Nanotechnology

Professor Daniel Mittleman

Richard E. Smalley Institute for Nanoscale Science and Technology

daniel@rice.edu

Rice University and the Smalley Institute

- Independent & Private
- 650 full-time faculty
- 423 part-time and adjunct
- 3485 undergraduates
- 2275 graduate students

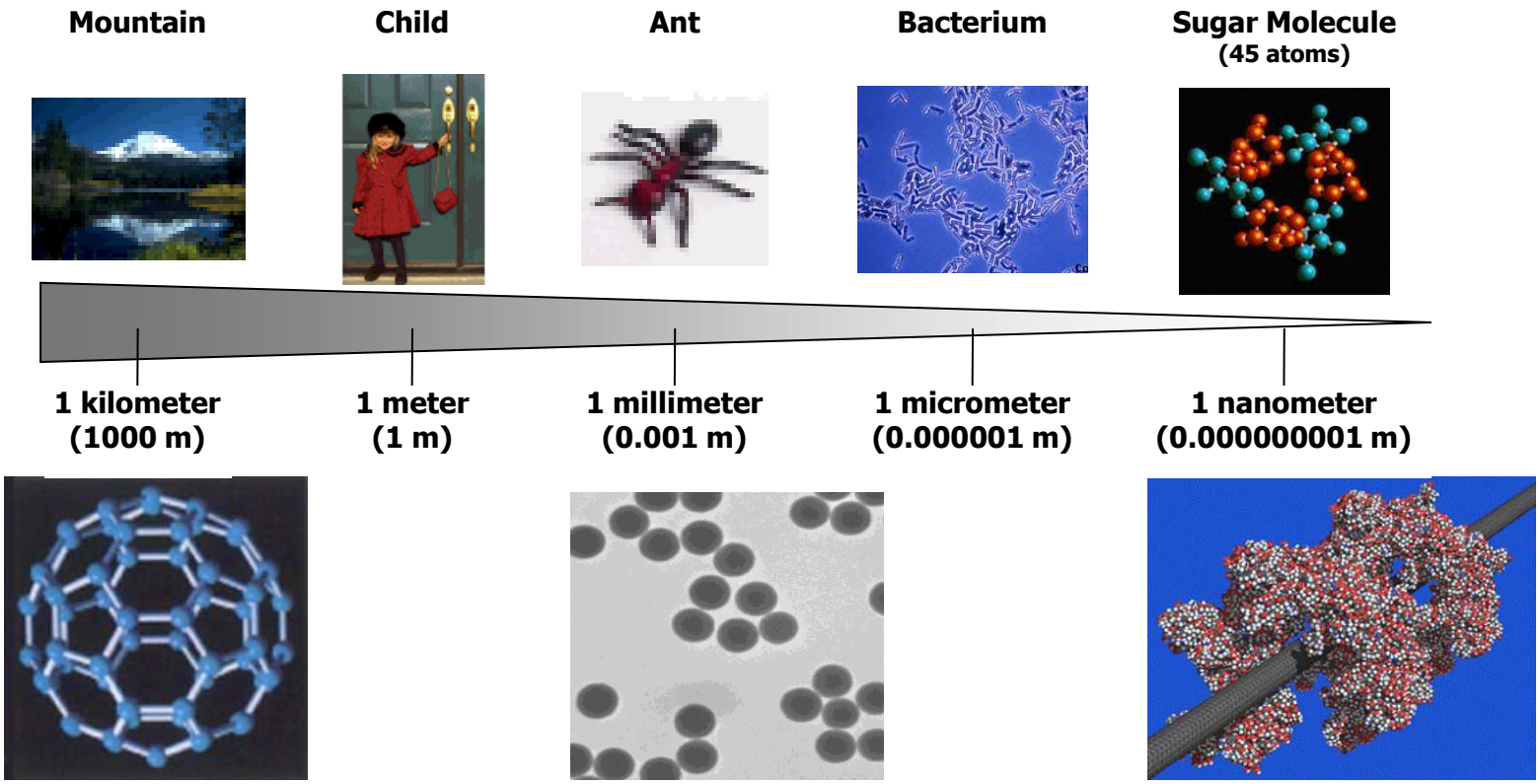
Smalley Institute
For Nanoscale Science and Technology at Rice University

- 1993 - Conceived by Prof. Richard Smalley and approved by Board of Governors – 1st in the world
- 1996 – Curl & Smalley win Nobel Prize in Chemistry
- 1997 – New building is dedicated – Dell Butcher Hall
- 2002 – New CNST Director – Wade Adams
- 2005 – Name changed to honor Richard Smalley
- 2012 – New SINST Director – Daniel Mittleman

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

What is Nanotechnology?

Nanotechnology is the study and use of materials with nanometer-scale dimensions.



LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

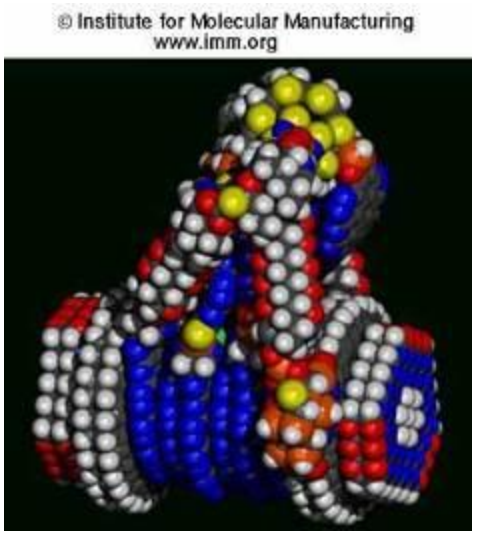
Ancient Nanotechnology?

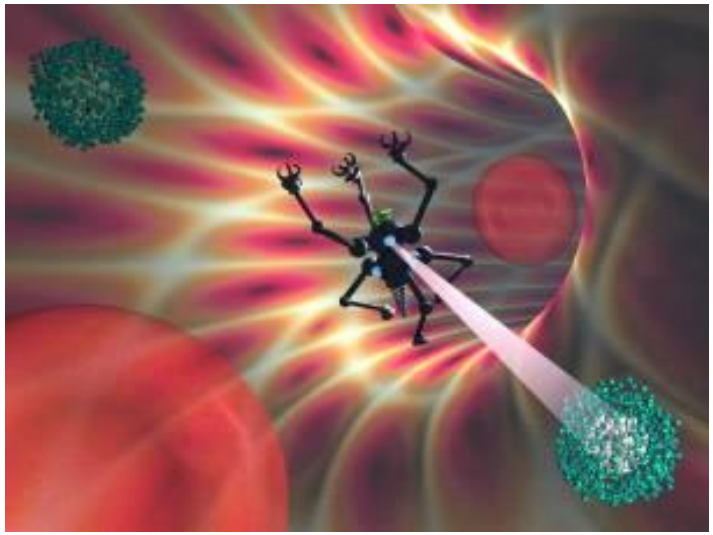
- Gold colloids in stained glass
- Carbon black in tires
- Colloid science for food products

Pre-1980s: people who made materials did "nano" but didn't know it

Nanotechology hype begins – 1980s

- Drexler 'Engines of Creation' – a book about assembling matter on the nanoscale
- 'Nanotechnology', the term, was associated with:





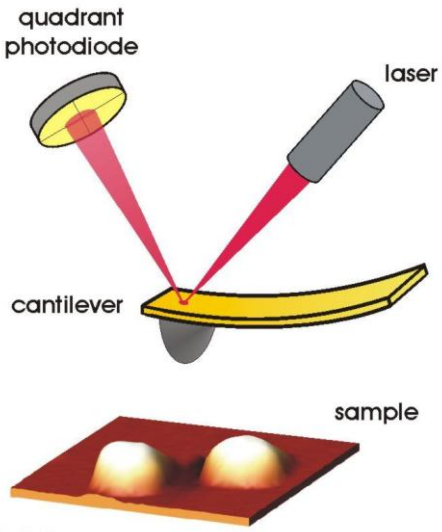
nanoscale robots, fantastical science fiction, **bad science**

1980s: Nanotechnology shunned by scientists, nanoscience embraced

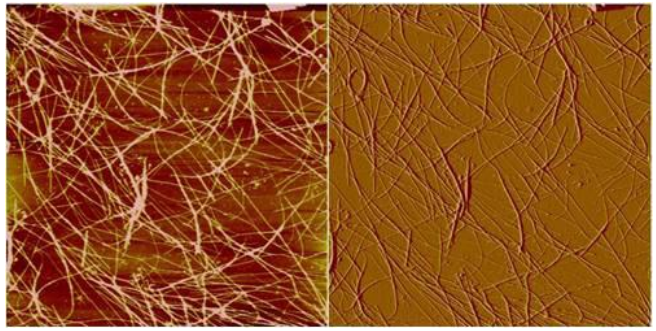
LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Nanotechnology started when we saw it

Pre-1990 – black powder?



Atomic force microscope

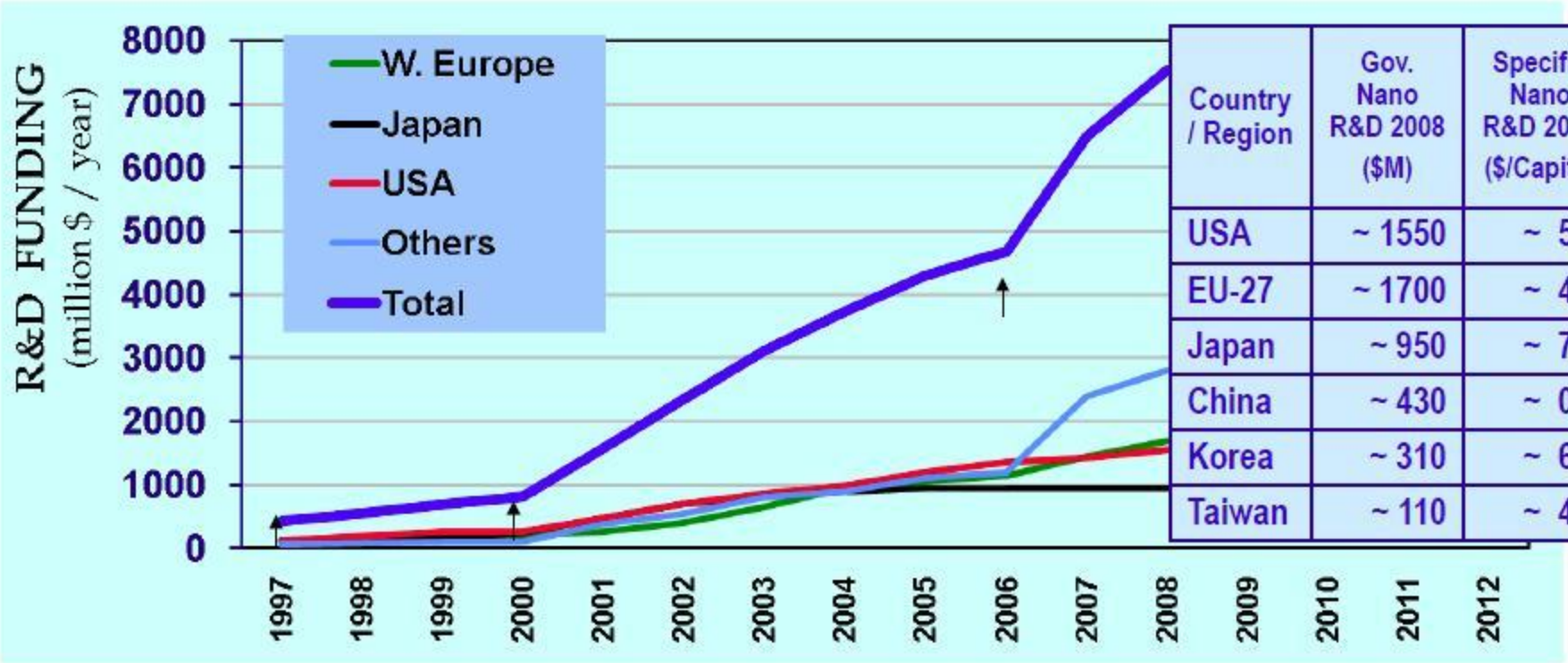


Hey! There are nanotubes!

1990s: Methods to image and study the nanoscale world ushered in nanotechnology – we began to control nano-matter precisely.

LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

National Nanotechnology Initiative



Country / Region	Gov. Nano R&D 2008 ($M)	Specific Nano R&D 2008 ($/Capita)
USA	~ 1550	~ 5.1
EU-27	~ 1700	~ 4.6
Japan	~ 950	~ 7.3
China	~ 430	~ 0.4
Korea	~ 310	~ 6.0
Taiwan	~ 110	~ 4.5

Seed funding 1991 - 1997

NNI Preparation vision/benchmark

1st Generation products passive nanostructures

2nd Generation active nanostructures

3rd Generation nanosystems

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

M. Roco, NSF

NNI: Where is the funding going?

NNI funding 2009 - present

Table 1. National nanotechnology initiative funding for select agencies 2009–2013 (dollars in millions)

Agency	2009	2009 Recovery	2010	2011	2012 Estimate**	2013 Proposed
Department of Energy (DOE)	333	293	374	346	315	443
National Science Foundation (NSF)	409	101	429	485	426	435
Department of Health and Human Services (HHS)/National Institutes of Health (NIH)	343	73	457	409	410	409
Department of Defense (DOD)	459	—	440*	425	361	289
Department of Commerce (DOC)/ National Institute of Standards and Technology (NIST)	93	43	115	96	95	102
National Aeronautics and Space Administration (NASA)	14	—	20	17	23	22
Environmental Protection Agency (EPA)	12	—	18	17	18	19

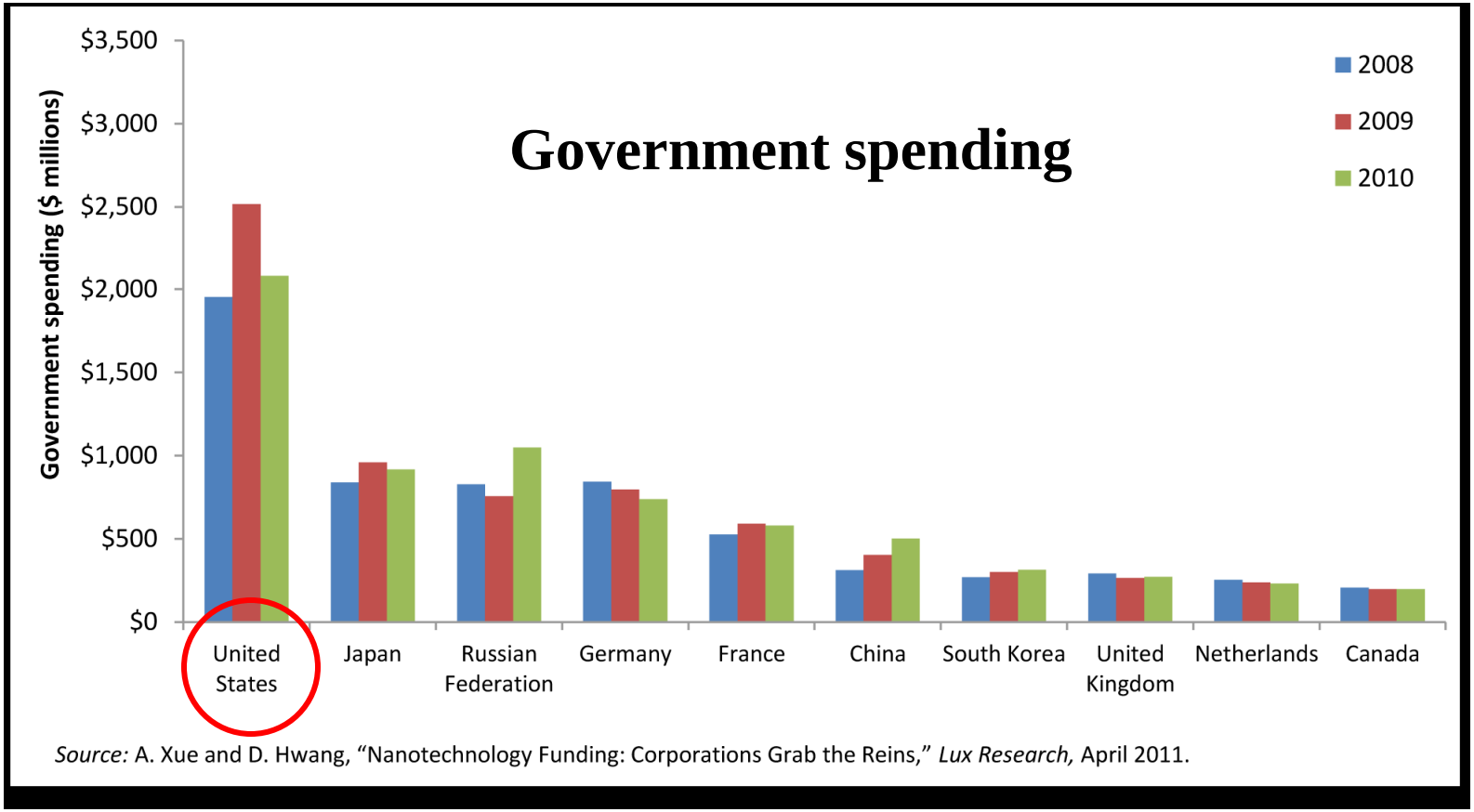
* Includes $75 million in congressionally directed funding that is outside the NNI plans.

** Based on FY 2012 appropriated levels.

Source: PCAST NNI summary report, April 2012

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

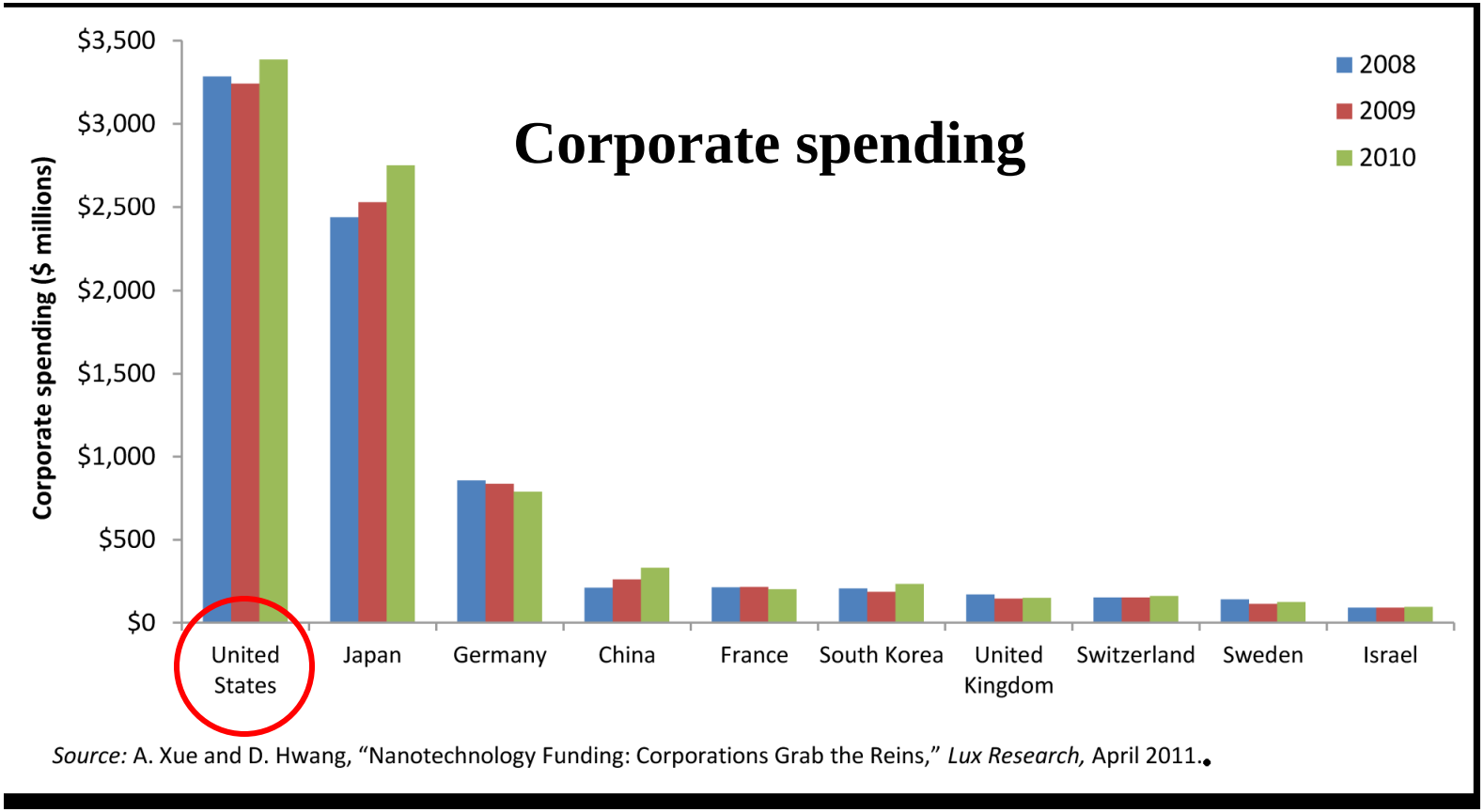
US remains a leader



Source: A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research,* April 2011.

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

US remains a leader

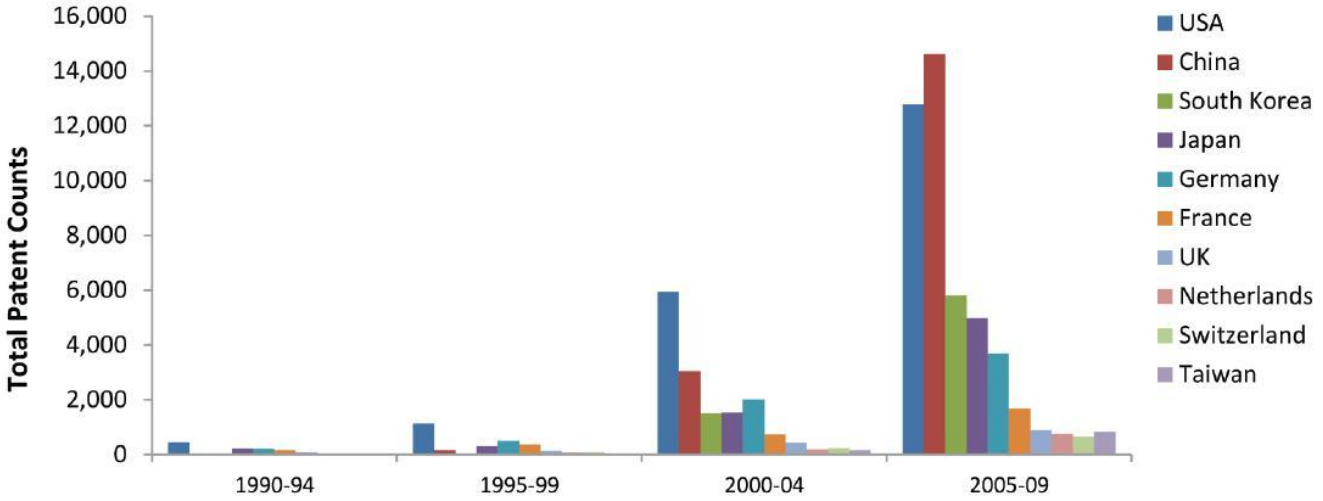


Source: A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research,* April 2011.

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Innovation is worldwide

Figure 3. Counts of patent applications in nanotechnology in PATSTAT, by year and assignee country, 1990–2009



Source: L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2010]. PATSTAT stands for the Patent Statistical Database, which is maintained by the European Patent Office.

Note: Based on definition of "nanotechnology" by A. L. Porter, J. Youtie, P. Shapira, and D. Schoeneck, "Refining Search Terms for Nanotechnology," *Journal of Nanoparticle Research*, 10 (5): 715–728.

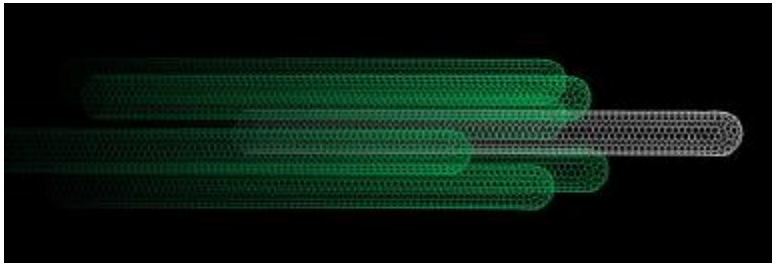
LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Nano is Now…

Product	"Nano Inside"	Value Added
	Active ingredient: Nanoscale TiO_2/ZnO	Transparency, UV absorbance
	Active ingredient: Carbon nanotubes	Strength and bounce
	Embedded with "Nano Whiskers"	Stain- and wrinkle-resistance

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Nanomaterial-containing products



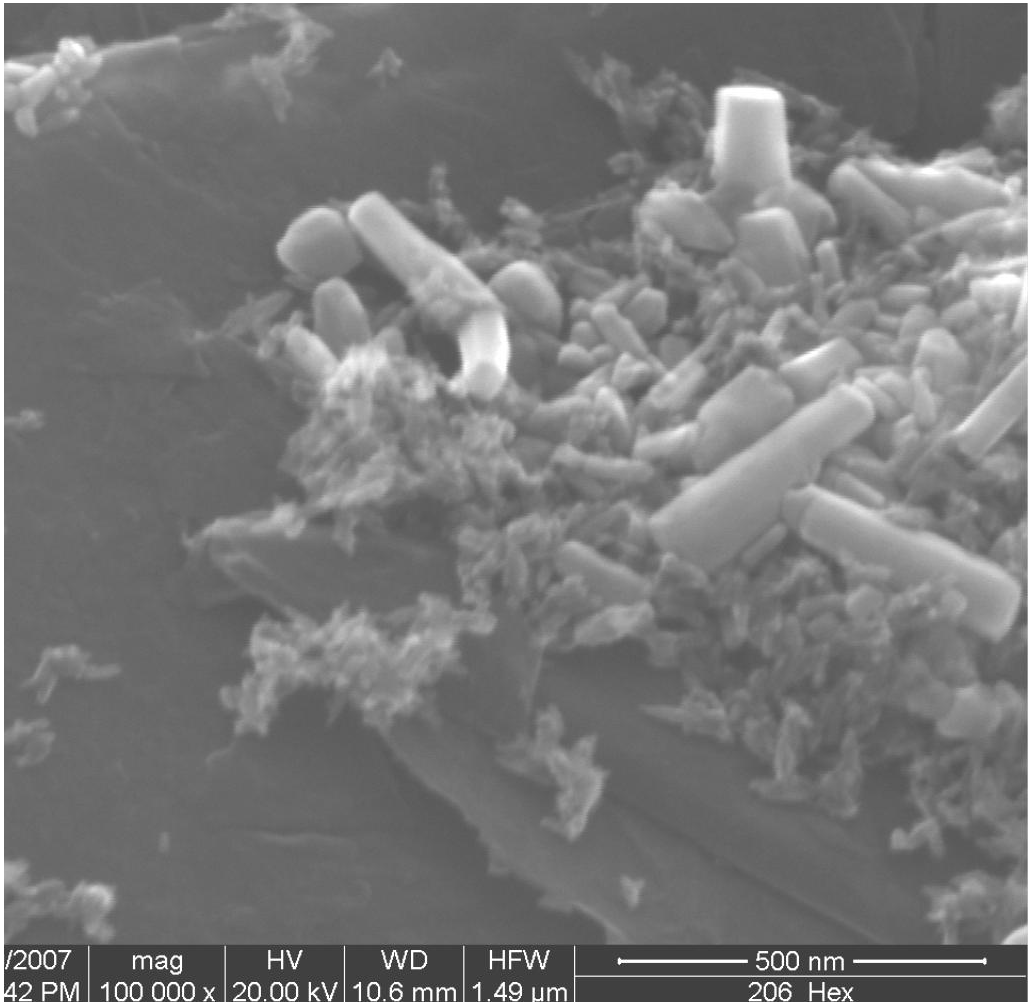
Babolat VS NCT Drive tennis racket

Maruman Exim Nano driver

Easton Stealth CNT baseball bat,
On sale at Academy Sports $379.99!!

LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

Nano is on YOU



LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

… and Nanotechnology is in the future

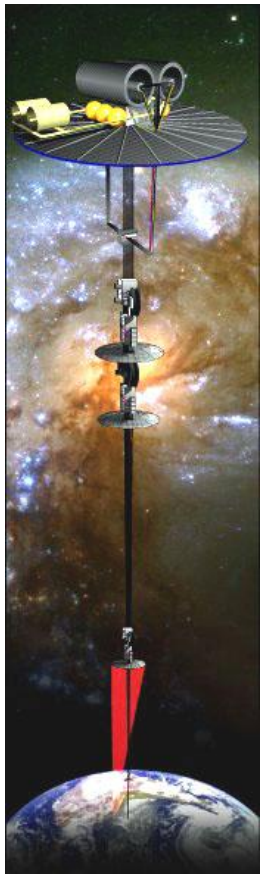
Battlesuit that monitors health, eases injury, communicates & enhances performance

Able to leap tall buildings in a single bound?

Cancer detection and treatment in a single office visit

Hypospray: Nano Inside?

Elevator that ferries satellites, spaceships, and pieces of space stations into space

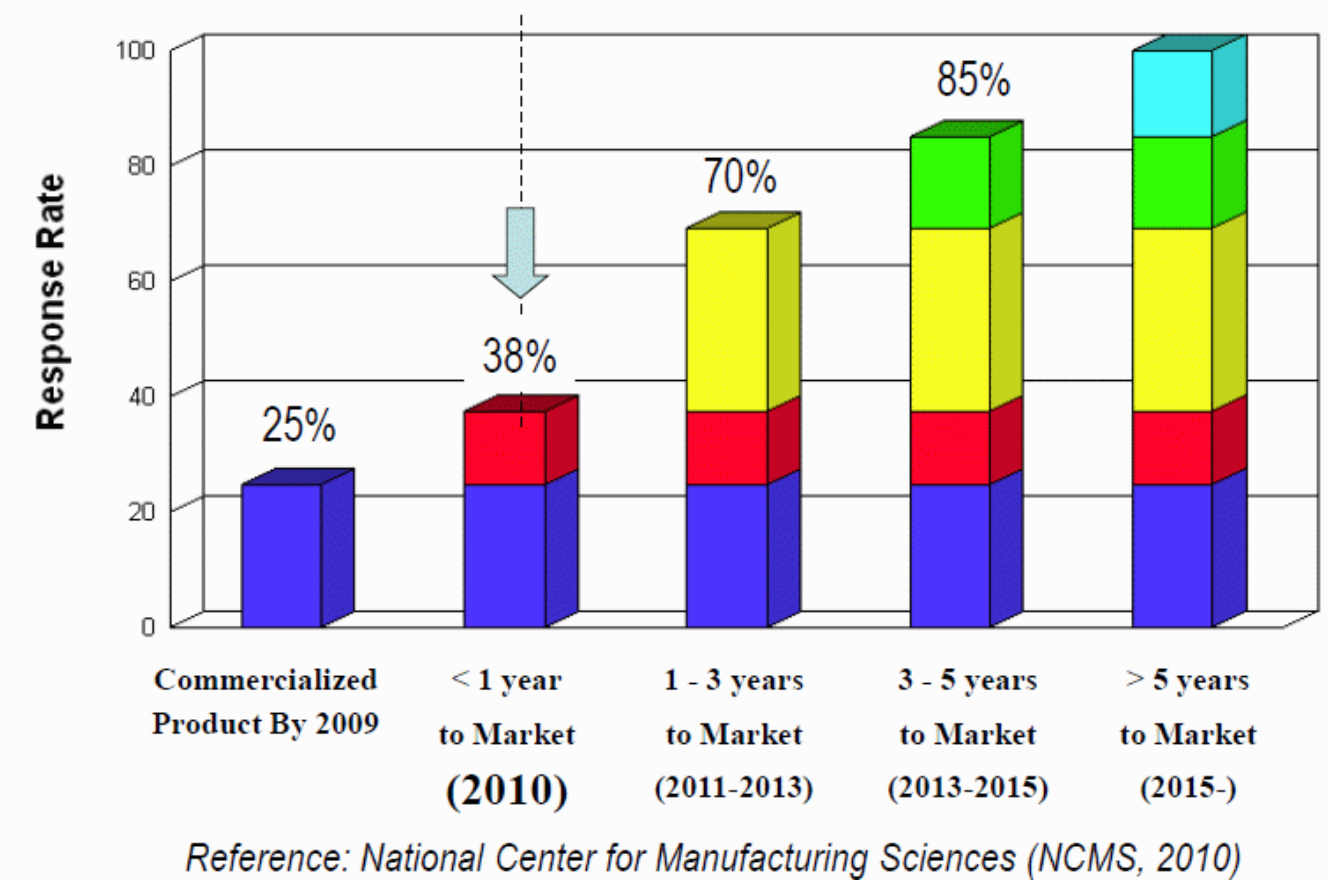


LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Many nano-products are on the way

A survey of 270 manufacturing companies (2009).

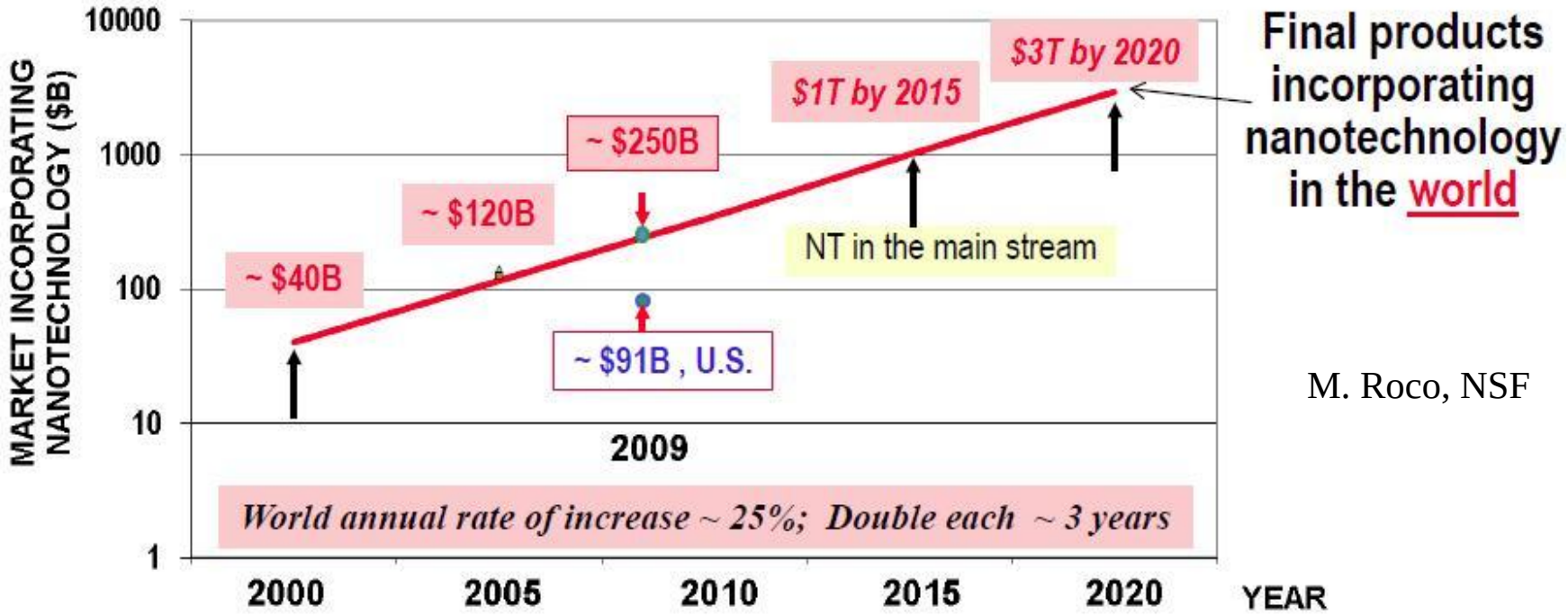
Every respondant will introduce a new nano-enabled product within five years.



Reference: National Center for Manufacturing Sciences (NCMS, 2010)

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

What's Coming for Nanotechnology



- Enormous government push in national initiatives
- International 'space race' mentality in investments
- Transition from laboratory into industry is in the early days

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Talking About Nanotechnology

"Nanotechnology now represents no less than the next industrial revolution"
Red Herring Dec 2001

"Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications"
Scientific American 2006

"Anything is nanotechnology that, under the rubric of nanotechnology, makes money."
Anonymous, Rice Alliance, 2006

Which definition is the 'BEST' ? Which is closest to a consensus?

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Defining Nanotechnology

From E56 ASTM terminology standard – free on www.astm.org

nanotechnology, *n*—A term referring to a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension between approximately 1 and 100 nanometers (nm). Such applications exploit those properties, distinct from bulk or molecular systems, of nanoscale components.

Materials are central in nanotechnology

Critical and defining dimension ~ 1 – 100 nm

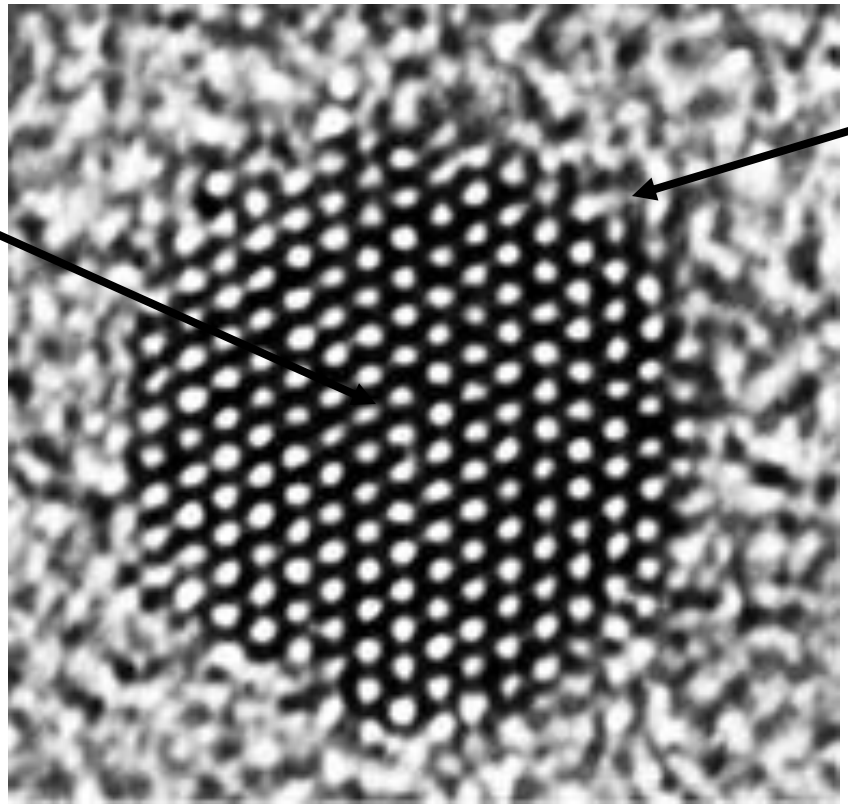
Really bizarre and unusual properties

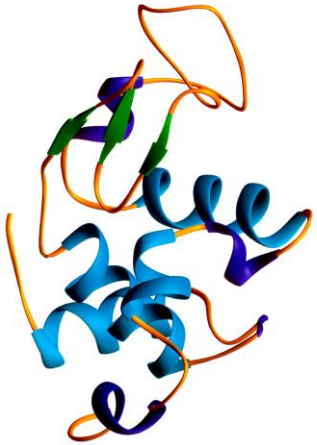
Nanotechnology contains stuff that is really small and strange

“The Most Beautiful Picture” - V. Colvin

Biologically Accessible

Huge surface areas





C-sixty
1 nm

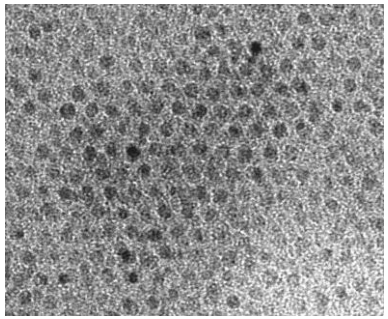
Cadmium Selenide nanocrystal
6 nm

Lysozyme
3 nm

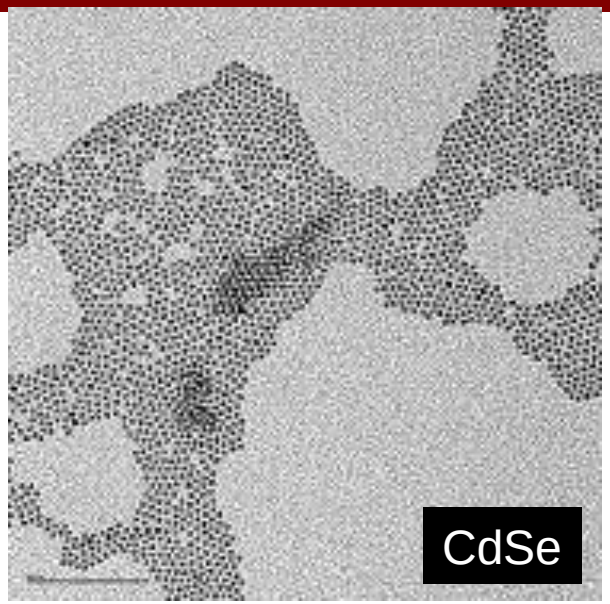
LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

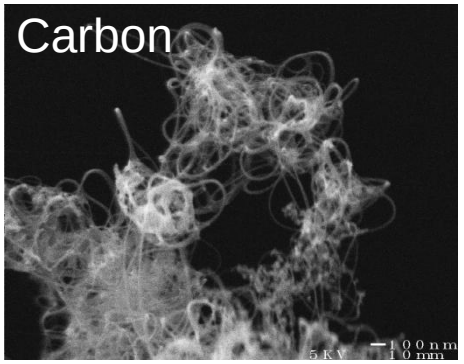
“NanoX”= any material you want

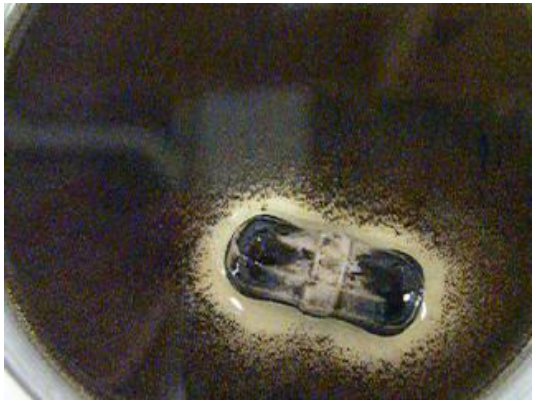
Fe_3O_4, d=4.5 nm

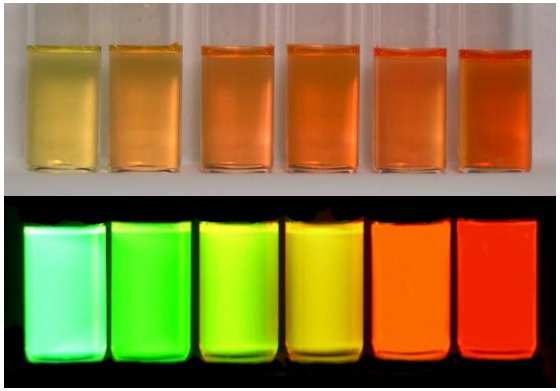


10 nm



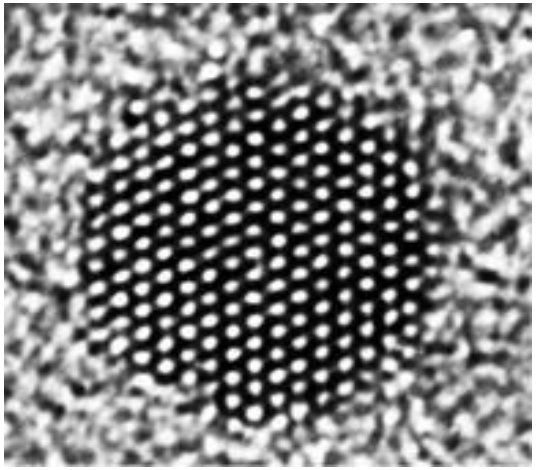




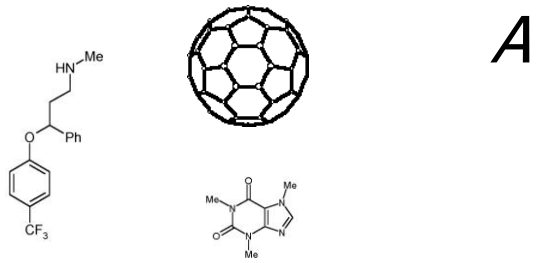


LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

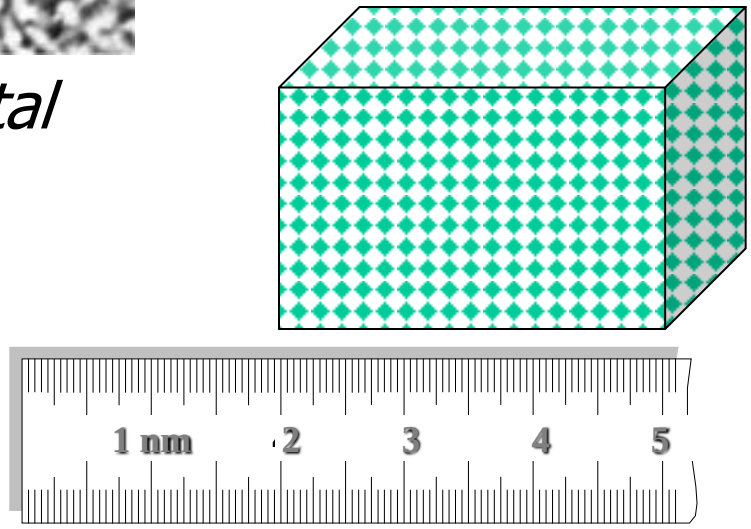
Nanomaterials :THEY ARE SMALL



A nanocrystal



Molecules



Solids

LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

SIZE and SCALE

1 nanometer = 10 angstroms = one billionth of a meter

If you were ten nanometers tall ….

… the nucleus of an atom would be far too small to see

… an atom would be the size of a quarter

… a caffeine molecule would be the size of a guitar

… a cold virus would be the size of Yao Ming

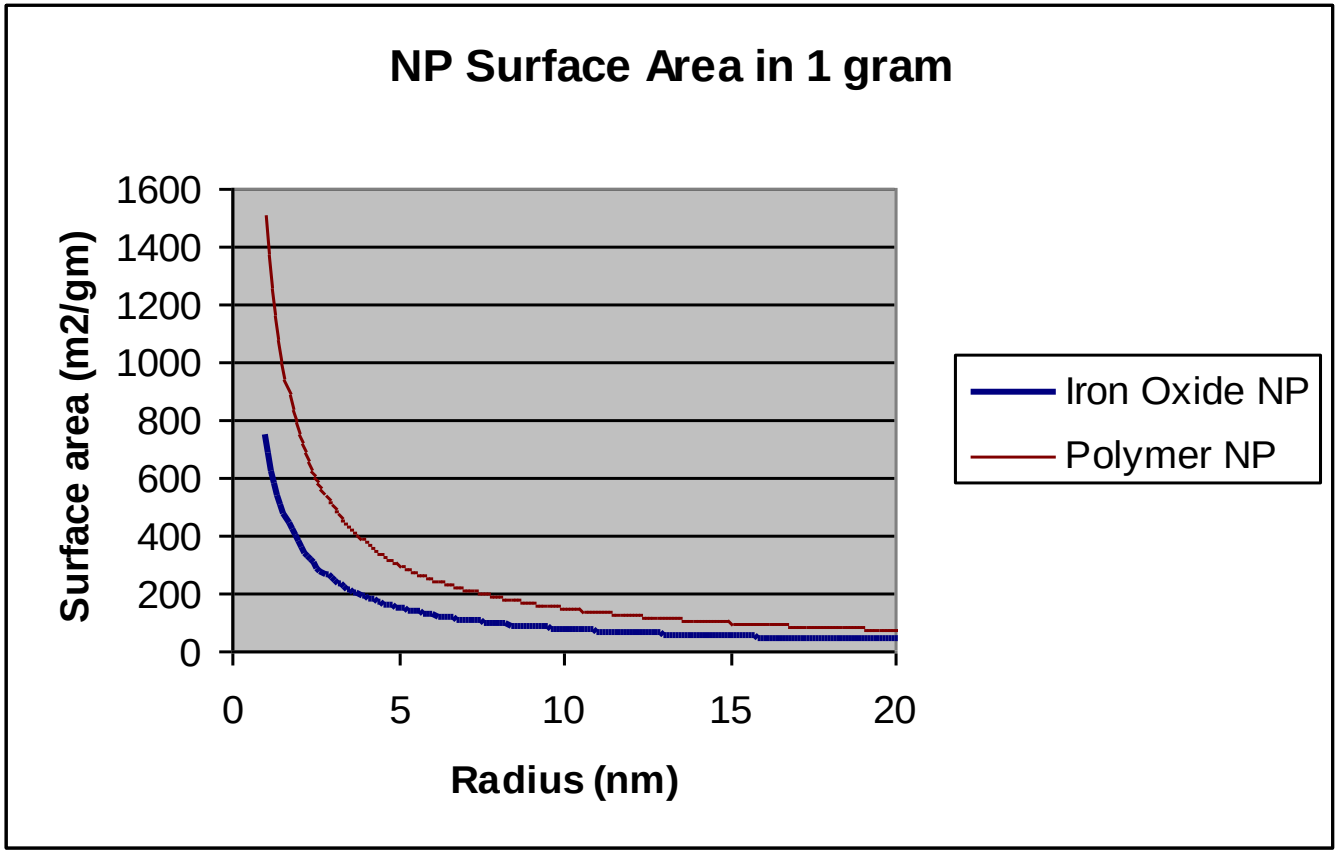
… a blood cell would be like an olympic swimming pool

… a human hair would have the diameter of a stadium

Nanotechnology exploits materials that are

- ***SMALL – one to one hundred nanometers***

More Surface Area

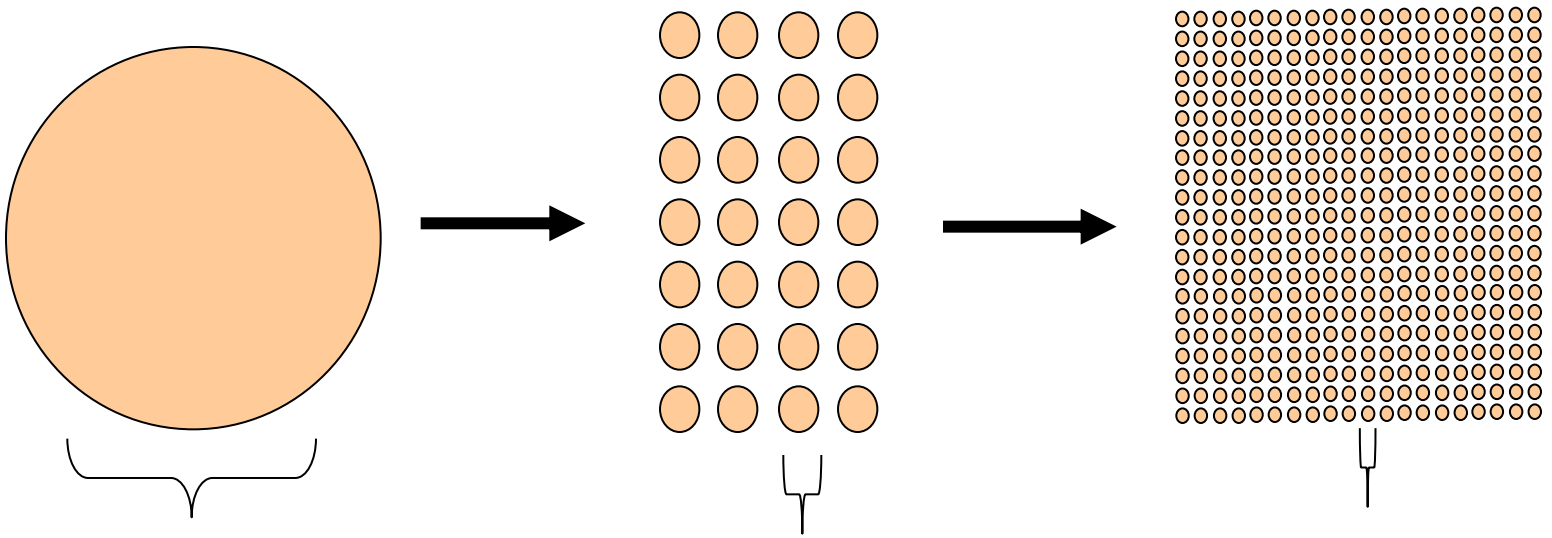


Surface area in 1 gram ~ $4 \pi r^2 / (4/3 \pi r^3 \cdot \text{density})$

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Small stuff, huge surface

One milligram of quartz sand:



100 micron
9 square cm

One hundred particles

1 micron
3 square meters

One billion particles

10 nm
300 square meters

One hundred trillion particles

Can you think of a technology that would benefit from materials with lots of surface area??

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

What color is gold?

Of course, gold is gold-colored. Until you make it nano.

macro-gold

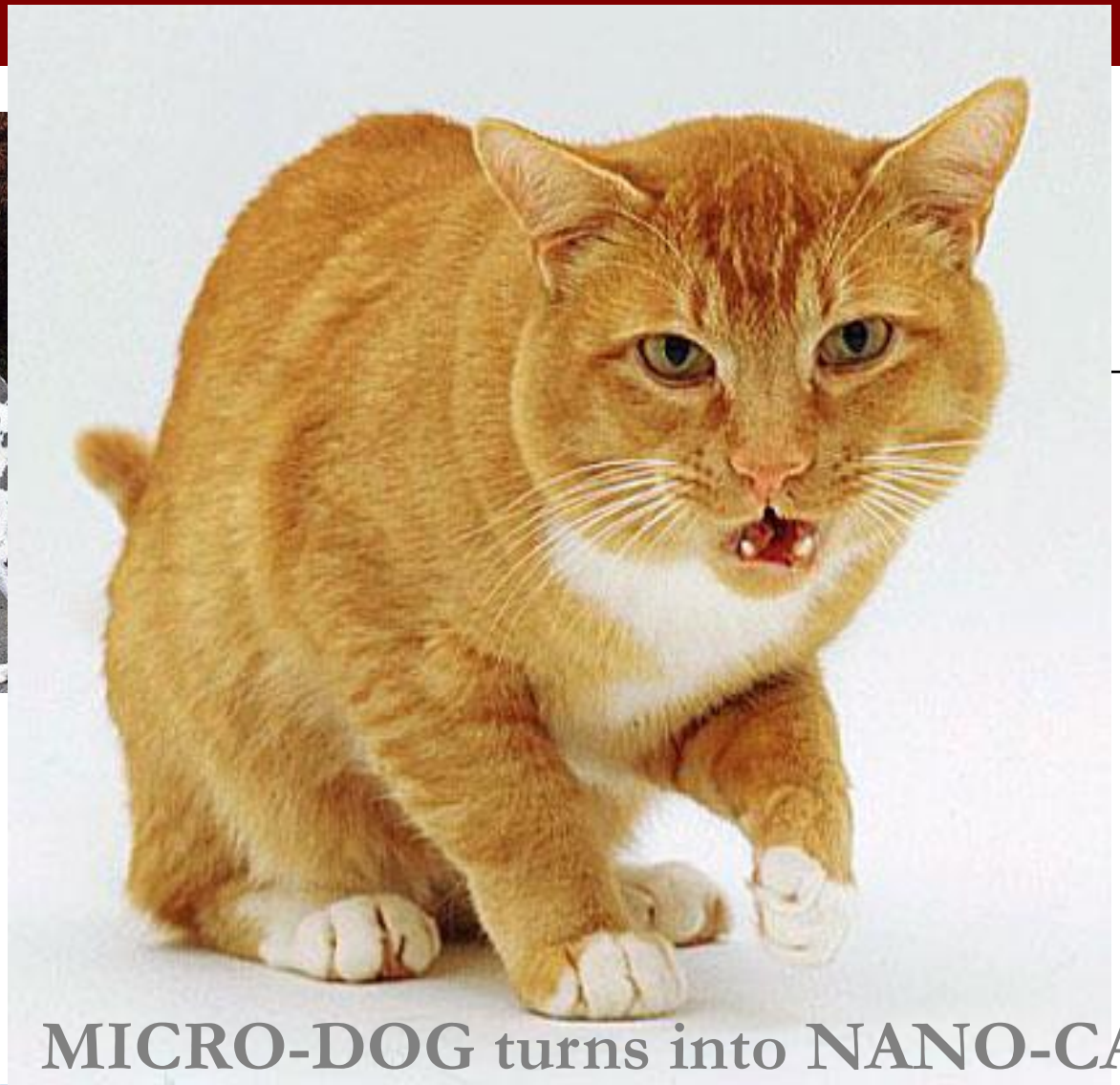
nano-gold

Gold nanoparticles give rise to the red colors in stained glass windows

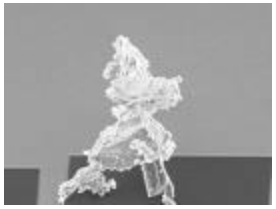
Why would the size of an object affect its color?

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Nanomaterials: THEY ARE STRANGE



MICRO-DOG turns into NANO-CAT



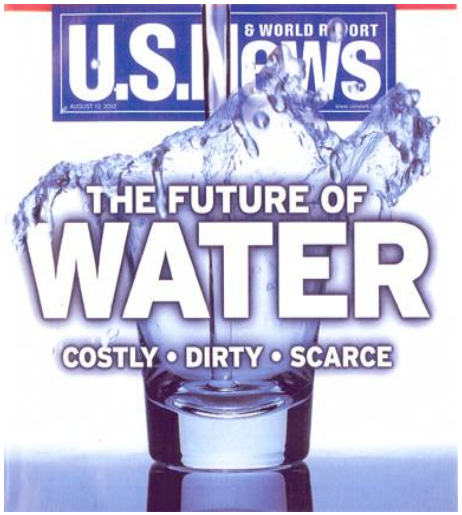
Microns!

LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

Nanotechnology exploits materials that are

- ***SMALL – one to one hundred nanometers***
- ***STRANGE – with high surface areas and (often) really different properties***

Nanomaterials: THEY ARE IMPORTANT

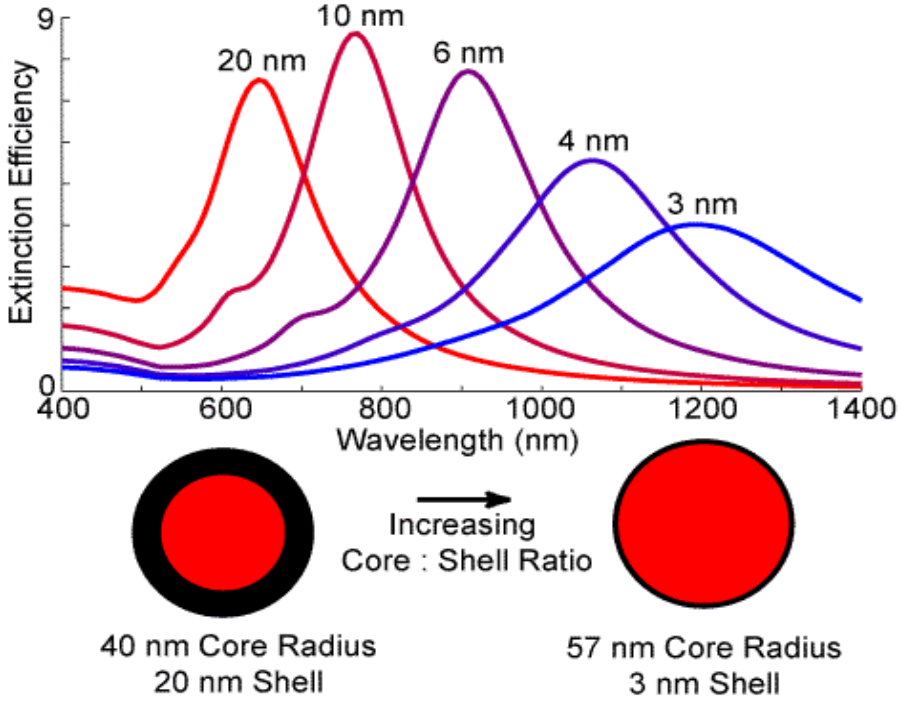


Water purification that is cheaper, better and easier

Detecting and curing disease with practical medicine

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

Gold Nanoshells – Cool Optics
Naomi Halas and Jennifer West



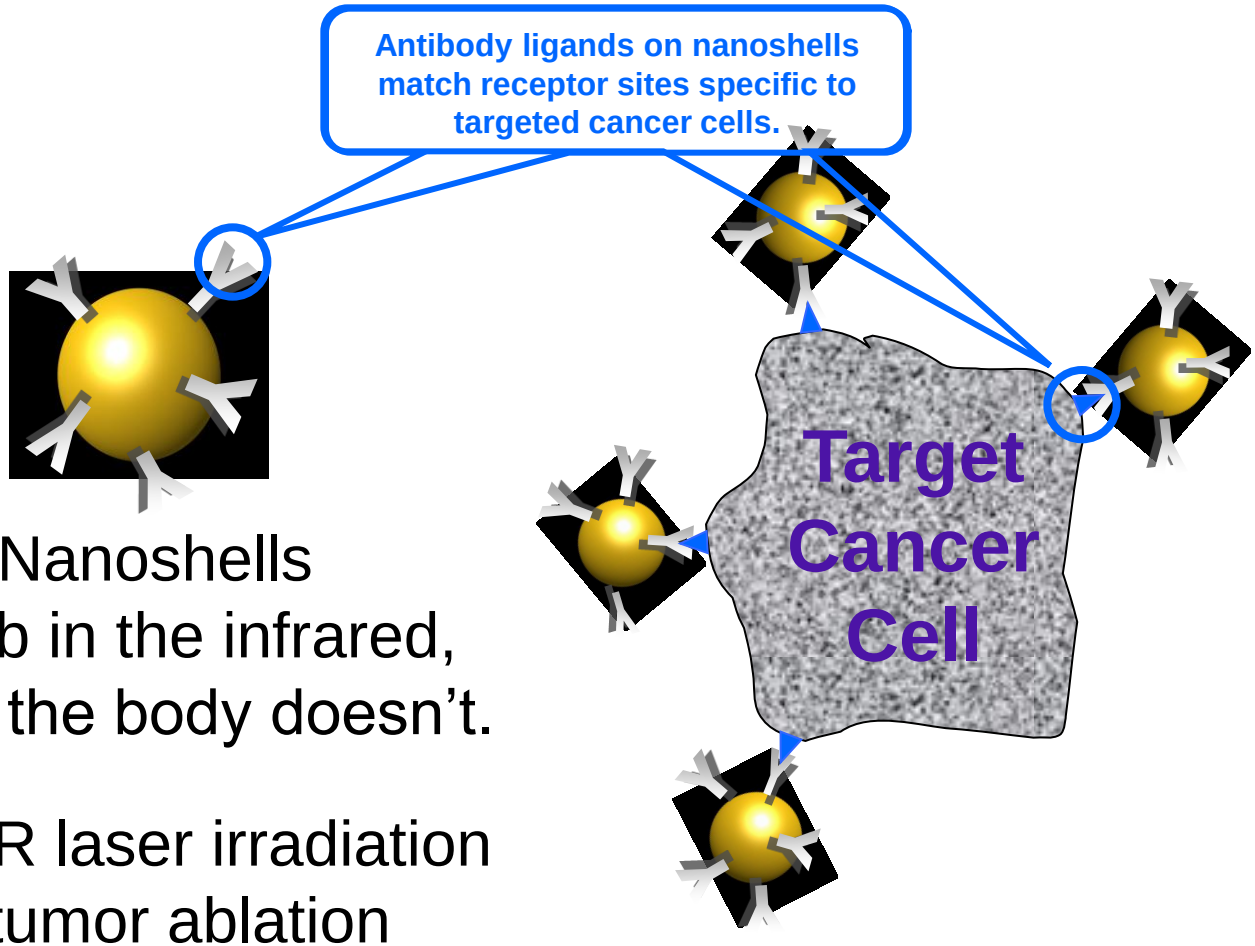
What is changing in these various vials?

Why is the vial at the end completely clear?

LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

So why is this useful?

Many reasons.
Here's one.

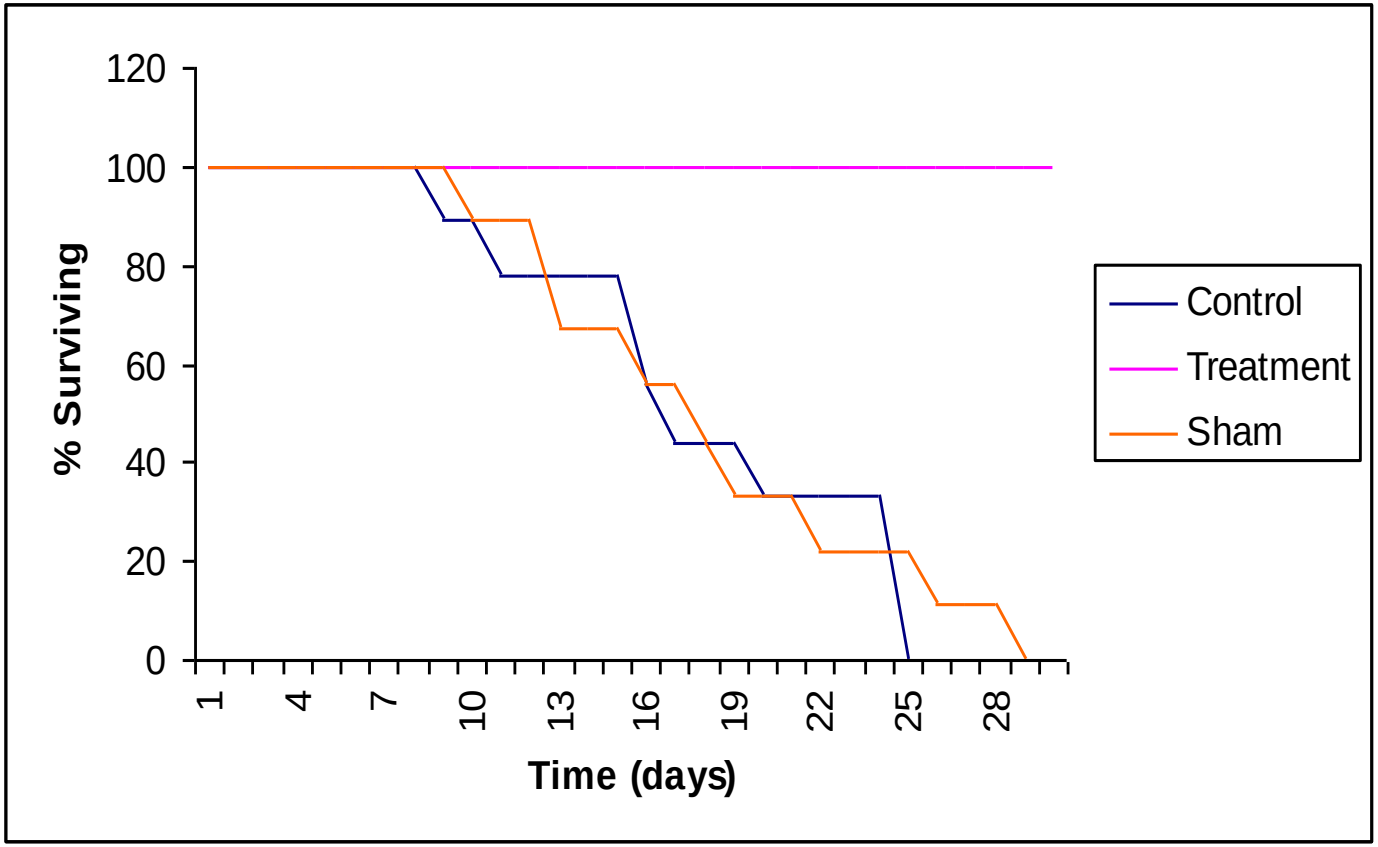


Nanoshells
absorb in the infrared,
where the body doesn't.

Then: IR laser irradiation
for tumor ablation

LANCER
Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University

It works in mice

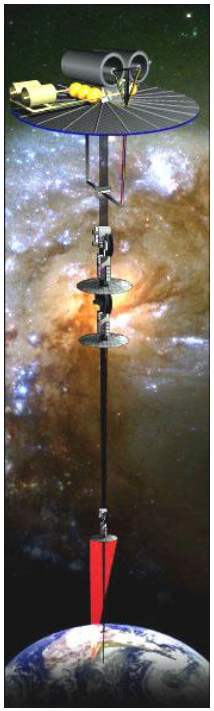


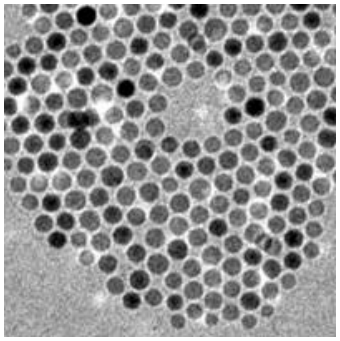
LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

Nanotechnology exploits materials that are

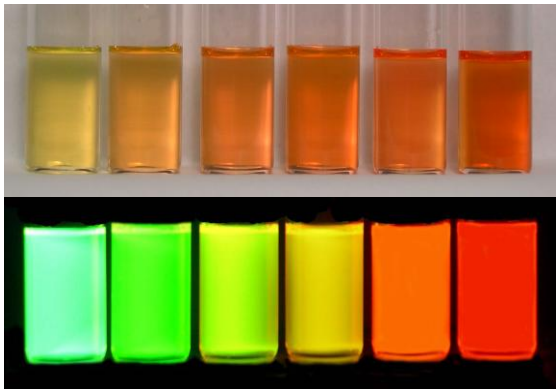
- ***SMALL – one to one hundred nanometers***
- ***STRANGE – with high surface areas and really different properties***
- ***IMPORTANT – solving important, tough problems of society***

Nanotechnology is …





- BROADLY used
- ENABLING
- MATERIAL based
- both HIGH and LOW tech



LANCER
Lockheed Martin Advanced Nanotechnology
Center of Excellence at Rice University

Nanotechnology trends, 2010 - 2020

- Theory, modeling, simulation: 1000x faster, essential to design
- A shift from ‘passive’ to ‘active’ nanostructures
- Nanosystems - self-powered, self-repairing, dynamic
- Penetration of nano in industry - towards mass use
- Nano-EHS: more predictive
- Personalized nanomedicine: from monitoring to treatment
- Photonics, electronics, magnetics: new capabilities
- Energy, photosynthesis, storage: becomes economic, mass use
- Enabling and integrating with new areas - bio, info, …

M. Roco, NSF

Any Questions?