McDermott
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NANOTECHNOLOGY

Who will be the leaders in the fifth technology revolution?

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Modern history can be broken into several periods of technological revolutions that developed in different regions throughout the world, and which interestingly correspond to the regions of global power for the given time period. First, from about 1780 to 1840, the steam engine, the textiles industry and mechanical engineering were born in the United Kingdom. Then, from about 1840 to 1900, railways, electricity and the steel industry began in England, Germany and the United States. The third technology revolution, spanning from about 1900 to 1950, brought electrical engines, heavy chemicals, automobiles and mass production of consumer durables, and has been largely based in the United States. Finally, from about 1950 to present times, the Pacific Basin Japan, and the United States (especially California) have been the epicenter for the fourth technology revolution, involving synthetics, organic chemicals and computers.[1]

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We are now in a unique time as the world transitions into a fifth technology revolution based on nanotechnology and molecular manufacturing. The question is, which regions of the world will be the technology leaders, and consequently the global powers for the next half-century?

Nanotechnology

Nanotechnology is the understanding and control of matter at the nanoscale (approximately 1 nm to 100 nm). Nanotechnology encompasses nanoscale science, engineering and technology, and involves imaging, measuring, modeling and manipulating matter at the nanometer length scale.[2]

Similar to computers, nanotechnology is both an enabling technology and a technology sector in its own right. Nanotechnology is prolific in the research and development efforts of almost every economic sector, from aerospace to medicine to energy. Many commercial products now incorporate nanomaterials or nanotechnology principles. For example, incorporation of silver nanoparticles into wound dressings provides antibacterial properties. Manufacturers of sports equipment and automobiles use nanoparticles to decrease the weight and increase the strength of the composites. Further, paints include nanoparticles to enhance the color, reduce or eliminate volatile organic compounds, and stop bacteria or fungal growth, which latter property may be particularly useful in hospitals and clinics.

American Innovation

As shown above, with respect to the various technological revolutions, the United States has been an innovator and technology leader for over a century. However, as we transition into the fifth technology revolution, is the United States being surpassed by other countries such as China and India?

To investigate innovation trends in nanotechnology, we have analyzed "nanotechnology patent literature," which includes U.S. Published Patent Applications, U.S. Granted Patents, and Published International Patent Applications, using the term "nano*" to search the claims, title or abstract (with the asterisk serving as a wildcard character).[3] While the U.S. Patent Office has a nanotechnology class, specifically Class 977, the results of searching only class 977 were found to be too narrow and did not apply to International Patent Applications. Accordingly, the data herein is based on the wider search described above. While this search strategy may not probe every piece of patent literature dealing with nanotechnology, it should provide a large enough representation for us to extract general trends in nanotechnology innovation.

First, looking at nanotechnology in general, Table 1 provides a historical look at the prevalence of nanotechnology in patent literature. Both U.S. Published Patent Applications and U.S. Granted Patents in nanotechnology have seen a steady increase since 2006. This increase in patent applications and granted applications likely corresponds to a growing research effort, which is further evidenced by the fact that the number of publications in scientific journals (a category distinct from patent literature) has more than doubled since 2006. Interestingly, the trend in International Published Patent Applications in nanotechnology shows an up-and-down trend, which mirrors the general trend seen in all International Published Patent Applications.

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[1] *Technological Revolutions and Financial Capital* by Carlota Perez.
[2] National Nanotechnology Initiative at www.nano.gov.
[3] The search results do not discriminate between corresponding U.S. Patent Applications and International Patent Applications if both were published in 2011.

TABLE 1

TRENDS IN NANOTECHNOLOGY PATENT LITERATURE OVER THE PAST SIX YEARS

Year	U.S. Published Patent Applications	U.S. Granted Patents	International Published Patent Applications
2011	8,469	4,435	5,207
2010	8,837	4,177	5,100
2009	7,307	2,897	6,276
2008	6,827	2,466	6,995
2007	5,923	2,370	5,966
2006	5,552	2,268	4,302

The number of U.S. Published Patent Applications in 2011 equaled nearly 150 percent of the number published in 2006, while the number of U.S. Granted Patents has almost doubled in that same timeframe. Overall, the number of International Published Patent Applications over the last six years has increased by only about 25 percent, with the peak increase in 2008 of about 60 percent over the 2006 level. These general trends indicate that nanotechnology innovation is on the rise. Discussions of each are below.

To get an indication of the regions of nanotechnology innovation, we investigated the location of the inventors and the most prolific assignees in the nanotechnology patent literature by searching U.S. Published Patent Applications, U.S. Granted Patents and International Published Patent Applications simultaneously. Table 2 provides the 2011 nanotechnology patent literature categorized by the country of at least one inventor's address. Table 3 provides the top 20 assignees in 2011 nanotechnology patent literature, with the country of the corporate headquarters in parentheses.

Relative to the location of inventors, U.S. inventors are most prevalent, accounting for slightly more than half of the nanotechnology patent literature in 2011. A reasonable conclusion may be drawn that persons residing in, or citizens of, the United States are at the forefront of nanotechnology innovation as compared to the rest of the world. Asian inventors make up the next group and account for a little less than a quarter of the nanotechnology patent literature. These inventors are closely followed by the European inventors, who account for less than a fifth of the nanotechnology patent literature.

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Of particular note, while the total number of nanotechnology patent publications from U.S. inventors is up, the percentage of total nanotechnology patent publications relative to the rest of the world is down. This could indicate at least two trends: that nanotechnology innovation is rising at a faster pace outside the United States, or that the global view has shifted and placed a higher value on patents as intellectual property.

TABLE 2

COUNTRY OF INVENTOR'S ADDRESS FOR NANOTECHNOLOGY PATENT LITERATURE

Country	2011	2005
United States	53%[4]	64%
South Korea	8%	6%
Japan	7%	8%
Germany	7%	7%
France	4%	4%
China	4%	1%
Taiwan	3%	3%
Canada	3%	2%
Great Britain	3%	2%
Australia	2%	1%
India	1%	1%
Israel	1%	1%
Spain	1%	< 1%
Russia	1%	< 1%

The same general conclusions can be drawn from the assignee data in Table 3, which illustrate that U.S.-based assignees account for 13 of the 25 top assignees in nanotechnology patent literature, followed by Asian-based assignees with seven and European-based assignees with four. However, half of the top six assignees are U.S.-based, with the other half being Asian-based. Given the location and sectors of these top six assignees, it appears that much of the current nanotechnology innovation could be developing as an extension of the fourth technology revolution, especially in the area of computers and electronics.

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However, viewing the economic sectors of all top 25 assignees, it is clear that nanotechnology innovation may still be primarily developmental in nature, as the majority of assignees are universities or government agencies. The majority of the universities and government agencies developing nanotechnology innovations are in the United States.

[4] Percentages represent the percent of total patents having with at least one inventor with an address from the designated country.

The economic sectors that indicate growth opportunities for nanotechnology innovation include consumer products, health care and energy. The most prominent assignees in these up-and-coming nanotechnology sectors, *i.e.*, other than computers and electronics, are U.S.-based or European-based.

TABLE 3

TOP 25 ASSIGNEES IN 2011 NANOTECHNOLOGY PATENT LITERATURE

	Assignee	Country	Sector
1	Samsung	South Korea	Computers and Electronics
2	IBM	United States	Computers and Electronics
3	Hon Hai Precision Industry	Taiwan	Computers and Electronics
4	University of California	United States	University and Government
5	Tsinghua University	China	University and Government
6	3M	United States	Consumer Products
7	Massachusetts Institute of Technology	United States	University and Government
8	GeneASys	Australia	Health Care
9	Xerox	United States	Computers and Electronics
10	DuPont	United States	Chemical
11	Micron Technology, Inc.	United States	Computers and Electronics
12	Atomic Energy and Alternative Energies Commission	France	Energy
13	BASF	Germany	Chemical
14	General Electric Company	United States	Energy, Health Care and Consumer Products
15	National Center for Scientific Research	France	University and Government

	Assignee	Country	Sector
16	University of Texas	United States	University and Government
17	Hewlett Packard	United States	Computers and Electronics
18	Agency for Science, Technology, and Research	Singapore	University and Government
19	Northwestern University	United States	University and Government
20	Lockheed Martin Corporation & Applied NanoStructured Systems	United States	Aerospace, Advanced Material and Energy
21	Industrial Technology Research Institute	Taiwan	University and Government
22	Baker Hughes	United States	Energy
23	Siemens	Germany	Energy, Health Care and Communications
24	University of Korea	South Korea	University and Government
25	Toyota	Japan	Automotive

Table 4 illustrates that U.S.-based companies account for at least three of the top five assignees of nanotechnology patent literature in Computers and Electronics, Traditional and Alternative Energy, Health Care and Medicine, and Universities and Government Agencies, and two of the top three in the Chemical sector.[5] The Technology sector provides a catch-all for assignees that do not neatly fit into a specific sector because of a business portfolio that is diverse and prevalent in a plurality of economic sectors.

U.S.-based companies account for over half of the top assignees in each of Computers and Electronics, Traditional and Alternative Energy, Health Care and Medicine, Chemicals, and Universities and Government.

[5] Assignees were categorized by sector and then ranked by total nanotechnology patent literature found in 2011. Accordingly, some nanotechnology patent literature for an assignee may fall outside the sector in which it is categorized. Individual keyword searches were not performed.

TABLE 4

TOP ASSIGNEES IN 2011 NANOTECHNOLOGY PATENT LITERATURE BY SECTOR

Computers and Electronics		
1	Samsung	South Korea
2	IBM	United States
3	Hon Hai Precision Industry	Taiwan
4	Xerox	United States
5	Micron Technology, Inc.	United States
Traditional and Alternative Energy		
1	Atomic Energy and Alternative Energies Commission	France
2	Baker Hughes	United States
3	Schlumberger Technology Corporation	France
4	ExxonMobil	United States
5	Halliburton Energy Services	United States
Health Care and Medicine		
1	GeneASys	Australia
2	Boston Scientific	United States
3	Merck	United States
4	Abbott Laboratories	United States
5	Life Technologies Corporation	United States

Chemical		
1	DuPont	United States
2	BASF	Germany
3	Dow	United States
Technology		
1	General Electric Company	United States
2	Lockheed Martin Corporation & Applied NanoStructured Systems	United States
3	Siemens	Germany
4	Hitachi	Japan
5	Bayer	Germany
University and Government		
1	University of California	United States
2	Tsinghua University	China
3	Massachusetts Institute of Technology	United States
4	National Center for Scientific Research	France
5	University of Texas	United States

Innovation Within the United States

Taking a closer look at the United States, we analyzed the percent of nanotechnology patent literature for each of the 50 states based on the inventor's address or the assignee's location. Four states clearly emerged at the top of the pack in both criteria, as shown in Table 5. California is obviously first; a three-state cluster including New York, Massachusetts and Texas follows closely.

TABLE 5

TRENDS IN NANOTECHNOLOGY PATENT LITERATURE IN THE UNITED STATES

Year	California	New York	Massachusetts	Texas
Inventor Resident State				
2011	28%	12%	10%	8%
2006	26%	12%	9%	7%
Assignee Address				
2011	23%	11%	9%	10%
2006	24%	12%	11%	10%

Texas is increasing in both inventorship and assignee address, which may indicate that Texas has a growing technology base.

Of particular note, the percentage of nanotechnology patent literature having an assignee in Texas has held steady while the other states have dropped by as much as 2 percent. This may indicate that more Texas companies are getting into the nanotechnology game, and/or that nanotechnology companies are starting or re-locating in Texas. As an alternative explanation, these numbers may indicate that nanotechnology is becoming more integrated into sectors outside semiconductors, including energy, alternative energy, health care and chemicals—three sectors in which Texas is a major player.

To investigate this last point, we performed similar searches and removed nanotechnology patent literature associated with U.S. Class 438 (Semiconductor Device Manufacturing), U.S. Class 257 (Active Solid-State Devices, *e.g.*, Transistors and Solid-State Diodes) and International Class H01L (Semiconductor Devices and Electric Solid State Devices), the results of which are presented in Table 6.

When a substantial portion of the semiconductor technology is removed, Texas is increasing in both inventorship and assignee location, which may indicate that Texas has a growing technology base, in both inventors and companies, for nanotechnology patent literature outside the semiconductor industry. See Appendix 1 for more detail on nanotechnology innovation in Texas.

TABLE 6

TRENDS IN NANOTECHNOLOGY PATENT LITERATURE IN THE UNITED STATES THAT SUBSTANTIALLY EXCLUDE SEMICONDUCTOR/TRANSISTOR TECHNOLOGY

Year	California	New York	Massachusetts	Texas
Inventor Address				
2011	25%	9%	10%	9%
2006	24%	11%	10%	7%
Assignee Address				
2011	21%	8%	9%	10%
2006	22%	11%	11%	9%

When a substantial portion of the semiconductor technology is removed, Texas is increasing in both inventorship and assignee address, which may indicate that Texas has a growing technology base, in both inventors and companies, for applications outside the semiconductor industry. Since it is clear that there will be several nanotechnology epicenters in the United States, it appears that Texas is on the rise to claim a major role in the non-semiconductor applications that are only just emerging.

Conclusions

As the world transitions to the fifth technology revolution of nanotechnology and molecular assembly, it may still be too early to identify the associated global epicenters. However, the United States appears poised to be a world leader given its high levels of research and development and diversification of sectors impacted. Within the United States, four epicenters are emerging: California, New York, Massachusetts, and Texas. Further, it appears that Texas is on the rise in the non-semiconductor aspects of the next technology revolution.

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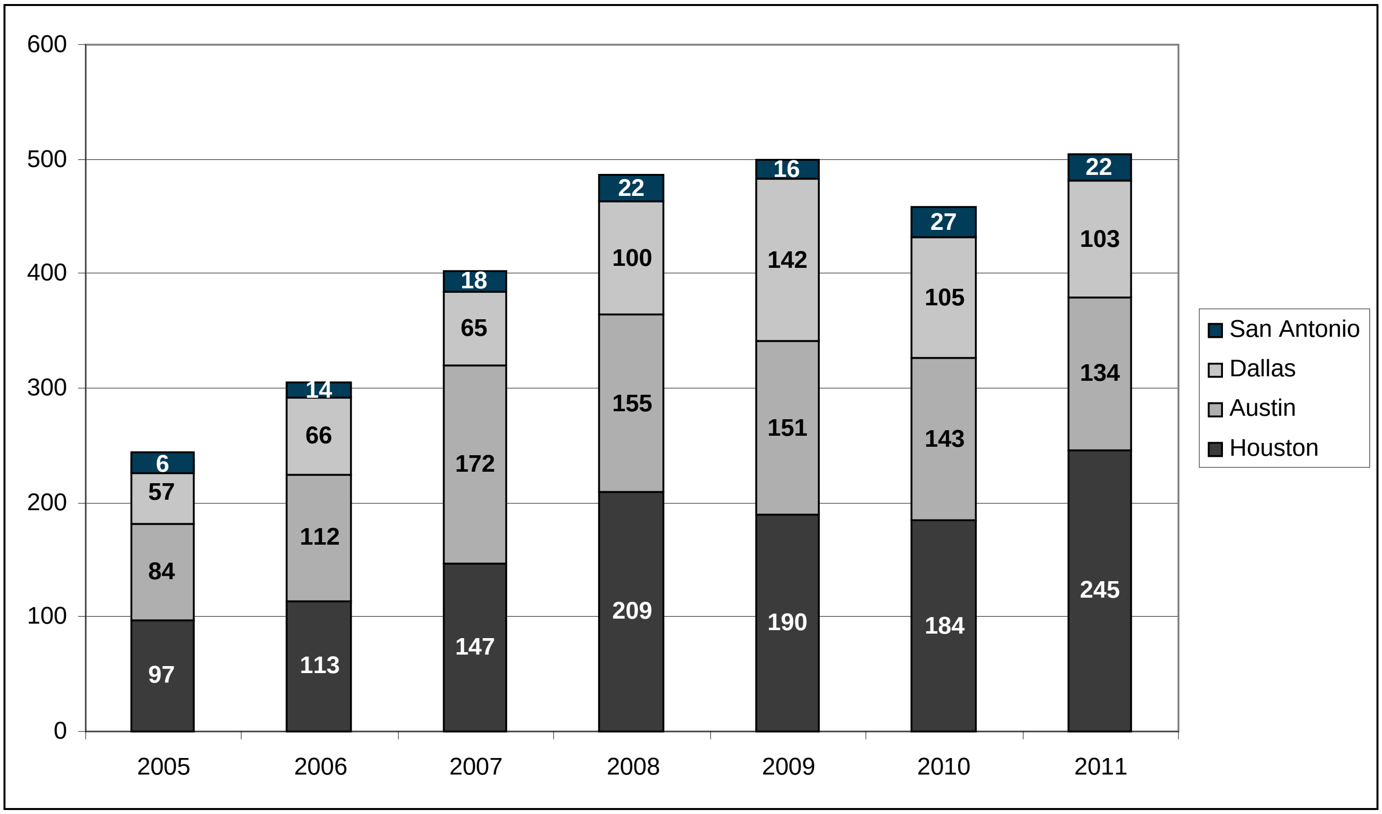
TOP 10 TEXAS ASSIGNEES BY YEAR

	2006	2007	2008	2009	2010	2011
1	Hewlett Packard	Hewlett Packard	Hewlett Packard	Hewlett Packard	Hewlett Packard	University of Texas
2	Rice University	Freescale Semiconductor	Rice University	University of Texas	University of Texas	Hewlett Packard
3	Freescale Semiconductor	Rice University	University of Texas	Baker Hughes	Rice University	Baker Hughes
4	University of Texas	University of Texas	Baker Hughes	Texas Instruments	Molecular Imprints Inc	Molecular Imprints Inc
5	Nano Proprietary Inc	Nano Proprietary Inc	Freescale Semiconductor	Freescale Semiconductor	Baker Hughes	Rice University
6	Texas Instruments	Molecular Imprints Inc	Nano Proprietary Inc	Rice University	Freescale Semiconductor	Freescale Semiconductor
7	Nanotechnologies, Inc	ExxonMobil	Texas Instruments	Applied Nanotech Holdings	Texas Instruments	Texas Instruments
8	Southwest Research Institute	Texas Instruments	Innovalight Inc	Molecular Imprints Inc	Applied Nanotech Holdings	Halliburton
9	University of North Texas	University of Houston	Dow Global	Texas A&M	University of Houston	ExxonMobil
10	Zyvex	Schlumberger	ExxonMobil	Schlumberger	TIE: ExxonMobil & Halliburton	Applied Nanotech Holdings

NANOTECHNOLOGY PATENT LITERATURE COUNT BY METROPOLITAN AREA (BASED ON INVENTOR ADDRESS)



TOP ASSIGNEES BY METROPOLITAN AREA
(2005–2011 BASED ON INVENTOR ADDRESS)

	Houston[6]	Dallas[7]	Austin[8]	San Antonio[9]
1	Rice University	Texas Instruments	Freescale Semiconductor	Southwest Research Institute
2	Baker Hughes	University of Texas	University of Texas	University of Texas
3	University of Texas	University of North Texas	Nano Proprietary, Inc.	CardioSpectra, Inc.
4	Schlumberger	Zyvex Corporation	Molecular Imprints, Inc.	KCI Licensing, Inc.
5	University of Houston	OmniProbe, Inc.	Applied Nanotech Holdings	BioNumerik Pharmaceuticals, Inc.

[6] The Houston Metropolitan Area includes the following cities: Houston, Pasadena, Pearland, Baytown, Conroe, Deer Park, Friendswood, Galveston, Lake Jackson, La Porte, League City, Missouri City, Sugar Land, Texas City, The Woodlands, Alvin, Angleton, Bellaire, Clute, Dickenson, Freeport, Galena Park, Humble, Jacinto City, Katy, La Marque, Richmond, Rosenberg, South Houston, Stafford and West University.
[7] The Dallas Metropolitan Area includes the following cities: Dallas, Fort Worth, Arlington, Plano, Garland, Irving, Grand Prairie, Mesquite, McKinney, Carrollton, Frisco, Denton, Richardson, Addison, Allen, Azle, Balch Springs, Bedford, Benbrook, Burleson, Cedar Hill, Cleburne, Colleyville, Coppell, Corinth, Crowley, DeSoto, Duncanville, Ennis, Euless, Farmers Branch, Flower Mound, Forest Hill, Forney, Glenn Heights, Grapevine, Greenville, Haltom City, Highland Village, Hurst, Keller, Lancaster, Lewisville, Little Elm, Mansfield, Midlothian, Mineral Wells, Murphy, North Richmond Hills, Red Oak, Rockwall, Rowlett, Royse City, Saginaw, Sachse, Seagoville, Southlake, Terrell, The Colony, University Park, Watauga, Waxahachie, Weatherford, White Settlement and Wylie.
[8] The Austin Metropolitan Area includes the following cities: Austin, Round Rock, Cedar Park, San Marcos, Georgetown, Pflugerville, Kyle, Leander, Bastrop, Bushy Creek, Buda, Dripping Springs, Elgin, Hutto, Jollyville, Lakeway, Lockhart, Luling, Shady Hollow, Taylor, Wells Branch and Windemere.
[9] The San Antonio Metropolitan Area includes the following cities: San Antonio, New Braunfels, Schertz, Seguin, Boerne, Canyon Lake, Cibolo, Converse, Leon Valley, Live Oak, Timberwood Park and Universal City.

TOP INTERNATIONAL CLASS/SUBCLASS BY METROPOLITAN AREA

(2005–2011 BASED ON INVENTOR ADDRESS)

	Houston	Dallas	Austin	San Antonio
1	Inorganic Chemistry (C01)	Basic Electric Elements (H01)	Basic Electric Elements (H01)	Medical or Veterinary Science (A61)
2	Medical or Veterinary Science (A61)	Medical or Veterinary Science (A61)	Measuring; Testing (G01)	Layered Products (B32)
3	Organic Macromolecular Compounds (C08)	Measuring; Testing (G01)	Medical or Veterinary Science (A61)	Coating Metallic Materials (C23)
4	Measuring; Testing (G01)	Organic Macromolecular Compounds (C08)	Working of Plastics (B29)	Measuring; Testing (G01)
5	Basic Electric Elements (H01)	Optics (G02)	Techniques Using Waves Other Than Optical Waves; Electrography; Holography (G03)	Organic Chemistry (C07)
6	Earth or Rock Drilling; Mining (E21)	Physical or Chemical Processes or Apparatus (B01)	Spraying or Atomizing (B05)	Biochemistry; Microbiology; Enzymology (C12)
7	Physical or Chemical Processes or Apparatus In General (B01)	Biochemistry; Microbiology; Enzymology (C12)	Inorganic Chemistry (C01)	Dyes; Paints; Polishes; Natural Resins; Adhesives (C09)
8	Dyes; Paints; Polishes; Natural Resins; Adhesives (C09)	Electric Communication Technique (H04)	Physical or Chemical Processes or Apparatus In General (B01)	Basic Electric Elements (H01)
9	Natural or Artificial Threads or Fibres; Spinning (D01)	Working of Plastics (B29)	Nanotechnology (B82)	Spraying or Atomizing (B05)
10	Nanotechnology (B82)	Inorganic Chemistry (C01)	Organic Macromolecular Compounds (C08)	Petroleum, Gas. or Coke Industries (C10)

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