClure, President and CEO ▪ Vladimir Mancevski, Founder and Chief Technology Officer ▪ Dr. Hal Bogardus, Advisory Board Member and former manager of Advanced Process and Equipment Control at International SEMATECH ▪ Dr. Ilene Busch-Vishniac, Advisory Board Member and Dean of Engineering at Johns Hopkins University.

Zyvex Corporation (www.zyvex.com)

Headquarters: 1321 North Plano Road, Richardson, Texas 75069
Phone: 972 235 7881
Key contact: Tom Cellucci (email: tcellucci@zyvex.com) or Timothy Gilmore (tgilmore@zyvex.com)

Industry/nanotechnology category:	Materials, tools, and structures for Aerospace and Defense, Healthcare and Medical, Electronics & Telecommunications
Corporate history:	Founded in 1997 by James R. Von Ehr II
Employees:	52
Revenues:	Not disclosed
Science/Product/Service:	▪ S100 nanomanipulation system ▪ Carbon nanotube functionalization ▪ MEMS design and control capabilities
Stage of development:	Product development
Intellectual property	▪ Four patents issued or allowed ▪ 44 patents pending
Investment history:	▪ 2$5M cost-shared NIST ATP award ▪ NASA SBIR ▪ DoE SBIT
Goals:	▪ Commercialize near-term tools and materials
Management:	▪ James R. Von Ehr, Chairman and CEO ▪ Dr. Thomas A. Cellucci, Chief Operating Officer ▪ Timothy Gilmore, Chief Financial Officer ▪ Dr. John Randall, Chief Technical Officer

Other Texas nanotechnology start-ups:

Bucky USA (www.flash.net/~buckyusa/)

C Sixty Inc. (www.csixty.com)

MicroFab Technologies (www.microfab.com)

Nanospectra Biosciences (www.nanospectra.com)

Nanospectra LLC

Nanotechnologies, Inc. (www.nanoscale.com)

Quantum Logic Devices (www.quantumlogicdevices.com)