DOE Activities in Nanoscience and Nanotechnology

Carl Mazzola for John Marsick

SCAPA Meeting, San Antonio, TX
May 10, 2007

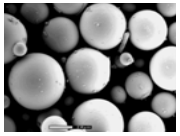
Scale of Things Natural and Manmade

Things Natural

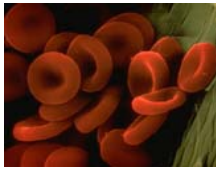
Dust mite
200 μm

Ant
~ 5 mm

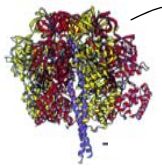
Human hair
~ 60-120 μm wide



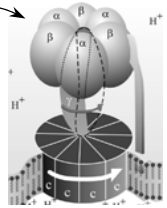
Fly ash
~ 10-20 μm



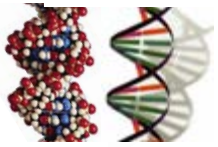
Red blood cells
~ 7-8 μm



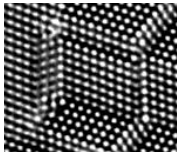
~10 nm
diameter



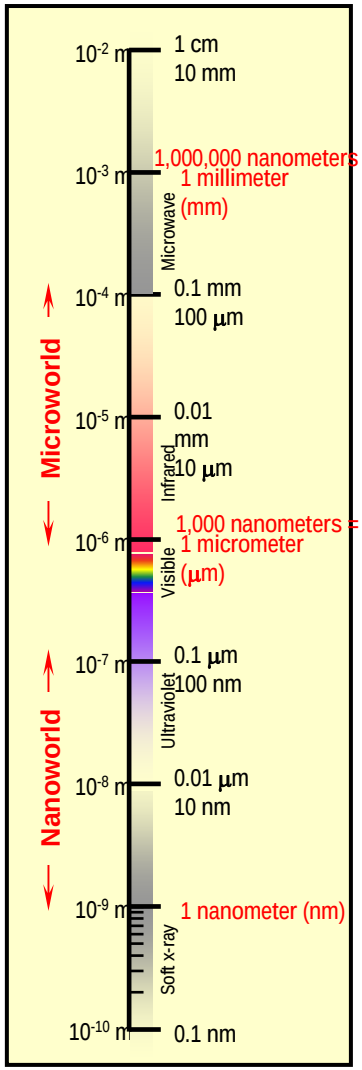
ATP synthase



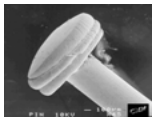
DNA
~2-1/2 nm diameter



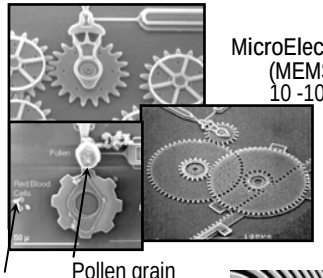
Atoms of silicon
spacing ~tenths of nm



Things Manmade



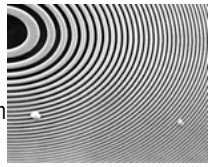
Head of a pin
1-2 mm



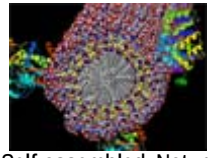
MicroElectroMechanical
(MEMS) devices
10 -100 μm wide

Pollen grain

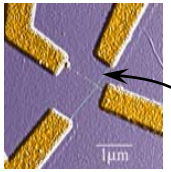
Red blood
cells



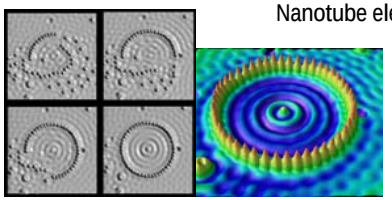
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



Self-assembled, Nature-
inspired structure
Many 10s of nm

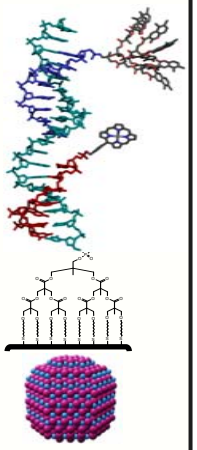


Nanotube electrode

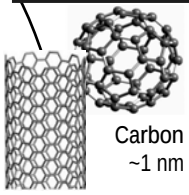


Quantum corral of 48 iron atoms on copper
surface positioned one at a time with an STM tip.
Corral diameter 14 nm

The Challenge



Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.



Carbon buckyball
~1 nm diameter

Carbon nanotube
~1.3 nm diameter

Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 10-07-03, pmd

Why Does Size Matter?

What is "Nanotechnology"?

- ***Nanotechnology is the understanding and control of matter at dimensions of roughly 1-100 nanometers, where unique phenomena enable novel applications***
- ***Nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale***

- ***Fundamental differences in physical, chemical, and biological behavior at this level compared to bulk materials or individual atoms/molecules***
  - ***Quantum phenomena***
  - ***Dominance of surfaces***
  - ***Self-assembly***

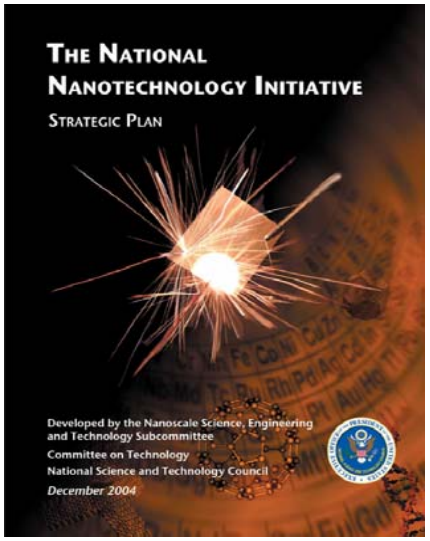
Key Points

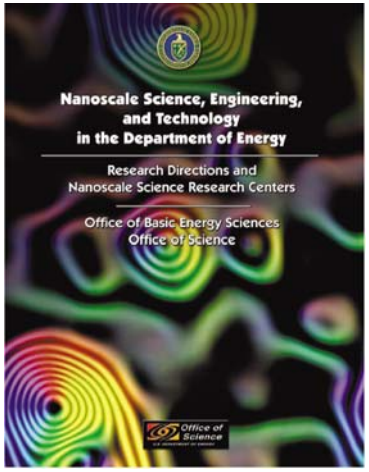
- ***Nanoscale science and technology open up new realms of possibility for materials behavior and design, with consequences that relate directly to DOE missions***
- ***DOE has critical interests in this area, and a major role in the corresponding federal research and development initiative***
  - ***"… all of the elementary steps of energy conversion (e.g., charge transfer, molecular rearrangement, chemical reactions, etc.) take place on the nanoscale."***
- ***DOE-supported research activities span a very broad range: nanotechnology is not a single "industry", but an enabling set of capabilities***
- ***DOE user facilities provide state-of the-art resources to the entire science and technology community via peer-reviewed allocation of instrument time, staff support, and collaboration***

DOE Role in National Nanotechnology Initiative

NATIONAL NANOTECHNOLOGY INITIATIVE

- *The National Nanotechnology Initiative (NNI) is an interagency program that coordinates Federal nanoscale research and development portfolio among 25 participating organizations*
- *Planned FY07 federal NNI expenditures: >$1.2 Billion*





- *DOE is one of original NNI participants, providing major funding for nanoscale science, engineering, and technology*
- *FY07 budget request includes over $250 Million for DOE nanoscience, supporting both fundamental research and facilities*

21st Century Nanotechnology R&D Act, December 3, 2003

On December 3, 2003, President Bush signed the 21st Century Nanotechnology Research and Development Act, which authorizes funding for nanotechnology research and development over four years, starting in FY 2005.

Secretary of Energy Spencer Abraham, who was present at the White House Oval Office ceremony, applauded the signing of the act. "As one of the lead agencies for nanotechnology research and development, the Department of Energy (DOE) is delighted that the President signed legislation today that brings us closer to that future," … "This new science of very small things can revolutionize the way we produce, use, and deliver energy …."

President Bush is joined by, from left, Stephen Empedocles SVP of NanoSys, F. Mark Modezlewski, Exec. Director NanoBusiness Alliance, Rep. Sherwood Boehlert, R-NY. , Spencer Abraham , Dr. Richard Smalley, Nobel laureate from Rice University, Alliance Board Member Steve Jurvetson of Draper Fisher Jurvetson, Sen. George Allen , R-Va., Floyd Kvamme of the President's Council of Advisors on Science and Technology, Alliance Board Member James Von Ehr, founder and president of Zyvex, and Alliance Board Member Josh Wolfe of Lux Capital and Nanotech Report, Joe Piche, CEO of Eikos.

NNI Activities & Documents Inform Federal Activity, Provide Resources to Community & Report Outcomes

NNI on http://nano.gov

DEPARTMENT OF ENERGY

Federal Energy Regulatory Commission

Office of the Secretary
Dr. Samuel Bodman, Secretary

Clay Sell, Deputy Secretary*

Chief of Staff

Departmental Staff and Support Offices

- Assistant Secretary for Policy & International Affairs
- General Counsel
- Chief Financial Officer
- Energy Information Administration
- Chief Information Officer
- Human Capital Management
- Management
- Assistant Secretary for Congressional & Intergovernmental Affairs
- Health, Safety & Security
- Economic Impact & Diversity
- Inspector General
- Hearings & Appeals
- Intelligence and Counterintelligence
- Public Affairs

Office of the Under Secretary For Nuclear Security/ Administrator for National Nuclear Security Administration
Amb. Linton F. Brooks

- Deputy Administrator for Defense Programs
- Deputy Administrator for Defense Nuclear Nonproliferation
- Deputy Administrator for Naval Reactors
- Deputy Under Secretary for Counter-terrorism
- Associate Administrator for Defense Nuclear Security
- Associate Administrator for Emergency Operations
- Associate Administrator for Infrastructure & Environment
- Associate Administrator for Management & Administration

Office of the Under Secretary

David K. Garman, Under Secretary

- Assistant Secretary for Energy Efficiency & Renewable Energy
- Assistant Secretary for Environmental Management
- Assistant Secretary for Fossil Energy
- Assistant Secretary for Nuclear Energy
- Civilian Radioactive Waste Management
- Electricity Delivery & Energy Reliability
- Legacy Management

Office of the Under Secretary for Science

Dr. Raymond L. Orbach, Under Secretary for Science

Office of Science

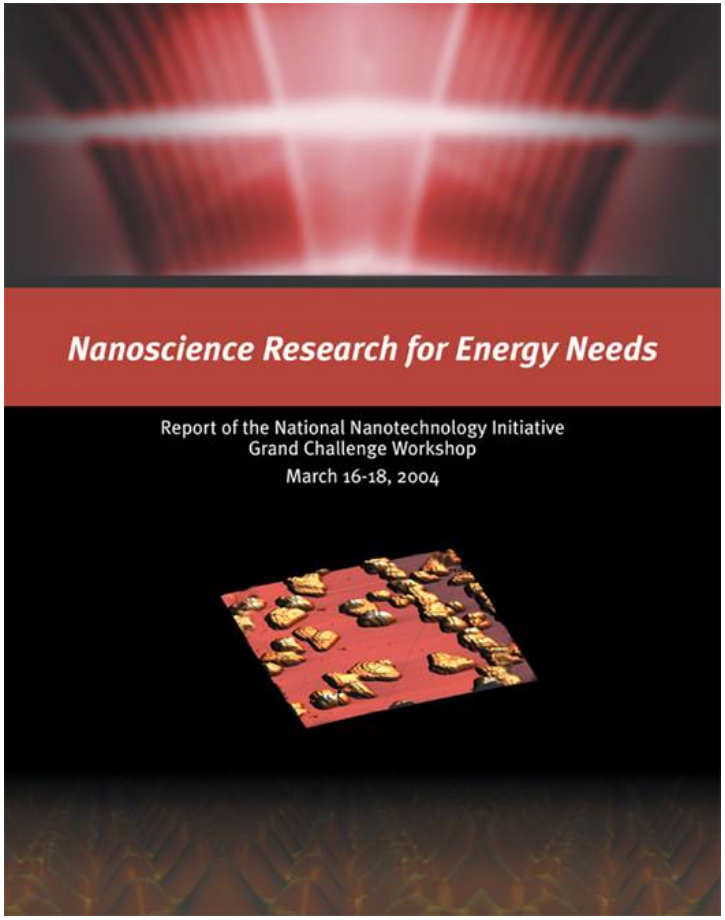
- Advanced Scientific Computing Research
- Basic Energy Sciences
- Biological & Environmental Research
- Fusion Energy Science
- High Energy Physics
- Nuclear Physics
- Workforce Development for Teachers & Scientists

- Bonneville Power Administration
- Southwestern Power Administration
- Southeastern Power Administration
- Western Area Power Administration

* The Deputy Secretary also serves as the Chief Operating Officer

26 Oct 06

Energy Conversion Happens at the Nanoscale



Nanoscience Research for Energy Needs (2004)

- ***From the Executive Summary:***

  "At the root of the opportunities provided by nanoscience to enhance our energy security is the fact that all of the elementary steps of energy conversion (e.g., charge transfer, molecular rearrangement, chemical reactions, etc.) take place on the nanoscale."

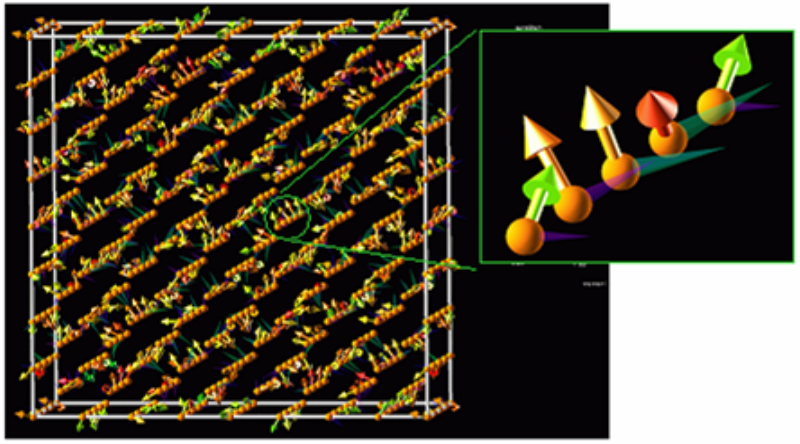
Nanotechnology Impact Areas in Energy & Environment

- *Energy*
  - *hydrogen storage*
  - *solid-state lighting*
  - *low-power displays*
  - *fuel cells*
  - *battery materials*
  - *solar power*
  - *catalysis*
  - *weight reduction*
  - *propellants and explosives*
  - *nanoscale energy (ATP motors, etc.)*

- *Environment*
  - *sensors*
  - *remediation*
  - *emissions reduction*
  - *membranes and separations*
  - *coatings*
  - *green processing*
  - *radioactive waste containment*

Mission of Office of Basic Energy Sciences

- ***Foster and support fundamental research to provide the basis for new, improved, environmentally conscientious energy technologies***



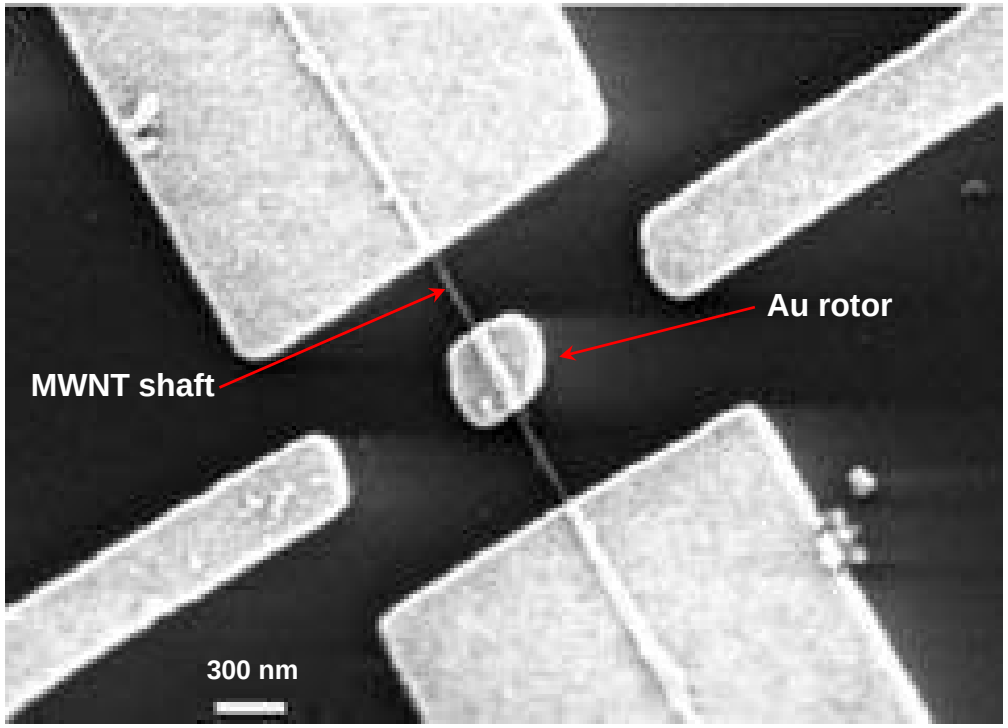
- ***Plan, construct, and operate major scientific user facilities for "materials sciences and related disciplines" to serve researchers from academia, federal laboratories, and industry***

DOE Nanoscience Programs

- **Office of Science** Core Research Programs (http://www.science.doe.gov/grants)
  - Annual Office of Science notices: continuing solicitations listing broad science areas and objectives
  - Primary criterion is quality of fundamental science; rigorous external peer review
- Targeted Solicitations (http://www.science.doe.gov/grants)
  - e.g.: FY 2001, FY 2002 Nanoscale Science, Engineering, and Technology Notices
    - awarded ~$45M (>120 grants and 24 laboratory awards)
  - e.g.: FY 2003 solicitation on "Theory, Modeling and Simulation in Nanoscience":
    - awarded ~$4.3M for 4 projects involving 13 universities and 4 national laboratories
- SBIR/STTR (http://sbir.er.doe.gov/sbir)
  - Past solicitations have contained numerous relevant technical topics, including e.g.:
    - Nanotechnology for Coatings in Coal-Fired Environments
    - Nanotechnology Applications in Industrial Chemistry
- Major Research Facilities (http://www.sc.doe.gov/bes/BESfacilities.htm)
  - BES Nanoscale Science Research Centers – the DOE "flagship" NNI activity
  - BES supports synchrotron, neutron, and electron scattering (and other) user facilities

First Synthetic Nanomotor

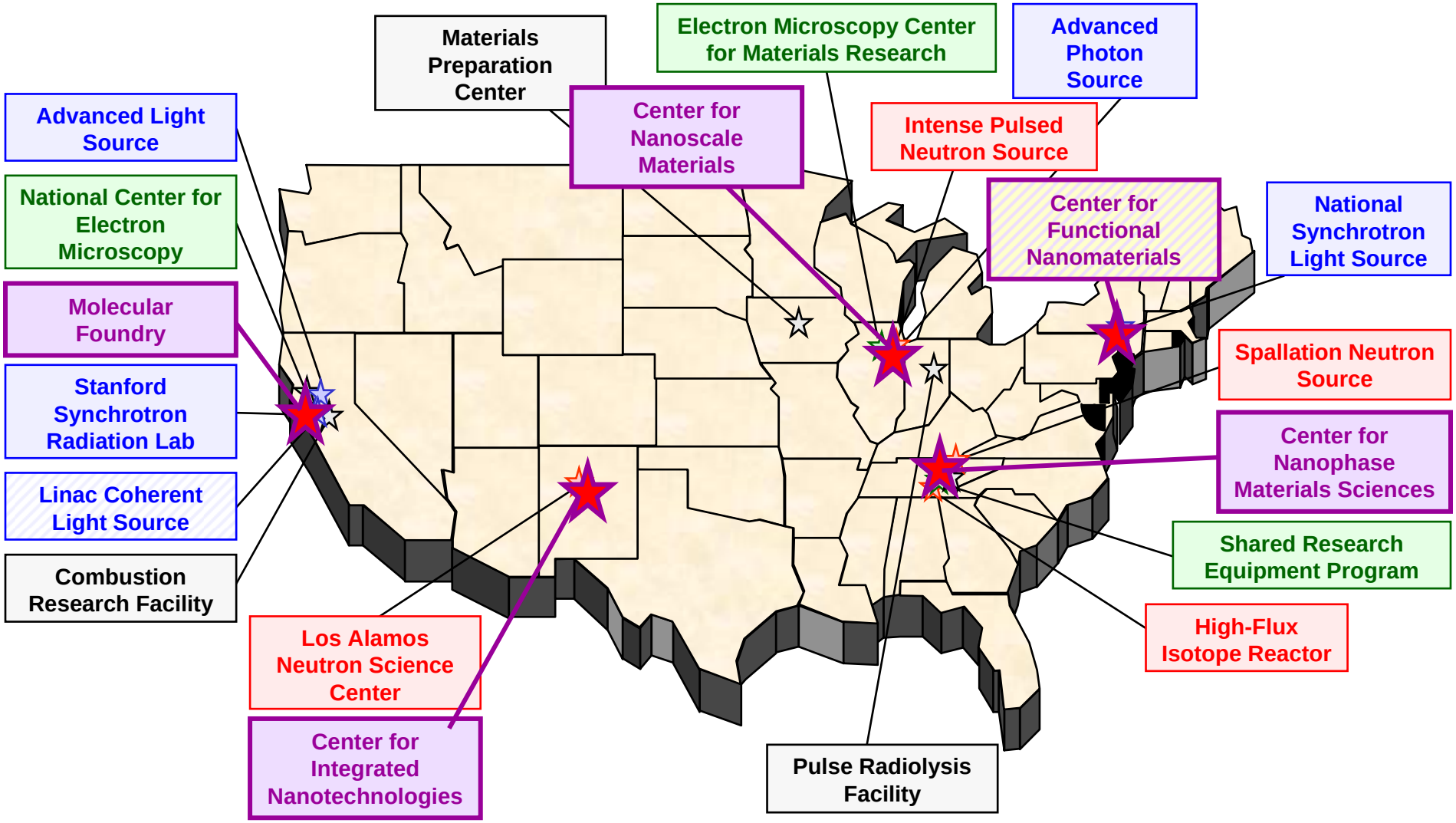
2004 R&D 100 Winner



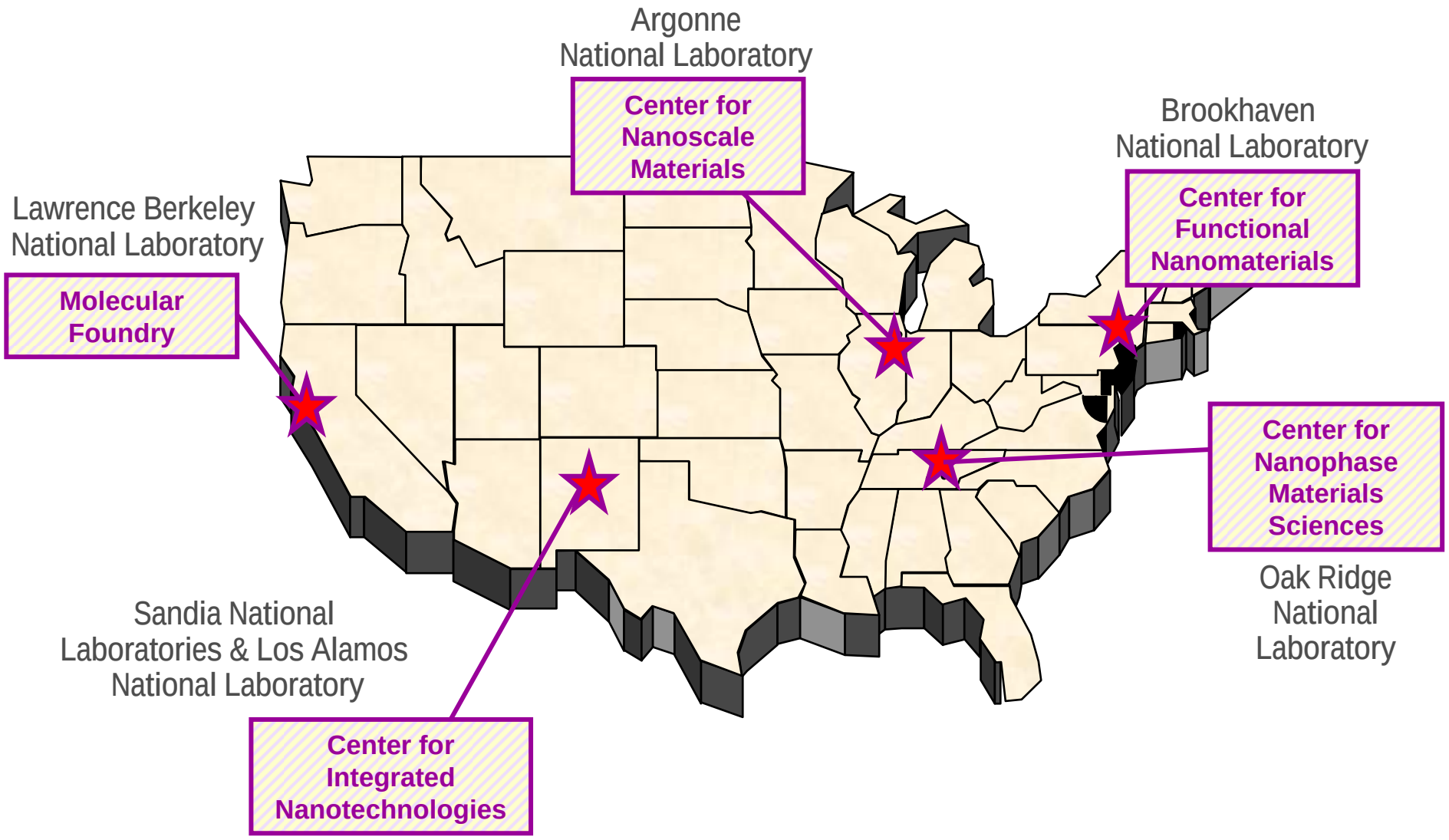
A. Zettl et al., LBNL

Scanning electron microscopy (SEM) image of the LBNL synthetic nanomotor. A 300 nm Au plate rotor is attached to a multi-walled carbon nanotube (MWNT) which acts as a support shaft and is the source of rotational freedom. Rotor can rotate through a full 360 degrees for thousands of cycles without apparent degradation or wear.

DOE-BES User Facilities, including the NSRCs (★)

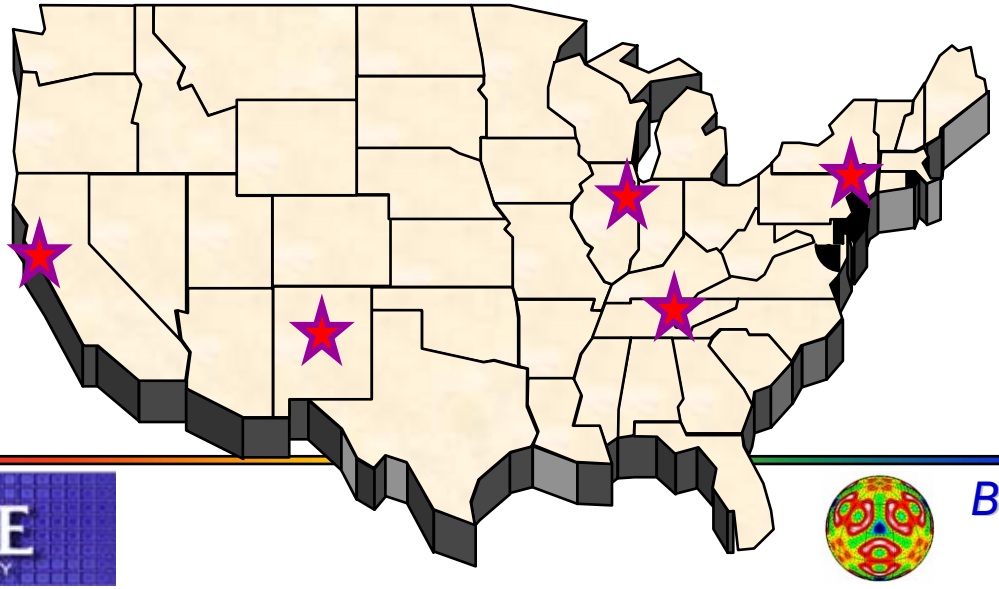


The Five DOE Nanoscale Science Research Centers (NSRCs)



Nanoscale Science Research Centers: Basic Information

- *Research facilities for synthesis, processing, and fabrication of nanoscale materials*
- *Provide specialized equipment, unique tools, and support staff that are difficult for individual institutions to build and maintain*
- *Operated as user facilities; available to all researchers; access determined by peer review of proposals; cost recovery for proprietary work*
- *Co-located at DOE National Laboratories with existing major user facilities (e.g., synchrotron radiation light sources, neutron scattering facilities) to provide characterization and analysis capabilities*



Construction is Complete and Initial Operations are Underway at Four of the Five NSRCs

Center for Functional Nanomaterials
(Brookhaven National Laboratory)
- under construction

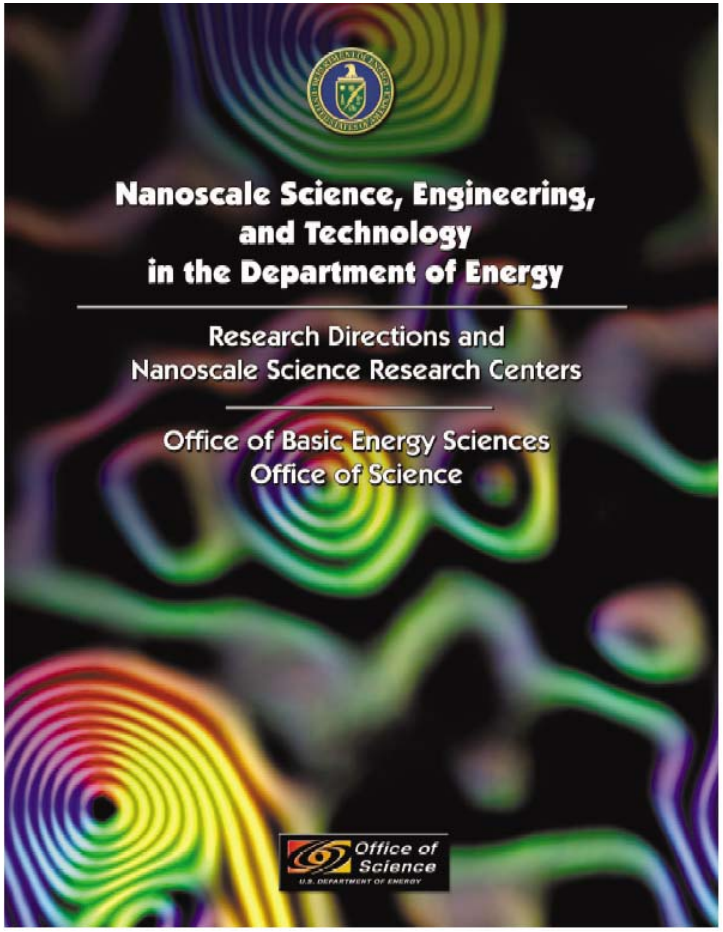
Molecular Foundry
(Lawrence Berkeley
National Laboratory)

Center for Nanoscale Materials
(Argonne National Laboratory)

Center for Nanophase Materials Sciences
(Oak Ridge National Laboratory)

Center for Integrated Nanotechnologies
(Sandia & Los Alamos National Labs)

Further Information



Extensive information on DOE Office of Science programs in nanoscience, including this summary brochure, is available at: http://nano.energy.gov

ES & H Nanotechnology Research

- ***Unfortunately Very Limited***
  - ***<3% of Nanotechnology Funding***
- ***Insufficient Funding Critiques***
  - ***United Kingdom***
  - ***Pew Foundation***

Nanotechnology Standards Activity

- ***NIST***
  - ***Measurement and Standards***
- ***ASTM***
  - ***E56 (2005)***
- ***ANSI***
  - ***US Technical Advisory Group to TC 229 of ISO (2005)***

Nanotechnology Health Studies

- ***Fish Study (2004)***

Nanotechnology Ecological Studies

- ***Bacteria***
- ***Soil***

Congressional Actions on Nanotechnology

- ***2006 Congressional Hearings***
- ***Call for GAO to Look into Limited ES&H Research Funding***
- ***Joint Economic Committee Report***

DOE Nanotechnology Activity

- ***IG Reports***
- ***Development of Nanotechnology Policy***
- ***Development of Draft Nanotechnology Notice***
- ***Nanoscale Science Research Center***
  - ***Guidance***
  - ***Teleconferences***

Nanotechnology Advocates

- **Center for Responsible Nanotechnology**

http://www.crnano.org/about_us.htm

. **European Nanotechnology Gateway**

http://www.nanoforum.org/index.php?code=2836be05e71a8f34902a6e6b37350134&userid=5675443

. **Institute of Nanotechnology**

http://www.nano.org.uk/index.htm

. **Consultative Board for Advancing Nanotechnology (CBAN)**

http://www.chemicalvision2020.org/nanotechnology.html

Nanotechnology Advocates (continued)

- ***ICON***

  http://icon.rice.edu/about.cfm?doc_id=4381

- ***European Union***

  http://cordis.europa.eu/nanotechnology/home.html

Nanotechnology Workshops and Meetings

- ***NIOSH-Sponsored***
- ***International***
  - ***Minneapolis (2005)***
  - ***Cincinnati (2006)***
  - ***Taiwan (2007)***
- ***US Universities***
- ***Other***

Web-Based Nanotechnology Resources

- **NIOSH**
  http://www.cdc.gov/niosh/topics/nanotech/default.html
- **NNI**
  http://www.nano.gov/html/research/home_research.html
- **ORC**
  http://www.orc-dc.com/Nano.Guidelines.Matrix.htm

---DOE

http://www.orau.gov/ihos/

Web-Based Nanotechnology Resources (continued)

-- EPA

http://es.epa.gov/ncer/nano/

-- FDA

http://www.fda.gov/nanotechnology/

-- AIHA

http://www.aiha.org/Content/Topics/nano/

-- United Kingdom

http://www.hse.gov.uk/research/rrhtm/rr274.htm

-- Nanotechnology Risk Resources

http://www.nsec.wisc.edu/NanoRisks/NS--NanoRisks.php