Trajectories of Nanotechnology Research & Innovation

Trends, Clusters, Cases, and Propositions

Philip Shapira [1,2,3]

[1]Manchester Institute of Innovation Research, Manchester Business School, UK
[2]Georgia Institute of Technology, Atlanta, USA
[3]Center for Nanotechnology in Society (CNS-ASU), USA

Nanotechnology Winter School, Pinsot, France29 March 201129 March 2011March 28, 2011!!

CNS-ASU research, education and outreach activities are supported by the National Science Foundation under cooperative agreement #0531194. Any opinions, finding, and conclusions are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Nanotechnology research and innovation

Some Key Questions

- **Why** the focus on nanotechnology?
- **How** is nanotechnology defined?
- **Who** are the key sponsors, performers and users of nanotechnology innovations?
- **Where** is nanotechnology research and innovation occurring?
- **When** is nanotechnology research and innovation occurring?
- **What** are the economic, societal and policy implications?

2

Center for Nanotechnology in Society (CNS-ASU)

RTTA1: Nanotechnology Research and Innovation Systems Analysis Group

Key Probes:

P/Is: Shapira (GT/UNIMAN), Youtie (GT), Porter (GT), Rogers (GT), Lobo (ASU)

1. **Trajectories of emerging nano-science** - NSE knowledge development, exchange, & interdisciplinarity

2. **Nanotechnology enterprise and applications** - nano innovation: large & small enterprises; commercialization pathways; regional, international developments; policy outcomes

Nanotechnology Research and Innovation Systems Analysis

Definitions & Data

Nanotechnology = manipulation of materials, applications, and systems at the scale of 1-100 nm which have novel properties due to their small scale

Core Resources:

oRefined two-stage two-stage bibliometric search method*

oDevelopment of large-scale global databases of

- Nanotechnology publications (1+ million, 1990-2010, including c 0.5 million SCI)
- 61,000 nano patents (70 patent offices, MicroPatents); + c 90,000 PATSTAT (1990-2009+)

•Complementary data and tools (e.g. small nano-firm start-up data; MNE nano patent families)

***Key Publication: Refining search terms for nanotechnology.** Porter, Youtie, Shapira, Schoeneck. *J. NanoParticle Research*, 2008.

Trajectories of nanotechnology research and innovation

1. Recent results and analyses of
   - Nano research funding and impacts
   - Corporate entry into nanotechnology

2. New "work in progress"
   - NNIN SMEs
   - Graphene innovation

3. Implications and research opportunities

5

Nano R&D

Nanotech's Top Ten Funders

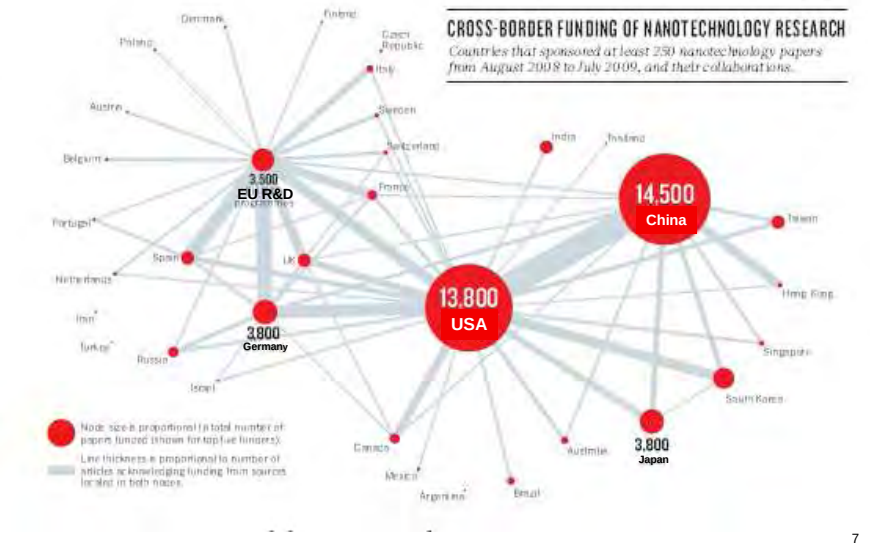
Sponsors of papers published 8/2008 – 7/2009

Research Sponsor	Papers X '000	% of Total	% Early impact papers
National Natural Science Foundation of China	10.2	16.7	4.7
US National Science Foundation	6.7	10.8	11.4
Ministry of Science & Technology of China	4.7	7.7	5.2
European Union R&D Programmes	3.5	5.8	10.4
US HHS (including NIH)	3.1	5.1	15.0
Ministry of Education of China	3.1	5.1	4.6
US Department of Energy	3.0	4.9	12.5
US Department of Defense	2.6	4.2	12.3
German Research Foundation	2.6	4.2	10.2
Ministry of Education (MEXT) of Japan	2.4	3.9	6.2

6

Analysis of 61,300 sponsored research papers. P. Shapira and J. Wang. *Nature*. 2010. 468. 627-628.

Transcending boundaries *and* national nanotechnology programs



Analysis of 61,300 sponsored research papers. P. Shapira and J. Wang. *Nature*. 2010. 468. 627-628.

7

Corporate nano

Anticipating nanotechnology commercialization: Some questions which need better answers

- The shift from discovery to application in nanotechnology ..
  - But when? How?
  - What kinds of applications? (Passive v. active?)
- Who is turning nanoscience knowledge into nanotechnology innovations?
  - Type of companies? Locations?
- To what extent is a nanotechnology system of innovation developing?
  - Or is it multiple systems?
- How do companies address uncertainty in nanotechnology applications?
  - Technical? Regulatory? Market? Competitive?
- How can we feed insight about nanotechnology commercialization into the processes of anticipatory governance?

Nanotechnology commercialization

"Knowns" and "Unknowns"

"Knowns" (or better "knowns")

- Corporate entry into nanotechnology through research publications and patenting
- Geographical concentration of corporate entrants in nanotechnology
- Linkages with public research and universities
- First generation consumer-oriented products

"Unknowns" (or mostly "unknowns")

- Corporate strategy (in the face of uncertainty)
- Influence of contrasting regulatory environments on corporate strategies in nanotechnology
- Fit in the global supply chain v. inventive activity
- International boundaries, consumer values and demand
- Employment and labor market implications

Corporate entry into nanotechnology

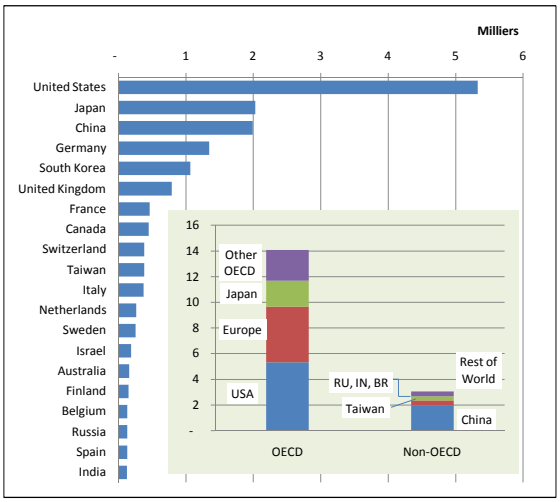
(1990 through mid-2008)

- **Worldwide:** 17,600+ unique companies entering nanotechnology
  - 52,100 nanotechnology articles published
  - 45,000 patent applications
  - 18,000 patent awards
- **US companies:**
  - 31% of companies (5,440)
  - 35% global nano patent applications
  - 44% global nano patents granted

P. Shapira, J. Youtie, L. Kay, National Innovation Systems Dynamics and the Globalization of Nanotechnology Innovation. *J of Technology Transfer*, 2011
Patent data from Patstat

Top 20 nanotechnology nations

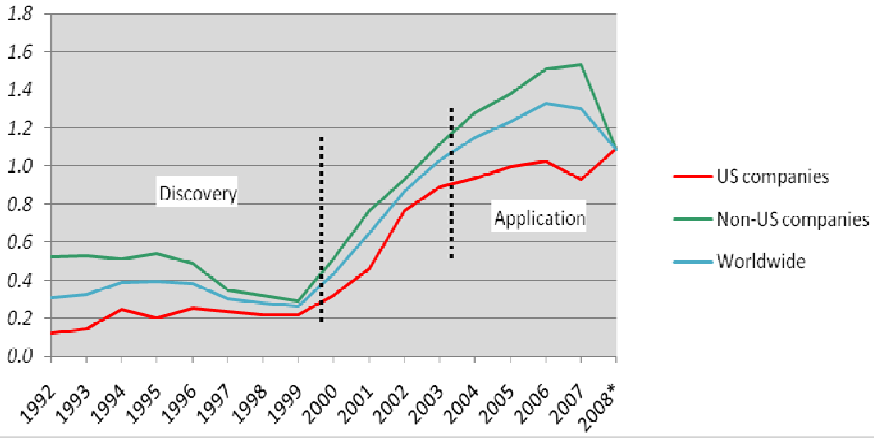
By corporate entry, 1990 through mid-2008



Analysis of corporate entry, Georgia Tech global nanotechnology publication and patent databases. Patent data from Patstat

11

Corporate shift from nanotechnology discovery to application, 1992-2008*

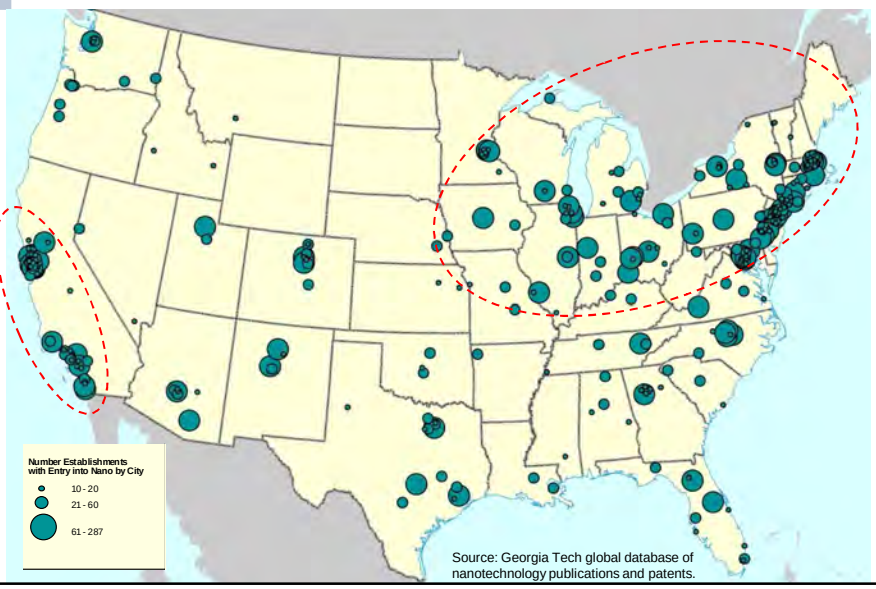


Source: Based on Georgia Tech global nanotechnology databases. Y-axis = ratio of corporate nanotechnology patent applications to corporate nanotechnology publications by year.

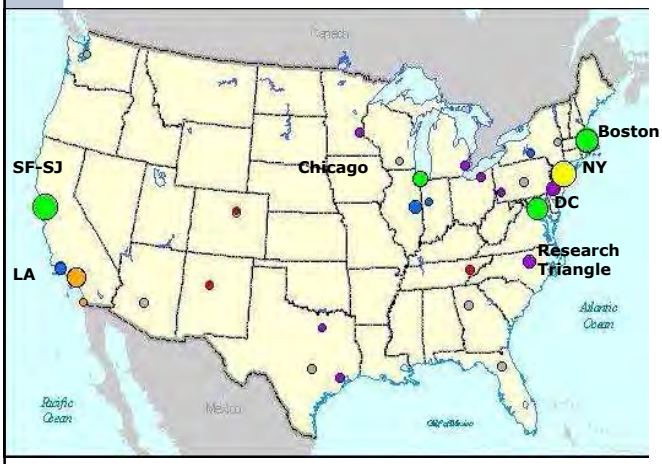
12

Corporate Entry into Nanotechnology by City

Number of establishments with nano publications or patents (1990 mid-2008) or cities with 10 or more establishments



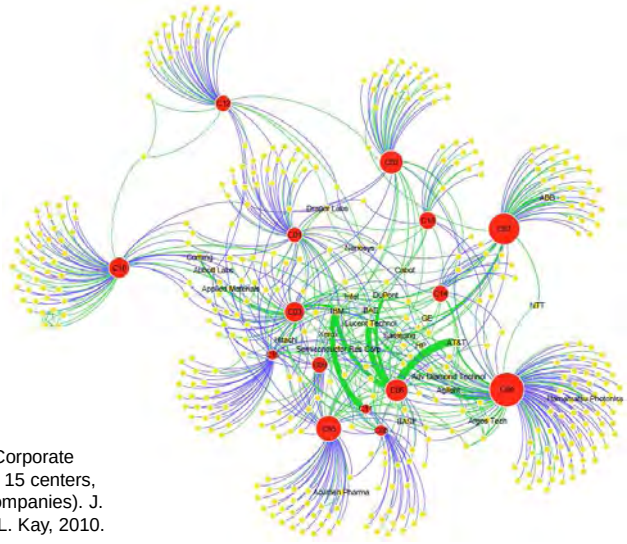
Where are US Nanodistricts emerging?



Refs: Shapira, Youtie (2008), Emergence of nanodistricts in the United States, *Econ Dev Quart.*; Shapira, Youtie, Carley (2009), Prototypes of emerging metropolitan nanodistricts in the US & Europe, *Annales* (forthcoming); Wang, Shapira (2010) Partnering with Universities: A Good Choice for Nanotechnology Start-up Firms? (*Small Business Economics*)

14

NSEC Assessment:
Corporate network use of public nano centers

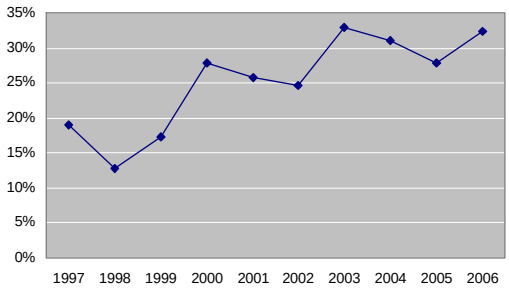


NSEC Network – Corporate collaborations with 15 centers, 2001-2010 (421 companies). J. Rogers, J. Youtie, L. Kay, 2010.

15

International Nano Patent Strategies: Small Businesses are Increasingly Emerging

Proportion of U.S. SMEs* with WIPO PCT filings (relative to U.S. Large)



* SBA standard definition, less than 500 employees

Authors: Andrea Fernández-Ribas with research assistance from Ronak Kamdar. Support obtained through CNS-ASU and the Kauffman Foundation and Georgia Research Alliance.

- Analysis of WIPO PTC nano-related applications 1997-2006 of 300+ US owned SMEs
- Increased geo-graphic breadth of patent protection; regional/ international (co-) invention patterns observed

Opportunities for SMEs and Large companies are in contrasting applications

Use of nanotechnology (classes of technologies—IPC codes)**	Firm size*	
	SME	Large
Nano-raw material (e.g. carbon nanotubes, proteins)	21%	10%
Nano-intermediate (e.g. semiconductors, films)	76%	88%
Nano-products (e.g. solar cells, cosmetics, drugs)	11%	6%

* United States, Fortune 1000 vs. Non-Fortune 1000; all nano-patents since 1990.

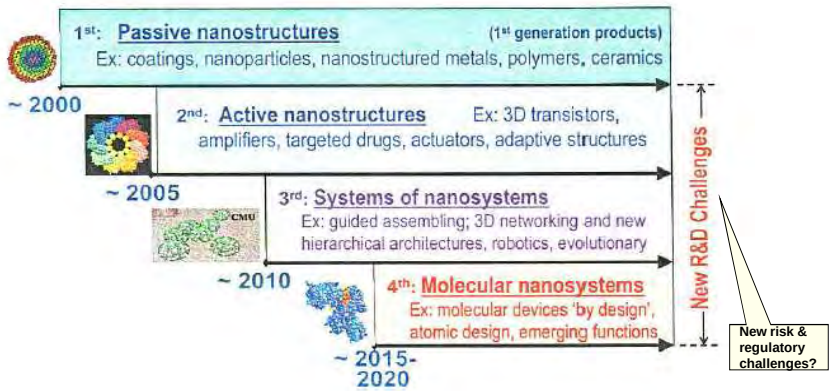
** Technologies classified according to definition in Alencar et al. (2007), multi-classification possible. Covers 57% of all nano-patent records

Source: Analysis of Georgia Tech global nanotechnology patent databases. For details and definition of nanotechnology, see Porter et al., 2008

17

Nanotechnology commercialization

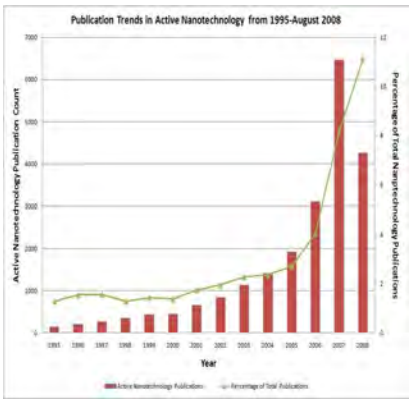
Can we anticipate direction over time?



Timeline for beginning of industrial prototyping and nanotechnology commercialization. Roco (2005).

18

Is there a shift to "active nanotechnology?"



- Active nanotechnology posited as 2nd generation, with important implications
- Filtered nano publication databases
  - Materials base (nano*, fullerene#, quantum dot#, dendri*, self assembl* and molecul*)
  - Active terms (motor, adaptive, self-healing, etc.)
- 21,000+ articles from WOS/SCI from 1995 to 2008
  - Shift? Yes, after 2006

Source: Vrishali Subramanian, Jan Youtie, Alan L. Porter, and Philip Shapira (2009). Is there a shift to "active nanostructures?" *Journal of Nanoparticle Research*,

19

Transition to active nanostructures:
What products can we expect?

- **Remote Actuated Active Nanostructures**: Nanotechnologies whose active principle is remotely activated or engaged.
  - Magnetic, electrical, light and wireless tagged nanotechnologies, used in light harvesting antenna, optoelectronics, remote-actuated drug delivery, wireless sensors, etc.
- **Environmentally Responsive Active Nanostructures**: Nanotechnologies that are sensitive to environmental stimuli like pH, temperature, light, oxidation-reduction, certain chemicals
  - Sensors, responsive drug delivery, environmentally responsive actuators, etc.
- **Miniaturized Active Nanostructures**: Nanotechnologies which are a conceptual scaling down of larger devices, technologies
  - Molecular electronics
- **Hybrid Active Nanostructures**: Nanotechnologies involving uncommon material combinations (biotic-abiotic, organic-inorganic)
  - DNA, protein, photosystem, etc. mobilized on a chip,silicon-organic hybrid nanotechnologies, etc.
- **Transforming Active Nanostructures**: Nanotechnologies that change irreversibly during some stage of its use or life
  - Self-healing materials like metal or plastic coatings, which on specific triggers, repair damage caused by corrosion, mechanical damage, etc.

Source: Vrishali Subramanian, Jan Youtie, Alan L. Porter, and Philip Shapira (2009). Is there a shift to "active nanostructures?" *Journal of Nanoparticle Research*,

20

Innovation strategies in emerging nanotechnologies

Two project cases:

1. NNIN SMEs*
2. Innovation in graphene

- "Work in progress"
- Pioneering new analytical methods

*SME = Small and medium enterprise

Case Study 1:

Innovation Strategies of 30 NNIN SMEs

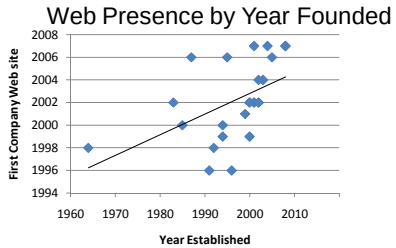
"Web Scraping"

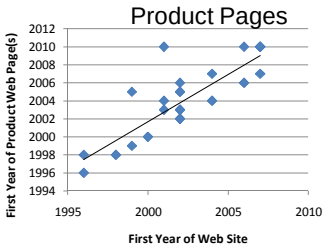
278 active companies with web sites from list of 358 non-Fortune 1000 companies reported as NNIN's facilities users as of December, 2008

Random sample of 30 nano SME web sites.

- 40% nanoelectronics
- 40% nanobio
- 17% energy

Coded current company web pages and archived pages from Wayback Machine (www.archive.org) since 1996 for each of the 30 companies under analysis, focusing on product transitions and financial strategies.



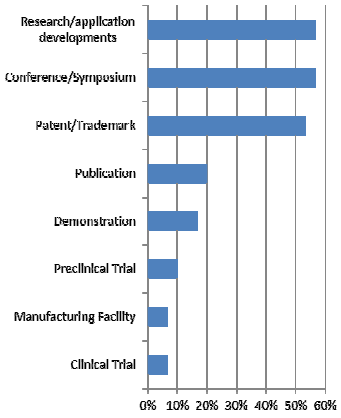


Source: Georgia Tech analysis of 30 NNIN company web sites, August 2010.

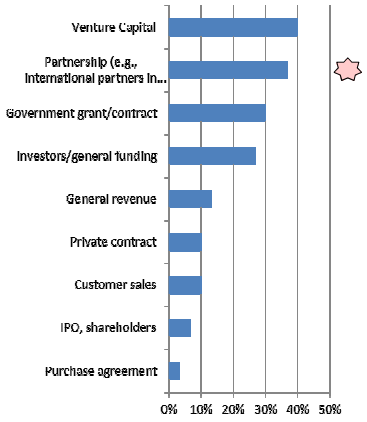
Business Developments and Relationships

30 NNIN SMEs

Product strategies



Financial strategies



Source: Georgia Tech analysis of 30 NNIN company web sites, August 2010.

Innovation Strategies

By nano-sector (30 NNIN SMEs)

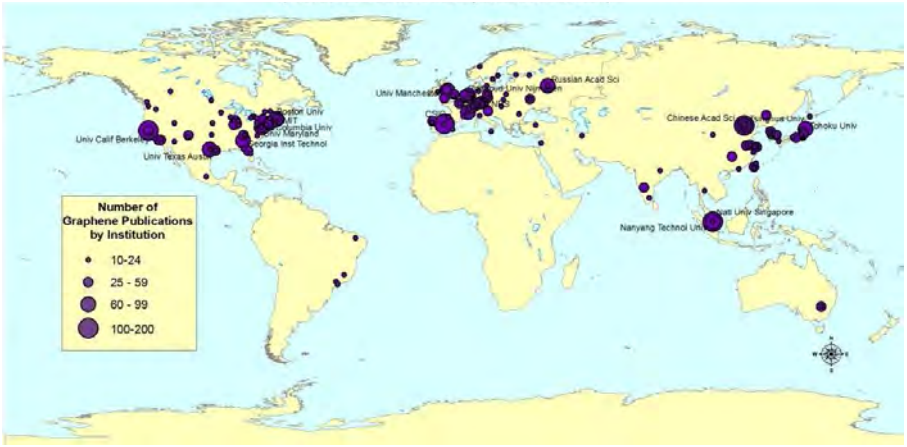
Nanoelectronics	**Nanobio**	**Nanoenergy**
Mixed timing	Late web, product site	Early web, product site
More research intensive	More research intensive	Less research intensive
International partnerships	In-house R&D	International partnerships
Customer sales	Venture funding	Customer sales
Government funding	Government funding	
Conference, symposium	Patent orientation	

Source: Georgia Tech analysis of 30 NNIN company web sites, August 2010.

Case Study 2: Graphene

Emergence of research clusters (to 2010)

Institutions with 10 or more graphene scientific publications, 2000-2010
(institutions with 60 or more publications labeled)



Source: Analysis of Web of Science published papers on graphene , 2000 through to 8/2010, N=4,706. P. Shapira, J. Youtie, S. Carley, Graphene Research Profile: UK and US Publications, 2000-2010. October 2010. http://works.bepress.com/pshapira/27/.

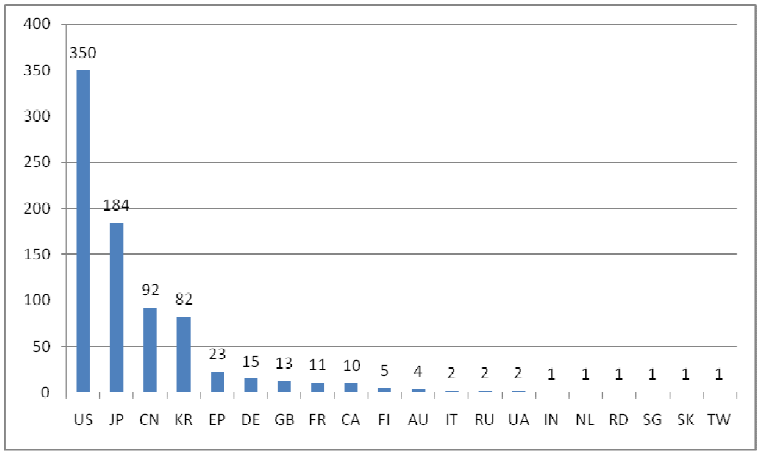
25

US Graphene Research Clusters and Start-up Companies, 2010

Shapira, Youtie, and Carley (2010) Graphene Research Profile, Center for Nanotechnology in Society at Arizona State University (CNS-ASU), funded by the National Science Foundation (Award No. 0531194) based on data from the Web of Science, Science Citation Index, August 2010.

26

Graphene Patent Families By Country of Assignee



Analysis of Derwent Patents (765 grants), 12/2010

27

Leading graphene patenting organizations (to 12/2010)

Corporate Assignee	Patents
Samsung (Korea)	29
Sandisk 3D (US)	21
Teijin (Japan)	20
Fujitsu (Japan)	15
Gunze Sangyo (Japan)	12
GSI Creos Corp (Japan)	11
Hitachi (Japan)	10
Univ. Sungkynkwan Foundation Corp. (Korea)	10

Analysis of Derwent Patents (765 grants), 12/2010

28

Implications

Internationalization of nanotechnology

- Nanoscience is transcending national boundaries and national nanotechnology initiatives
  - Three hubs: US, Europe, Asia
  - US and Europe retain edge in quality
- Corporate focus is shifting to applications
  - Large and small firms - varying roles & opportunities by nano sector
  - US powerful in SMEs
  - Large global companies taking lead in development of key nanomaterials and intermediates

Research opportunity: how and what are companies commercializing *within* specific nano sectors?

29

Implications

Regional clustering of nanotechnology

- While *use* of nanotechnology is likely to be widespread, the *production* of nanotechnology is clustered.
- Leading nano-regions are of different types: industry-led; university-led; diverse.
- Business strategies of companies in clusters transcend clusters
  - Linked multi-national firms
  - Emergence of born-global nanotechnology firms

Research opportunity: how do regional structures influence business strategies and technology choices?

30

Implications

Governance and policy

- Current nanotechnology products are mostly *incremental* improvements to existing technologies… but ..
- R&D is proceeding on more *radical* nanotechnology innovations – which will have greater economic and societal implications.
- High levels of uncertainty in commercialization – opportunities and needs for demand-side initiatives and engagement.

Research opportunity: Who is working on what radical nanotechnology innovations, and when are these likely to be introduced by companies and other organizations?
Do we have the governance and policy responses in place to address the implications of more radical innovations?

31

Nanotechnology research and innovation
Some Key Questions

- **Why** the focus on nanotechnology?
- **How** is nanotechnology defined?
- **Who** are the key sponsors, performers and users of nanotechnology innovations?
- **Where** is nanotechnology research and innovation occurring?
- **When** is nanotechnology research and innovation occurring?
- **What** are the economic, societal and policy implications?

32

Resources

- Center for Nanotechnology in Society: http://cns.asu.edu/
- Nanotechnology Research and Innovation Systems Assessment Group: http://www.nanopolicy.gatech.edu/
- Manchester Institute for Innovation Research: http://research.mbs.ac.uk/innovation/
- Philip Shapira: http://works.bepress.com/pshapira/

33