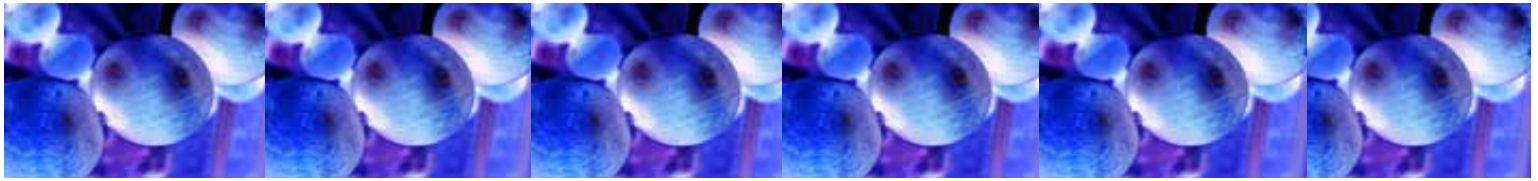
Nanotechnology:
Will it Drive a New Innovation Economy for the U.S.?



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Presentation and Webcast, Project on Emerging Nanotechnologies, Washington, DC, March 23, 2009

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Overview

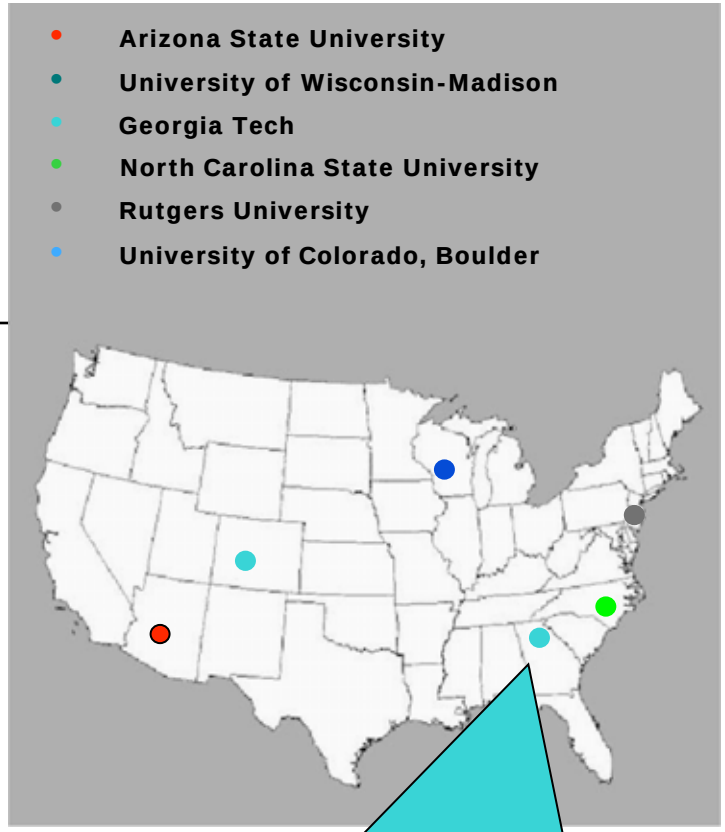
1. Introduction
   - Center for Nanotechnology in Society (CNS-ASU)
   - Georgia Tech group
2. Trend in Nanotechnology Discovery
   - Characterizing the state of nanoscience
3. Early Nanotechnology Innovation
   - Where, who, and what?
4. Issues and Implications
5. Q&A

What is Nanotechnology?

- Science, engineering and technology of understanding and controlling matter at c. 1-100 nm* scale (= nanoscale)
- To develop materials, devices, and systems that have novel properties and functions due to their nanoscale
- Argued to be a transformative general purpose technology with fundamental technological, economic and societal consequences

*1 nanometer (nm) = 1 billionth of a meter

Center for Nanotechnology and Society (CNS-ASU)



MISSION

- Research the societal implications of nanotechnologies
- Train a community of scholars with new insight into the societal dimensions of *NSE
- Engage the public, policy makers, business, & *NSE researchers in dialogues about NSE's goals and implications
- Partner with *NSE laboratories to introduce greater reflexiveness in the R&D process

SPONSORSHIP: NSF 2005-2010+

Georgia Tech group:

- Q. Who is doing what kinds of *NSE research?
- Q. How is *NSE innovation occurring?
- Q. Actors & drivers? Technological, economic, and regional impacts?

*NSE = Nanoscale Science and Engineering)

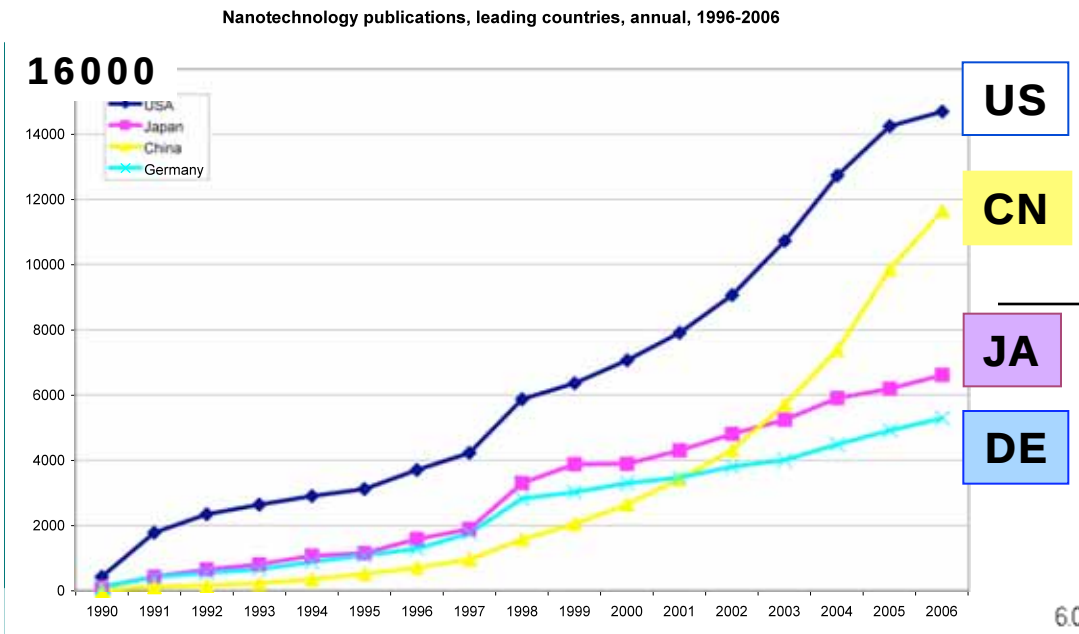
Georgia Tech group

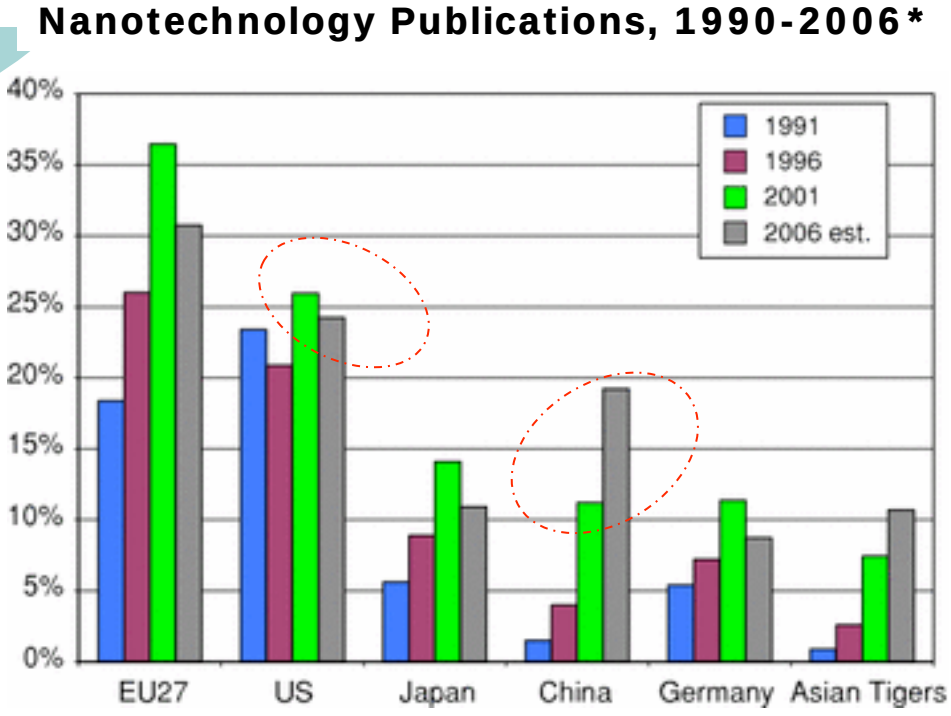
Core Resources:

- Refined two-stage two-stage bibliometric search method*
- Development of large-scale global databases of
  - Nanotechnology publications (c1.2 million, 1990-2008, including 508,000+ SCI)
  - 61,000 nano patents (70 patent offices, MicroPatents); + PATSTAT (1990-2008)
- Complementary data and tools (e.g. small nano-firm start-up data; MNE nano patent families)
- Field research and case studies

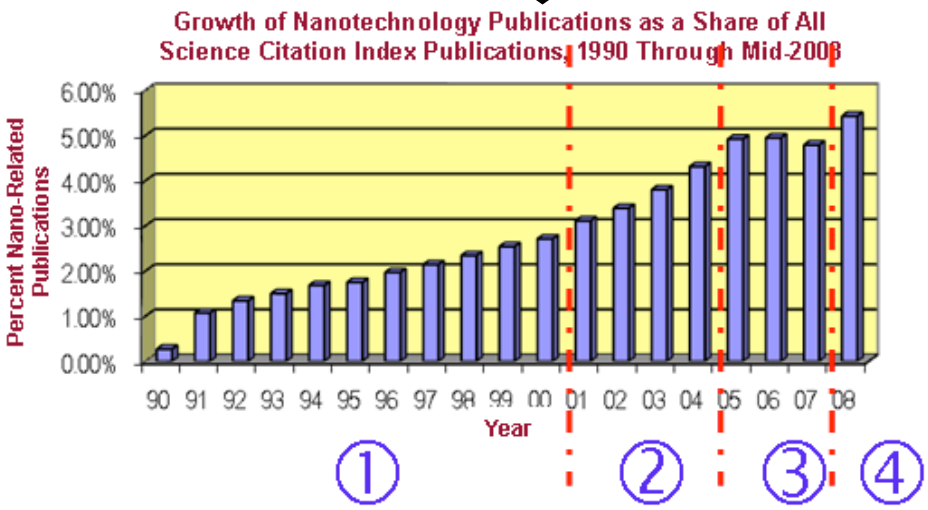
***Key Publication: Refining search terms for nanotechnology.**
Porter, Youtie, Shapira, Schoeneck. *J. NanoParticle Research*, 2008.

Trends in Nano Discovery:
Publications





Nano Share of Science (SCI) 1990-2008*

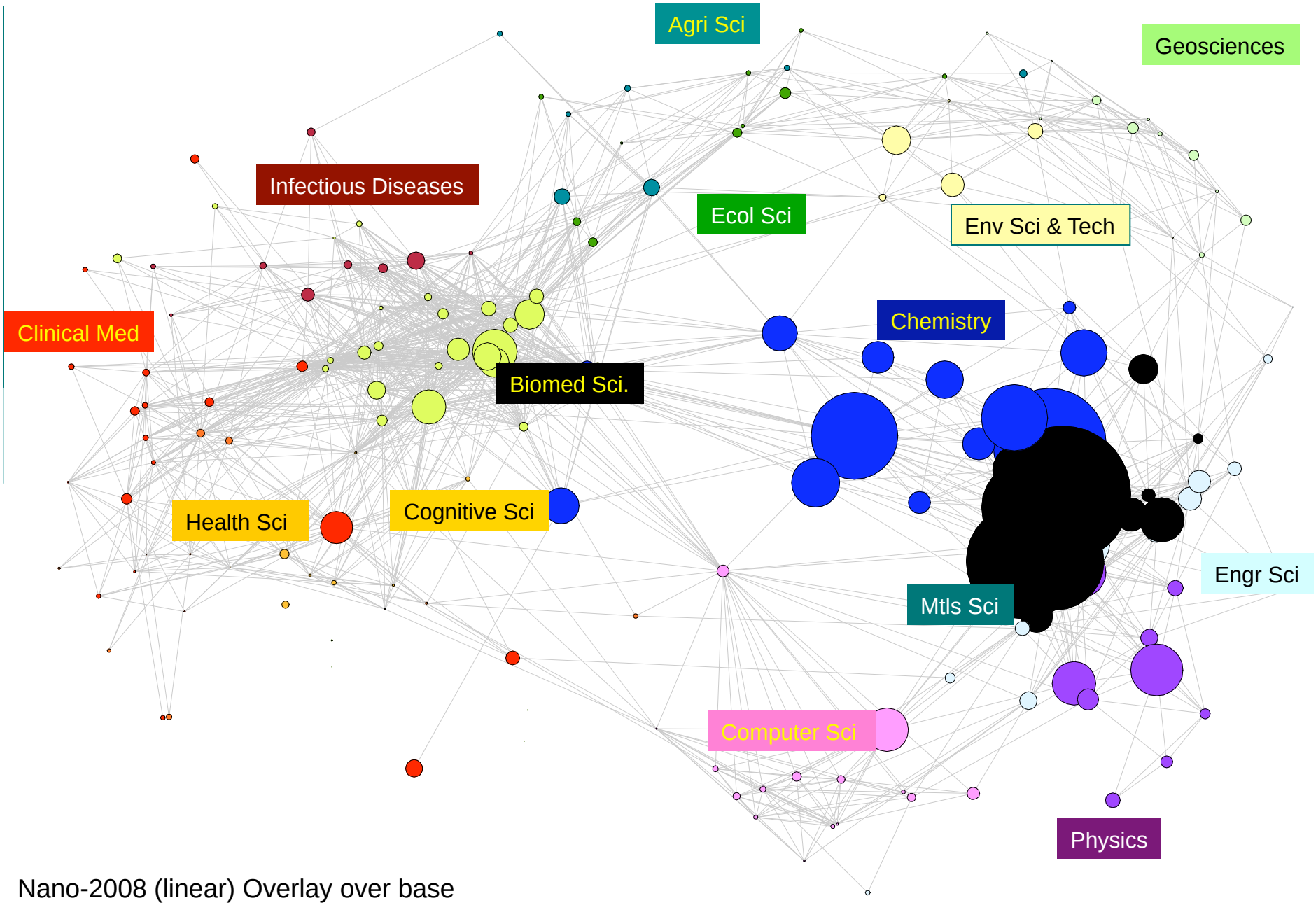


Based on all author affiliations. *estimated.
References: Youtie, J., Shapira, P., Porter, A., National Nanotechnology Publications and Citations, Journal of Nanoparticle Research, 2008; S. Carley, Nanotechnology Research Publication Databases, Updated to 2008, RTTA-1 Profile, 2008.

Trends in Nano Discovery:

Knowledge interchange

- Next slide overlays 2008 nano research (from an 8-module, Boolean search) in the Science Citation Index (SCI) on a base map of science
- Nano engages a wide swath of today's researchers! (~5% of SCI now)
- Following table shows that there is significant research knowledge interchange – nano is not confined within disciplinary "silos"



Nano-2008 (linear) Overlay over base
175 Subject Category Science Map
Leydesdorff&Rafols (Forthcoming) –

Reference: Porter, A.L., Youtie, J., How interdisciplinary is nanotechnology? J Nanoparticle Research, 2009 (Online First)

Pajek

Trends in Nano Discovery:

% of Nano Articles in each Macro-discipline (rows) citing a source in the Macro-discipline (Column)

# Pubs	Macro-Disciplines: Publications \ Cited	Mtls Sci	Chemistry	Physics	Biomed Sci	Engr Sci
19301	**Mtls Sci**	98	77	57	58	44
7020	**Chemistry**	91	96	53	77	33
2989	**Physics**	89	68	90	56	29
2647	**Biomed Sci**	51	83	24	94	19
2503	**Engr Sci**	95	74	48	54	81

Reference: Porter, A.L., Youtie, J., How interdisciplinary is nanotechnology? J Nanoparticle Research, 2009 (Online First)

Trends in Nano Discovery:

Changing nano shares

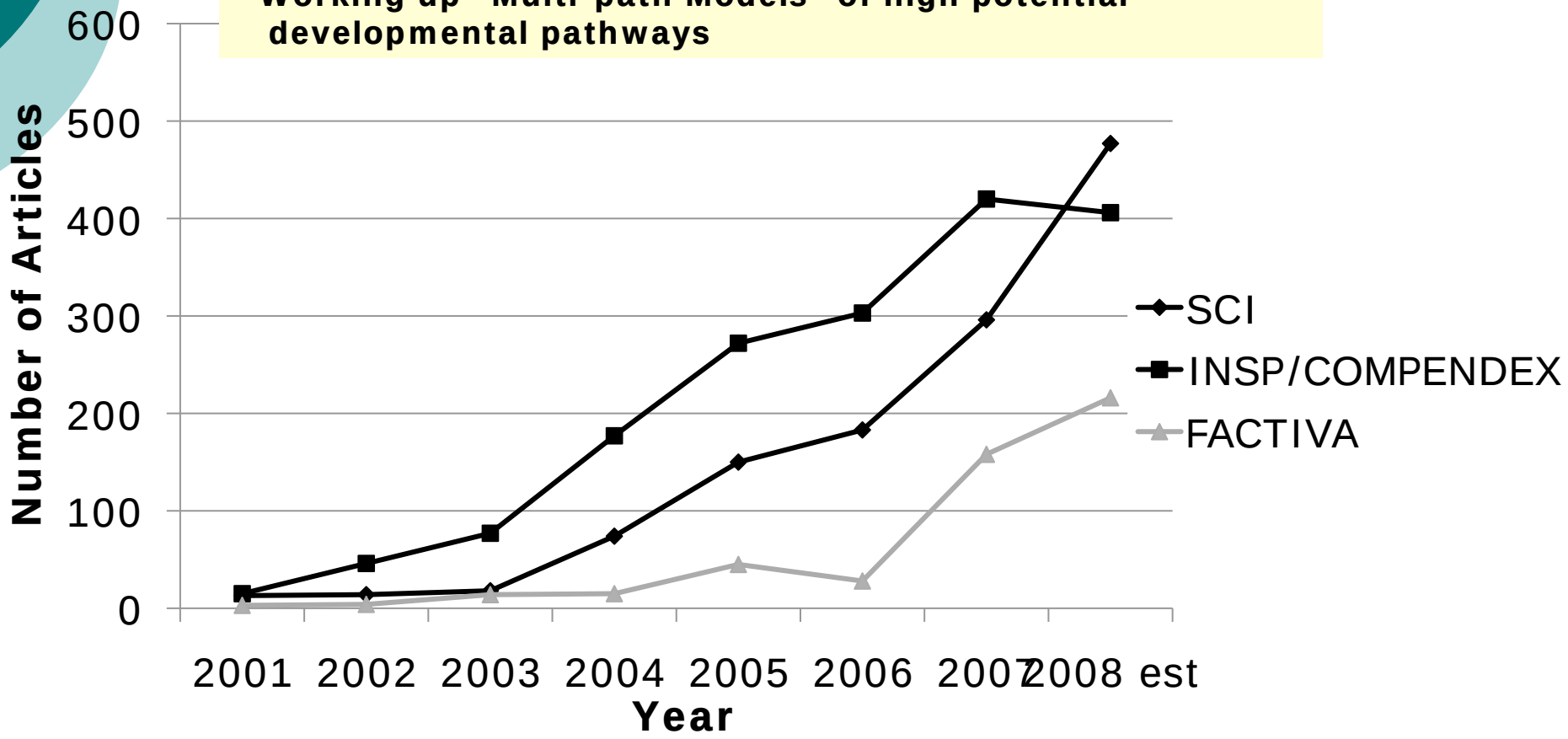
Subject Category	% of nano publications for year					% Change 1991-2008	2008 Rank
	1991	1995	2000	2005	2008		
Materials Science, Multidisciplinary	13.0	19.5	17.3	19.9	25.8	**+100%**	1
Physics, Applied	25.7	18.0	18.0	16.4	18.7	**-27%**	2
Chemistry, Physical	8.3	11.5	13.7	14.5	17.9	**+115%**	3
Physics, Condensed Matter	16.5	17.2	16.7	12.0	12.9	**-22%**	4
Nanoscience & Nanotechnology	n/a	n/a	n/a	n/a	12.6		5
Chemistry, Multidisciplinary	4.5	6.4	7.5	10.3	10.6	**+133%**	6
Polymer Science	4.7	5.2	5.2	6.5	6.2	**+32%**	7

Source: Analysis by the Program in Research and Innovation Systems Analysis, Center for Nanotechnology and Society (CNS-ASU) at Georgia Tech. Bibliometric definition as in Porter et al. 2008. SCI nanoscience/nanotechnology publications, 508,000, 1991-2008 (part-year).

Trends in Nano Discovery:

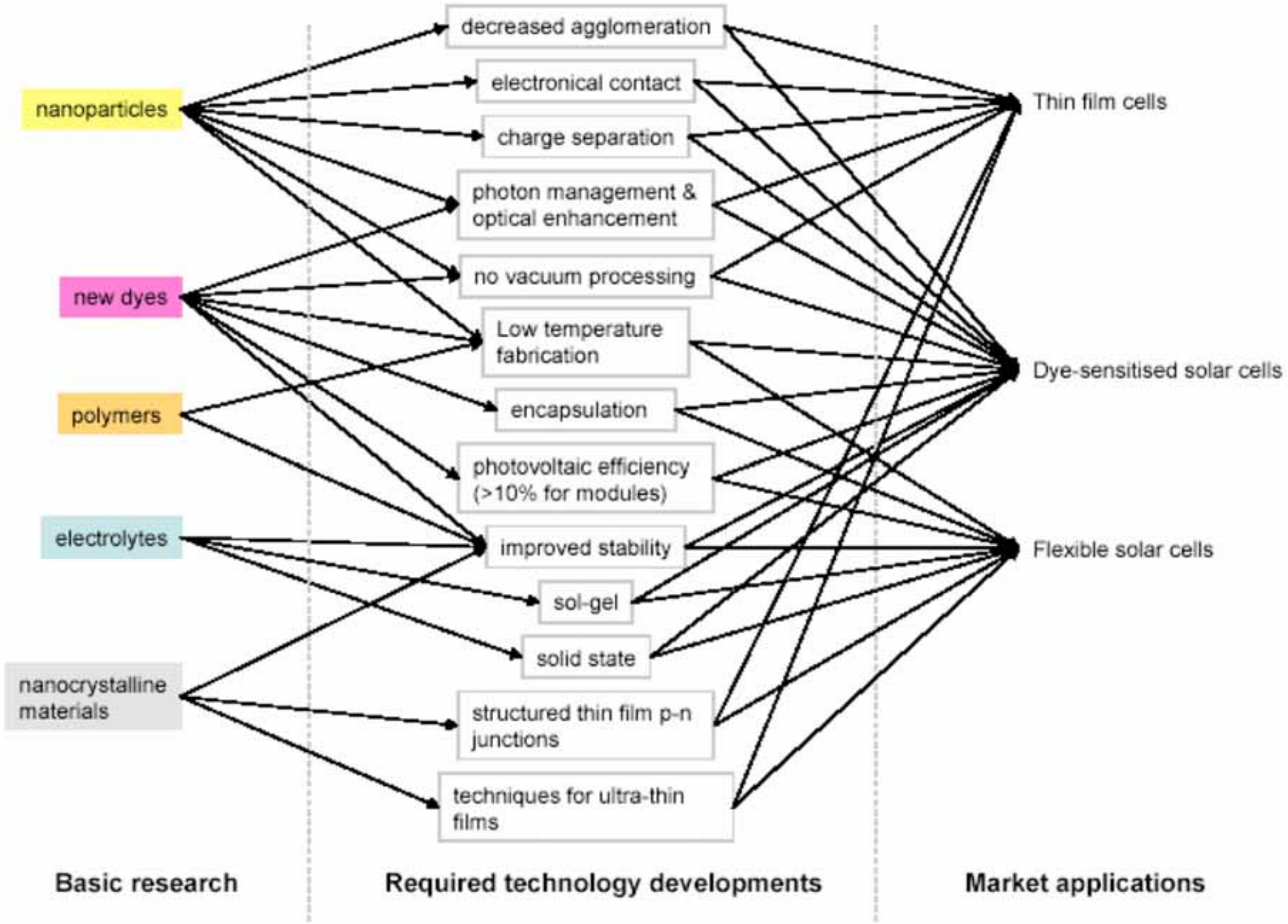
Anticipating breakthroughs - biosensors

Biosensor Trends (Lu Huang)
~ Fundamental Research; Engineering R&D; Business
Fit growth models to project
Working up "Multi-path Models" of high potential developmental pathways



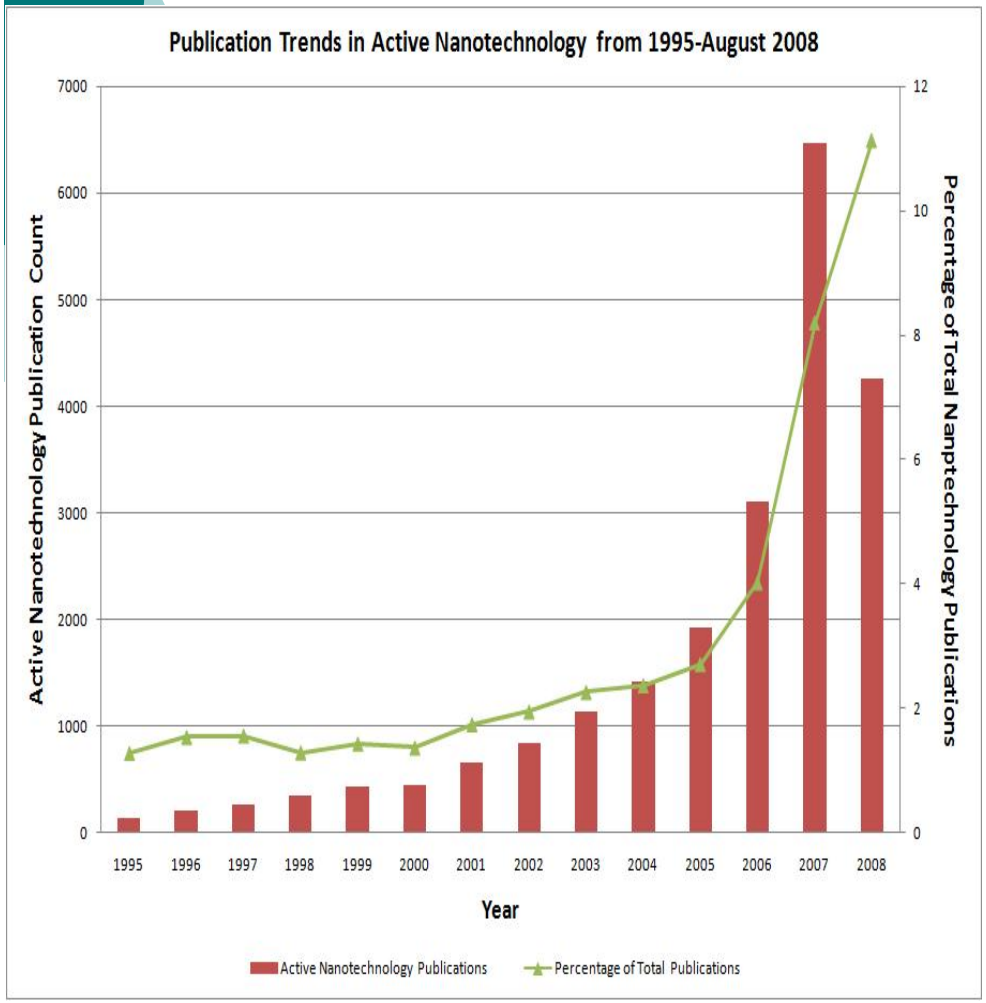
Prospects for Nano-enhanced Solar Cells (Ying Guo)

Basic research underway with the technology developments required to achieve the desired applications



Trends in Nano Discovery:

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
- **Next question:** How to interpret this shift?

Reference: Subramanian V, Youtie J, Porter A.L , Shapira P (2009) Is there a shift to "active nanotechnology"? (in preparation)

Trends in Nano Discovery:

What Products Can We Expect?

- **Remote Actuated Active Nanostructures**: Nanotechnologies whose active principle is remotely activated or sensed.
  - 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 those 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 and technologies to the nanoscale.
  - Molecular electronics
- **Hybrid Active Nanostructures**: Nanotechnologies involving uncommon combinations (biotic-abiotic, organic-inorganic) of materials.
  - 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 and plastic coatings which on specific triggers, repair damage caused by corrosion, mechanical damage, etc.

Early nanotechnology innovation

Nano products that exist today

- Sunscreen, cosmetics (titanium dioxide)
- Stain-resistant clothing
- Anti-bacterial socks, dressings, ointments (silver nanoparticles)
- Sports equipment (carbon nanotubes)
- Household appliances, air filters
- Cleansers and polishes
- Semiconductors and processors
- Paints, finishes, sealants, adhesives
- Drug delivery (micellar nanoparticles)

Ref: 800+ nano-based consumer products on the market Project on Emerging Technologies (2009)

Current nano-enabled product:

Hot-water dispenser

- Nano-coated/alloy heating element
- Boils fast (6 secs), saves energy

Current nano-enabled product:
Manufacturer: Wbnami (Shenzin, China)

Hot-water dispenser

- Nano-coated/alloy heating element
- Boils fast (6 secs), saves energy
- Claimed to improve water quality

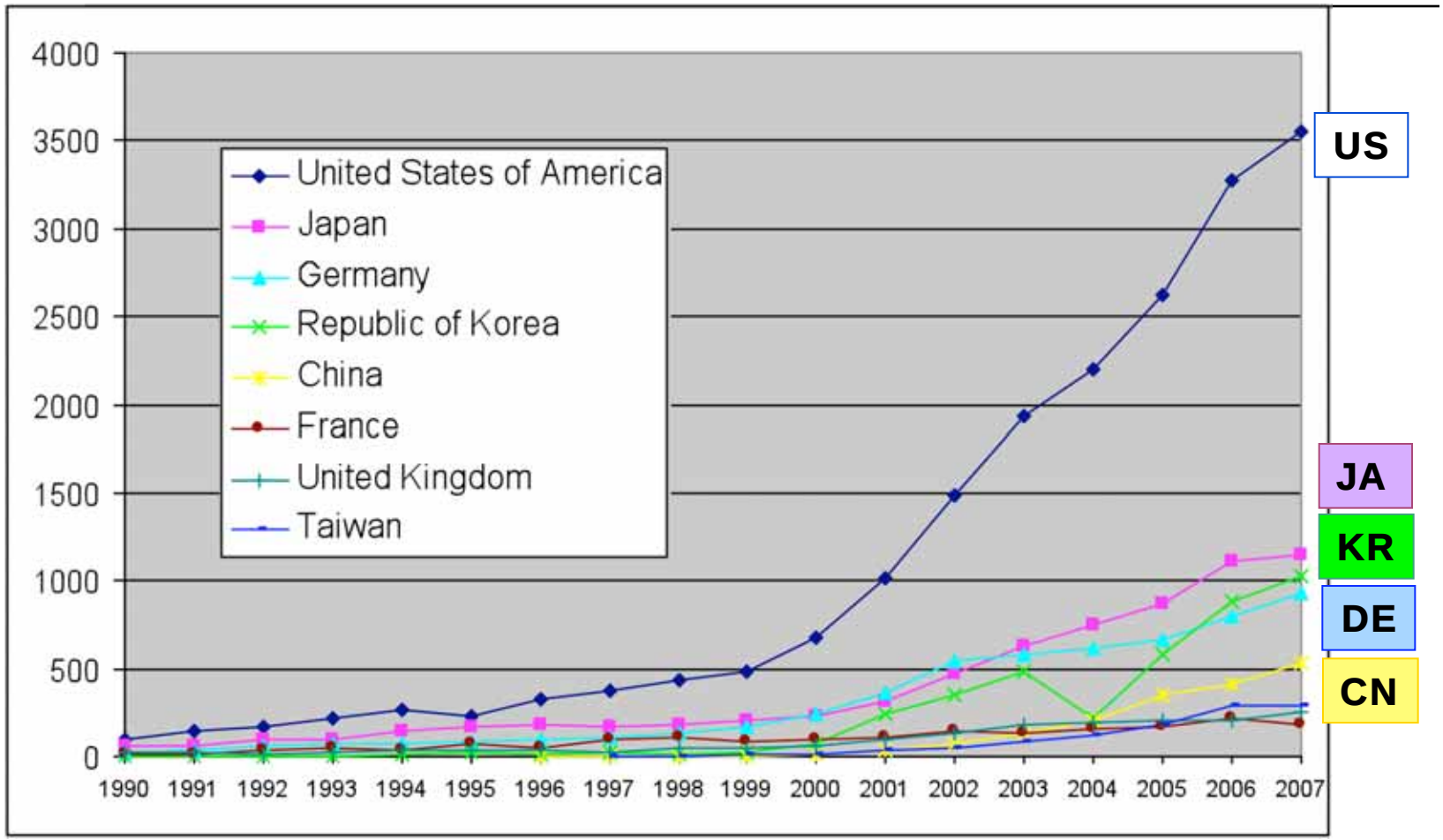
Highlights

- Nano applications ⇨ existing products
- Nano manufacturing jobs ⇨ globalized
- Production volume ⇨ next-round R&D
  - VCR analogy?

- Validation of performance claims and testing

Early nanotechnology innovation

Growth of nano patenting



Source: PATSTAT. Patent records by year, 1990-2007 by applicant country.
Note: Initial analysis, subject to revision. Nanotechnology definition as in Porter et al. 2008

Early nanotechnology innovation

US nano patents (USPTO granted)

	2001-02	2005-06
Top-10 US primary classes	Share of total US patents	
257-Active solid-state devices	4.9%	8.1%
428-Stock material or miscellaneous articles	7.1%	7.2%
438-Semiconductor device manufacturing: process	8.7%	6.9%
424-Drug, bio-affecting and body treating compositions	6.0%	6.6%
435-Chemistry: molecular biology and microbiology	4.2%	4.8%
313-Electric lamp and discharge devices	2.3%	3.4%
423-Chemistry of inorganic compounds	2.1%	3.2%
524-Synthetic resins or natural rubbers	2.7%	2.9%
250-Radiant energy	2.7%	2.4%
427-Coating processes	2.5%	2.4%
All USPTO nano patents (N)	3865	9275

Sectors:
Electronics
Materials
Medical
Chemical
Energy

	2001-02	2005-06
Top-10 assignee countries	Share of total US patents*	
US	73.0%	58.0%
Japan	6.7%	12.6%
China (including Taiwan)	2.5%	6.8%
S. Korea	1.0%	5.1%
Germany	3.1%	4.9%
France	5.1%	3.5%
Netherlands	0.8%	1.6%
Canada	0.9%	1.6%
UK	1.2%	1.0%
Switzerland	0.9%	0.8%
Total records with assignee	1818	3522
	(47% coverage)	(38% coverage)

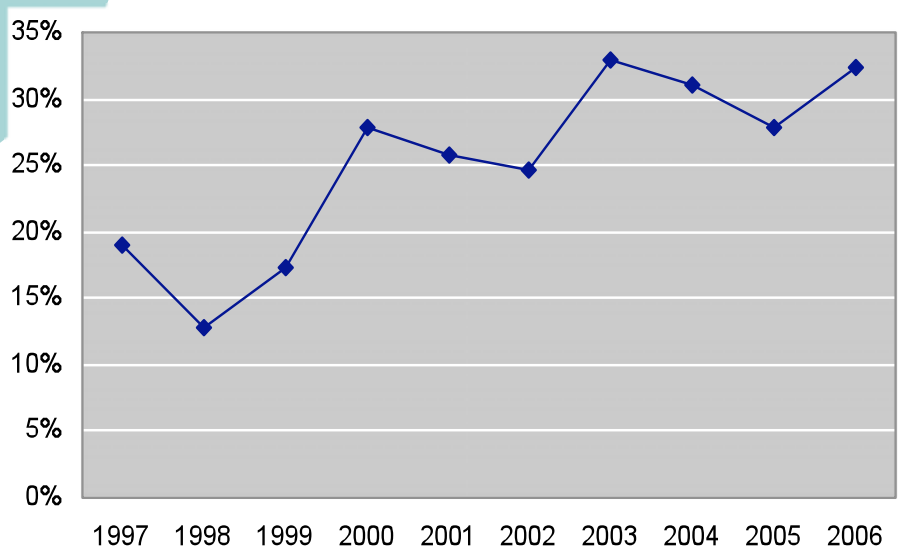
Shares:
US -
Asia + + +
Europe + / -

Source: Georgia Tech analysis of MicroPatents Nanotechnology definition as in Porter et al. 2008

Early nanotechnology innovation

Small Businesses: International Nano Patent Strategies

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



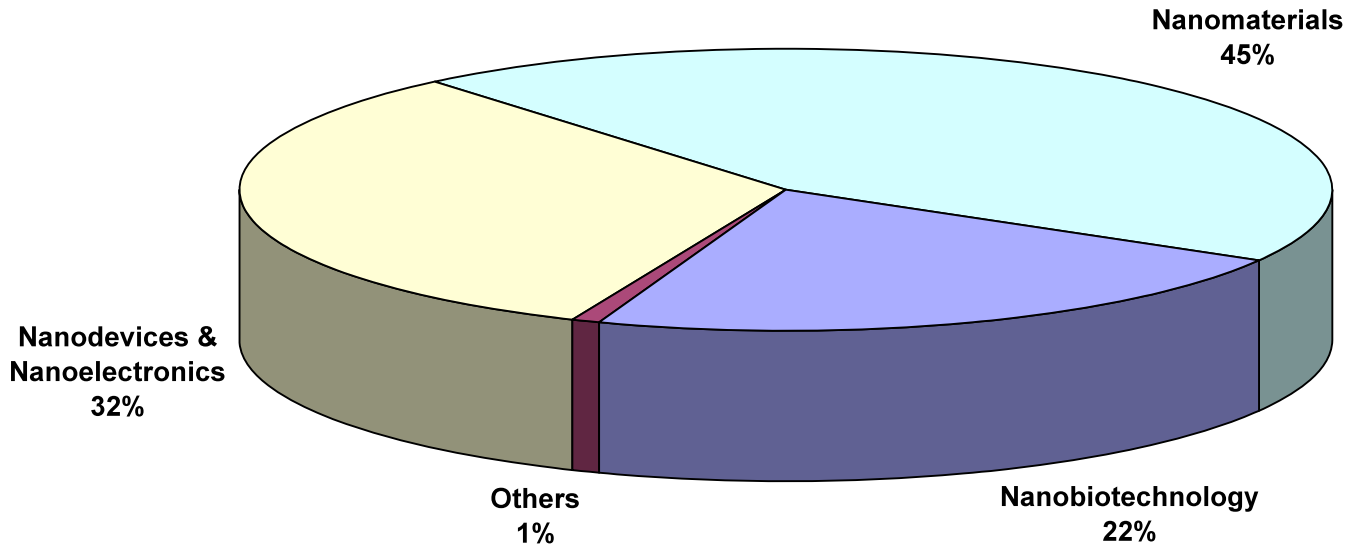
* SBA standard definition, less than 500 employees

Source: Andrea Fernández-Ribas with research assistance Ronak Kamdar, Georgia Tech CNS-ASU Group. Additional support obtained through 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

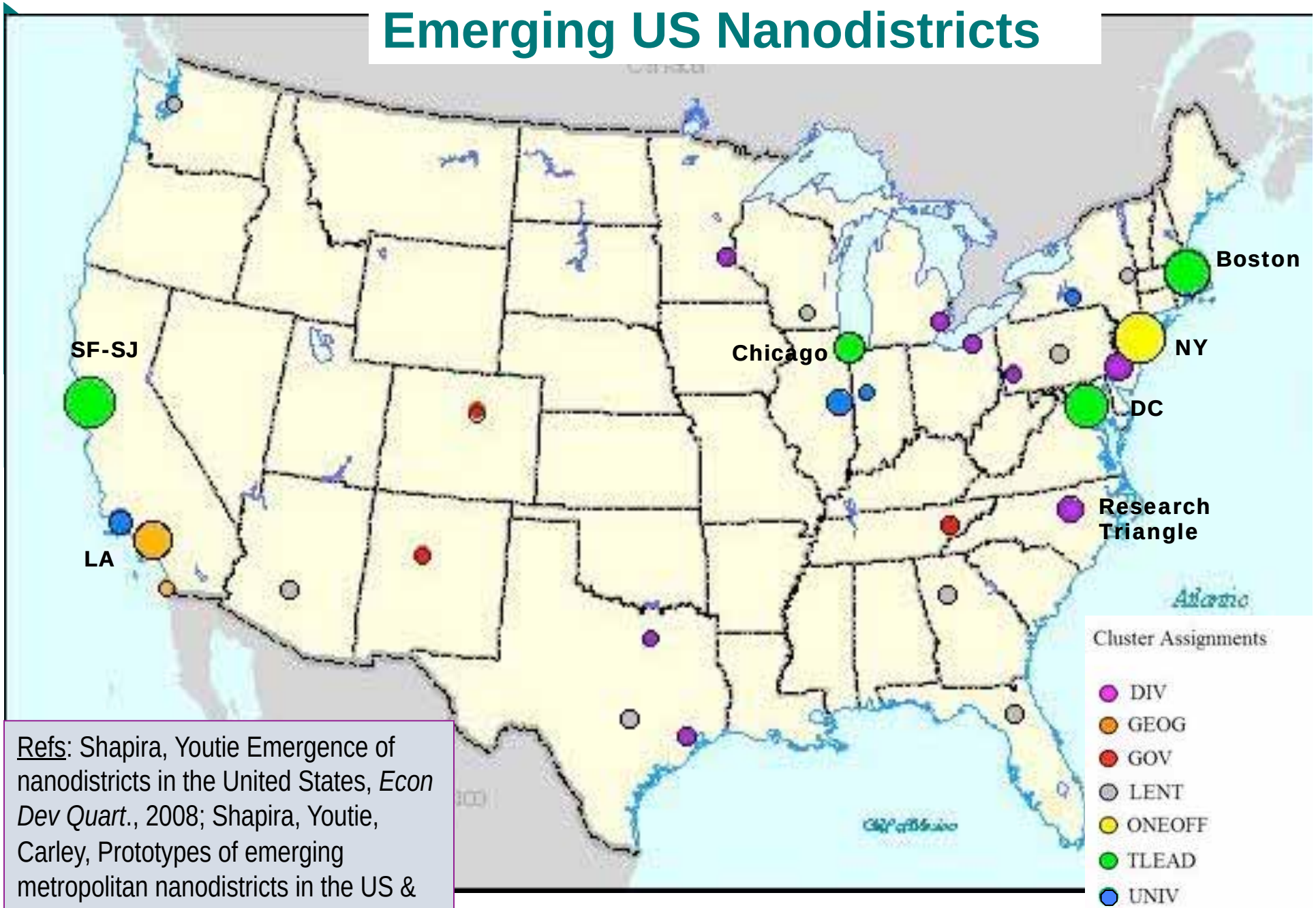
Early nanotechnology innovation

New nanotechnology-based firms in US (NNBFs)



Source: Analysis of 230 US NNBFs, 1990-2005, by J. Wang (Georgia Tech doctoral thesis, 2007). See also: Wang, J., Shapira, P., Partnering with Universities: A Good Choice for Nanotechnology Start-up Firms? [under review]

Emerging US Nanodistricts



Refs: Shapira, Youtie Emergence of nanodistricts in the United States, *Econ Dev Quart*., 2008; Shapira, Youtie, Carley, Prototypes of emerging metropolitan nanodistricts in the US & Europe (*Annales*, forthcoming)

Early nanotechnology innovation

Issues: Multiple uncertainties

- **Scientific uncertainty** (where is the science going, what will the applications be, and in what time frame);
- **Technological uncertainty** (will nano-enabled applications be scalable, reliable, better then conventional technologies);
- **Safety** (will nano-enabled applications be safe? the science is uncertain); & life-cycle uncertainty (even if declared safe now, will there be a problem in future, cf. asbestos, as scientific knowledge about effects evolves);
- **Consumer acceptance** (will consumers accept nano-enabled applications, under conditions of debate about safety – will all nano applications be tarred);
- **Regulatory uncertainty** (regulation is a known problem in nano, but there is uncertainty as to how regulations will evolve);
- **Labeling uncertainty**: What is a nano product?
- **Market and financial uncertainty** (will there be demand, how can we finance, esp. given current recession);
- **Competitive uncertainty** (there are many players in the marketplace, and players from new countries).

Prediction: Fundamental nano applications will take longer; safety & consumer concerns about nano will arise quickly

Early nanotechnology innovation

Policy Implications – for the US

- **Address uncertainty**
  - Regulatory development
    - US & International
  - Toxicology & other health & safety studies
- **Address implementation environment**
  - Not just research, but also commercialization
    - Role of states
  - Not just high-tech, but also mature industry
- **Ongoing research & dialogue**
  - Anticipate implications of nanotechnology

More information

- Web sites:
  - http://cns.asu.edu/
  - http://www.nanopolicy.gatech.edu

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