

Past and Future Directions in Nanotechnology

Federal Funding Agencies

National Nanotechnology Initiative

<http://www.nano.gov/>

- NNI is interagency program begun in 2001
 - Coordinates the Federal nanoscale R&D
 - 25 participating organizations
 - Strategic plan published in 2004
 - http://www.nano.gov/NNI_Strategic_Plan_2004.pdf
 - FY 2007 expenditures > \$1.2 Billion
 - FY 2008 proposed expenditures > \$1.4 Billion

21st Century Nanotechnology R&D Act

- Signed into legislation on 12/3/2003
 - Authorizes funding for nanotechnology R&D for 4 years, starting in FY 2005

NNI Budget History by Agency

(dollars in millions)

Agency	2001 Actual	2002 Actual	2003 Actual	2004 Actual	2005 Actual
NSF	150	204	221	256	335
DOD	125	224	322	291	352
DOE	88	89	134	202	208
DHHS (NIH)	40	59	78	106	165
DOC(NIST)	33	77	64	77	79
NASA	22	35	36	47	45
EPA	5	6	5	5	7
USDA			1	2	3
DHHS (NIOSH)					3
DOJ	1	1	1	2	2
DHS		2	1	1	1
TOTAL	464	697	863	989	1200

NNI Budget Overview by Agency

Agency	2006 Actual	2007 Estimate*	2008 Proposed
NSF	359.7	373.2	389.9
DOD	423.9	417.2**	374.7
DOE	231.0	235.2	331.5
DHHS (NIH)	191.6	193.8	202.9
DOC(NIST)	77.9	84.2	96.6
NASA	50.0	25.0	24.0
EPA	4.5	8.5	10.2
USDA (CSREES)	3.9	3.4	3.0
DHHS (NIOSH)	3.8	6.6	4.6
USDA/FS	2.3	2.6	4.6
DHS	1.5	2.0	1.0
DOJ	0.3	1.4	0.9
DOT (FHWA)	0.9	0.9	0.9
TOTAL	1351.2	1353.9	1444.8

Budget
increases

* The 2007 Estimates reflect 2007 Budget levels, except for the Departments of Defense and Homeland Security, which are the enacted levels. Several agencies have updated their 2007 Budget levels since the release of the 2007 NNI Budget Supplement.

** 2007 estimate includes about \$100 million in Congressional earmarks at DOD that are outside the NNI plan.

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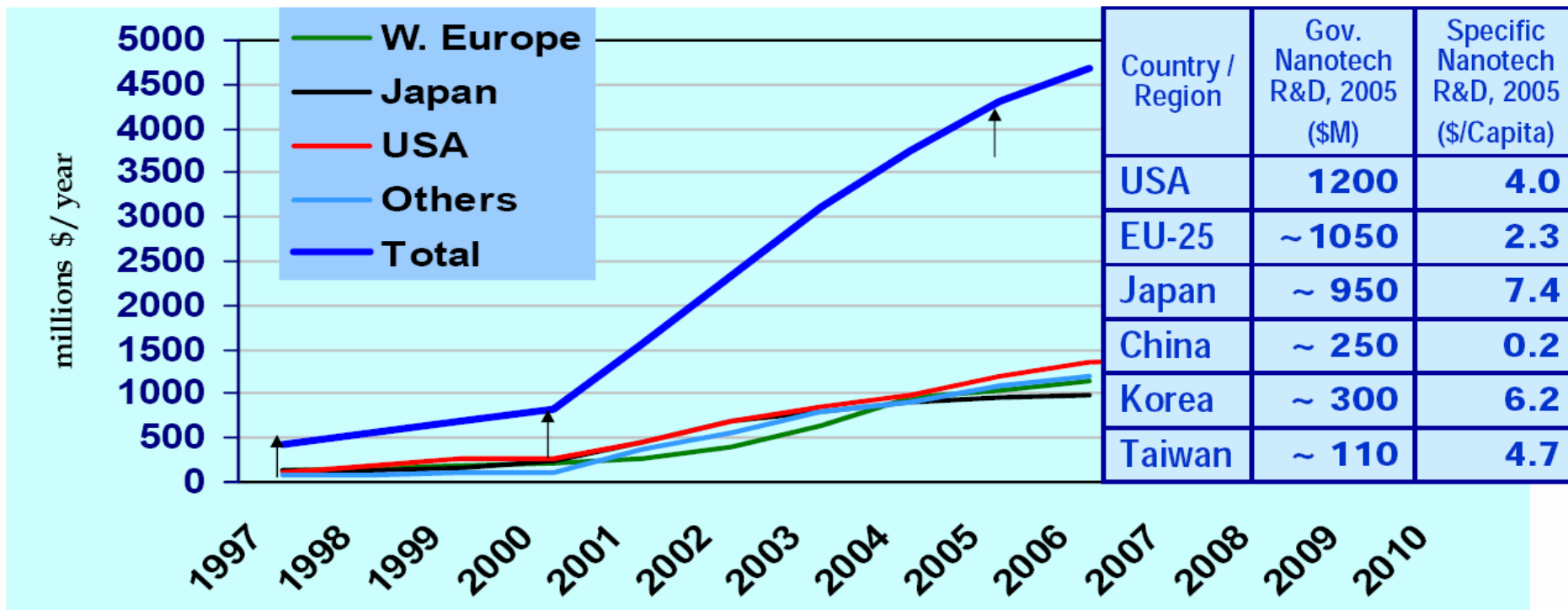
From <http://www.nano.gov/>

Table 3
Planned 2008 Agency Investments by Program Component Area
(dollars in millions)

	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instr. Research, Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Societal Dimensions	NNI Total*
NSF	142.7	60.2	51.1	14.5	26.9	31.6	62.9	389.9
DOD	179.1	91.7	70.6	8.3	1.0	23.0	1.0	374.7
DOE	85.4	99.8	13.5	26.7	2.0	100.6	3.5	331.5
DHHS (NIH)	53.3	16.5	114.9	6.7	1.7	0.1	9.7	202.9
DOC (NIST)	27.1	8.0	13.5	26.4	11.1	4.5	6.0	96.6
NASA	1.0	12.0	10.0	0.0	1.0	0.0	0.0	24.0
EPA	0.2	0.2	0.2	0.0	0.0	0.0	9.6	10.2
USDA (CSREES)	0.4	0.8	1.5	0.0	0.1	0.0	0.2	3.0
DHHS (NIOSH)	0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.6
USDA (FS)	1.7	1.5	1.0	0.2	0.2	0.0	0.0	4.6
DHS	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0
DOJ	0.0	0.0	0.1	0.8	0.0	0.0	0.0	0.9
DOT (FHWA)	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.9
TOTAL*	491.8	290.7	277.4	83.6	44.0	159.8	97.5	1,444.8

Context – Nanotechnology in the World

National government investments 1997-2006 (est. NSF)



Seed funding
(1991 -)

NNI Preparation
(vision / benchmark)

1st Strategic Plan
(passive nanostructures)

2nd Strategic Plan
(active ns. & systems)

Industry R&D (\$6B) has exceeded national government R&D (\$4.6B) in 2006

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From http://128.119.56.118/~nnn01/NewFiles/09_Roco_NNI_NSF.pdf

Key NNI R&D user facilities

Center Name	Institution
NSF	
National Nanofabrication Infrastructure Network (NNIN) – 13 nodes	Cornell University –central node
Network for Computational Nanotechnology (NCN) – 7 nodes	Purdue University – central node
DOE	
Center for Functional Nanomaterials	Brookhaven National Laboratory
Center for Integrated Nanotechnologies	Sandia NL and Los Almos NL
Center for Nanophase Materials Sciences	Oak Ridge National Laboratory
Center for Nanoscale Materials	Argonne National Laboratory
Molecular Foundry	Lawrence Berkeley National Laboratory



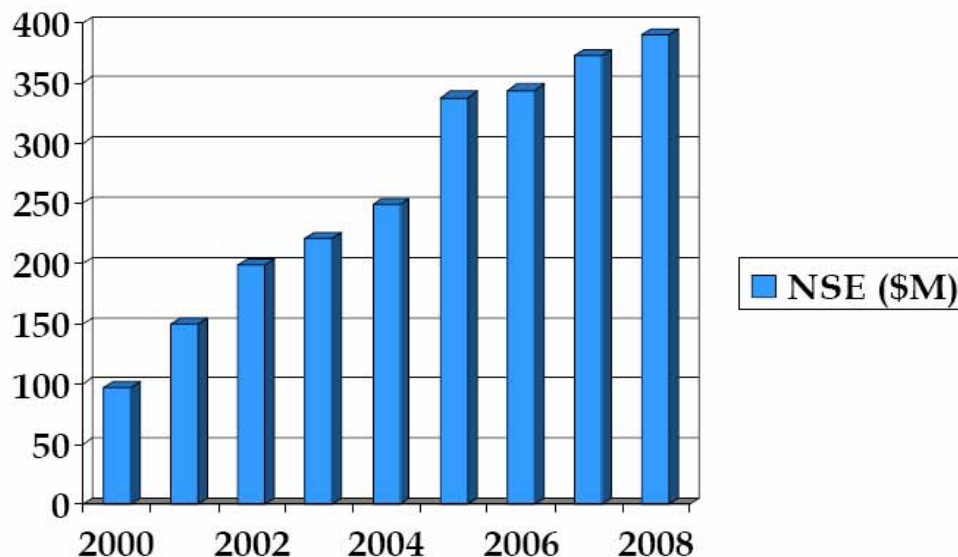
NSF – discovery, innovation and education in Nanoscale Science and Engineering (NSE)

www.nsf.gov/nano , www.nano.gov

FY 2008 Request: \$390M ~1/4 of Federal and ~1/12 of World Investment

- **Fundamental research** - seven PCAs with new priorities
- **Establishing the infrastructure** - over 3,000 active projects; 24 large centers, 2 user facilities (NNIN, NCN), multidisciplinary teams
- **Training and education** – over 10,000 students and teachers/yr

Fiscal Year	NSF
2000	\$97M
2001	\$150M
2002	\$199M
2003	\$221M
2004	\$254M
2005	\$338M
2006	\$344M
2007	\$373M
R 2008	\$390M



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MC Roco, 06/13/07

From http://128.119.56.118/~nnn01/NewFiles/09_Roco_NNI_NSF.pdf

Several Priorities at NSF / NNI (2007 -)

- Systems Nanotechnology
- Measuring tools of systems with atomic resolution
- "On-site" nanomanufacturing
- **Nanoinformatics**
- Use of nanotechnology for common use resources:
water, food, energy, environment
- Basic research on Beyond CMOS, partner with SIA/SRC
- Networking development for EHS, Education, ELSI

NIH

- NIH Roadmap: Nanomedicine
<http://nihroadmap.nih.gov/nanomedicine/>
 - Definition of Nanomedicine: Highly specific medical intervention at the molecular scale for curing disease or repairing damaged tissues, such as bone, muscle, or nerve.

NIH

- Established 8 Nanomedicine Development Centers, which serve as the intellectual and technological centerpiece of the NIH Nanomedicine Roadmap Initiative
 - Each center is planned to last for 10 years
 - 4 funded in 2005 and 4 funded in 2006
 - No future solicitations are planned to establish additional centers

NIH

- In addition to the Roadmap activities, each Institute (27 in total) within the National Institutes of Health has its own nanotechnology initiatives.

NIH National Cancer Institute

- NCI has had the earliest and most well funded activities.
 - \$144.3M initiative launched in 9/2004 (Alliance in Nanotechnology in Cancer)
 - Participates in NNI
 - <http://nano.cancer.gov/>
- NCI has established
 - 8 Centers of Cancer Nanotechnology Excellence (CCNEs)
 - No further solicitations planned
 - Nanotechnology Characterization Laboratory to establish protocols and then evaluate toxicity of nanoparticles for NCI funded researchers
 - Frederick, MD – collaborations with NIST and FDA
 - 12 Cancer Nanotechnology Platform Partnerships, including the VCU-VT effort on Metallofullerens
 - 4 NCI-NSF training grants through the IGERT program in 2005

NIH Bioengineering Consortium

- BECON hosts nanotechnology related grant opportunities

<http://www.becon.nih.gov/nano.htm>

- Currently 1 active research and training opportunity and 2 program announcements for grants as well as an SBIR and STTR solicitation

Department of Energy

“... all of the elementary steps of energy conversion (e.g., charge transfer, molecular rearrangement, chemical reactions, etc.) take place on the nanoscale.”

http://www.hss.energy.gov/HealthSafety/WSHP/chem_safety/ws2007/presentations/313%20Miller1015nanotalk.pdf

The Department of Energy's Office of Science supports nanotechnology through its Materials Sciences subprogram.

This subprogram extends the frontiers of materials sciences and engineering to expand the scientific foundations for the development of materials that improve the efficiency, economy, environmental acceptability, and safety in energy generation, conversion, transmission, and use.

DoE Basic Energy Science Allocations

Nanoscale Science Research Funding

Nanoscale Science Research Funding

(dollars in thousands)

	TEC	TPC	FY 2005	FY 2006	FY 2007
Materials Sciences and Engineering					
Research.....			65,307	70,328	108,542
Major Item of Equipment, Center for Nanophase Materials (ANL).....			12,000	14,000	—
Facility Operations					
Center for Functional Nanomaterials (BNL).....			—	—	—
Center for Integrated Nanotechnologies (SNL/A & LANL).....			—	11,900	19,190
ORNL, Center for Nanophase Materials Sciences			—	17,800	19,190
Center for Nanophase Materials (ANL).....			—	3,500	19,190
Molecular Foundry (LBNL).....			—	8,100	19,190
Chemical Sciences, Geosciences, and Biosciences					
Research.....			27,645	26,914	49,109
Project Engineering Design and Construction					
PED— All sites.....		21,318	1,996	—	—
Construction					
Center for Functional Nanomaterials (BNL).....	79,700	81,000	18,317	36,187	18,864
Center for Integrated Nanotechnologies (SNL/A & LANL)....	73,754	75,754	30,650	4,580	247
ORNL, Center for Nanophase Materials Sciences	63,740	64,740	17,669	—	—
Molecular Foundry (LBNL).....	83,604	84,904	31,828	9,510	257
Total			205,412	202,819	253,779

Grants and lab research

Rest of funding is for scientific user facilities

http://www.hss.energy.gov/HealthSafety/WSHP/chem_safety/ws2007/presentations/313%20Miller1015nanotalk.pdf

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DOE

- Several workshop to identify critical areas of research
 - *Basic Research Needs for the Hydrogen Economy*, May 2003
 - *Basic Research Needs for Solar Energy Utilization*, April 2005
 - *Basic Research Needs for Superconductivity*, May 2006
 - *Basic Research Needs for Solid-State Lighting*, May 2006
 - *Basic Research Needs for Advanced Nuclear Energy Systems*, July-August 2006
 - *Basic Research Needs for Clean and Efficient Combustion of 21st Century Fuels*, Oct.-Nov. 2006
 - *Basic Research Needs for Electric Energy Storage*, April 2007
 - *Basic Research Needs for Geoscience*, Feb, 2007

Reports are available at <http://www.sc.doe.gov/bes/reports/list.html>

DoD Nanotechnology

- **Recognized Applications of Nanoscience**
- Ultrasmall, highly parallel, computers with multi-teraflop speed
- Image information processors, e.g., extraction and recognition
- Low-power personal and autonomous communication and computation devices
- high-density information storage devices, e.g., terabit/cm² nonvolatile memory
- Lasers and detectors for weapons and countermeasures
- Optical (infrared, visible, ultraviolet) sensors for improved surveillance and targeting
- Integrated sensor suites for chemical and biological agent detection
- Catalysts for enhancing and controlling energetic reactions
- Synthesis of new compounds (e.g., narrow-bandgap materials)
- Designer materials with combinations of properties that do not currently exist

DoD

- DOD participants in the NNI are
 - the Directorate for Defense Research and Engineering (DDR&E),
 - the Defense Advanced Research Projects Agency (DARPA),
 - the Air Force,
 - the Army
 - the Navy.
- DOD supports nanoscale science and technology in order to meet the national security mission through
 - S&T investment into basic research (“6.1”),
 - applied research (“6.2”) and
 - advanced technology development (“6.3”)
 - the latter two focus on transitioning science discovery into innovative technology.

DoD

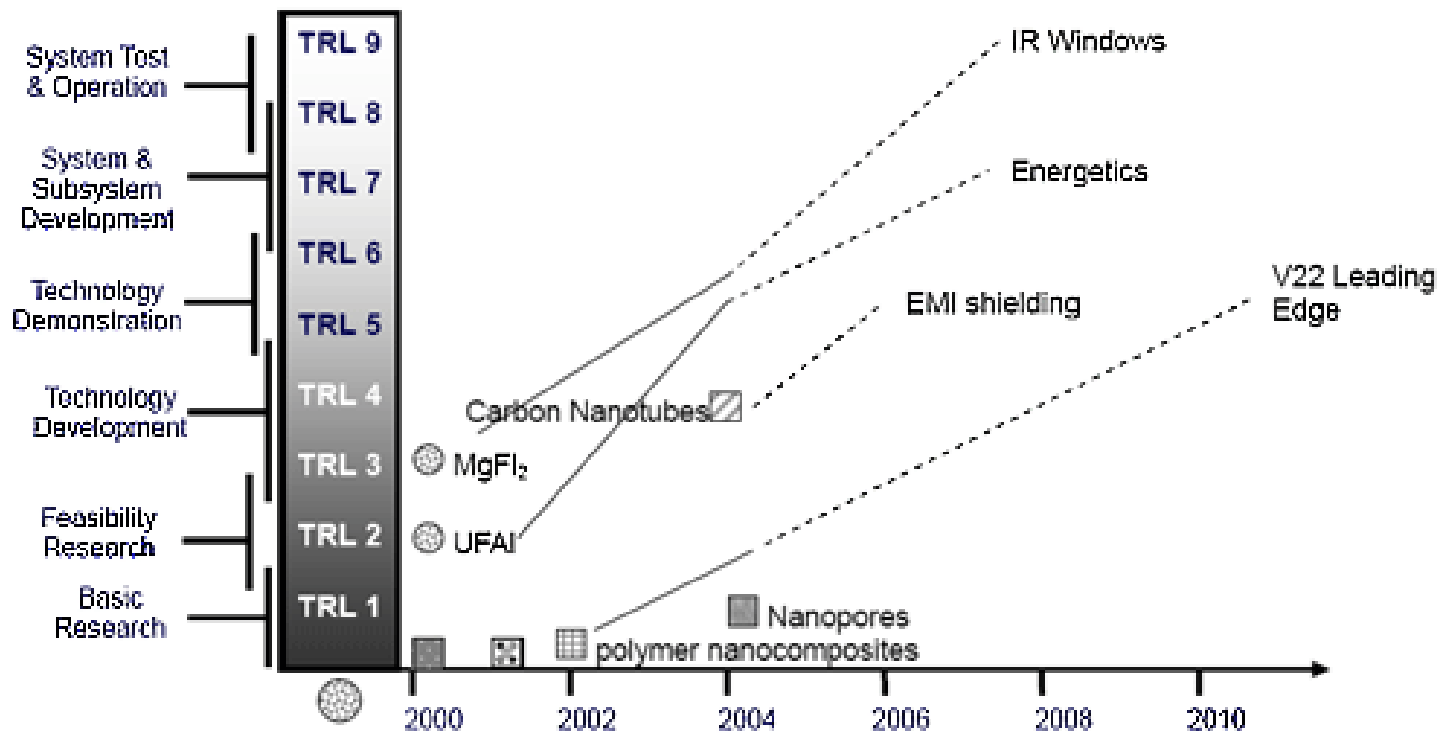
Broad Agency Announcements

- Topics:
 - Engineered biomolecular nanodevices/systems
 - Integrated nano-electronics
 - Applications of molecular electronics
 - Negative index materials
 - Synthetic multifunctional materials
 - Micro cryogenic coolers.
- Within the Defense Threat Reduction Agency (DTRA)
 - a new nanotechnology program in chem/bio defense has been initiated
- Other significant goals for DoD
 - Discovery of new phenomena and processes to enable breakthrough advantages for warfighter and battle systems capabilities
 - Develop robust strategies for synthesis, characterization
 - Assembly of individual nanostructures
 - Explore applications of nanostructures for revolutionary catalysis, scavengers, taggants, and sensors
 - Elucidate fundamental aspects of phonon and electron transport in individual nanowires and two and three dimensional nanostructures as they relate to the development of high performance thermoelectric, thermionic, and photovoltaic devices for advanced solid state power generation, cooling, and thermal management.

DARPA

- New DARPA programs exploiting nanotechnologies are expected in 2007-8
 - Topics under development will emphasize the application of nanotechnology in applications relevant to national defense
 - E.g., quantum computation and nanoelectronic devices

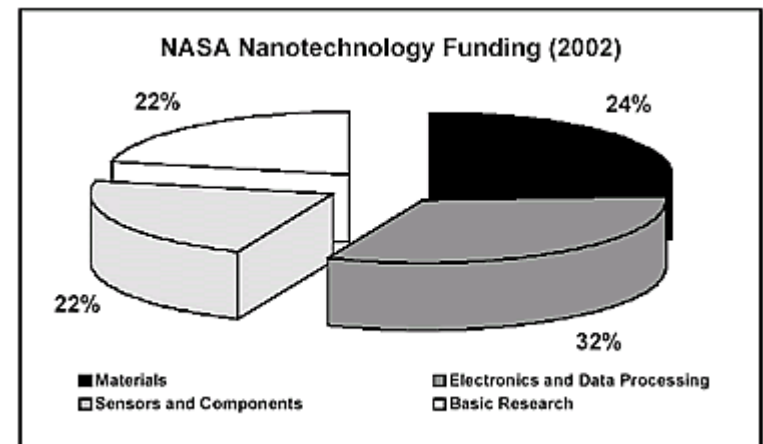
Nanotechnology Manufacturing Improvement Survey for ONR



http://www.aciusa.org/randd/randd_nano.htm

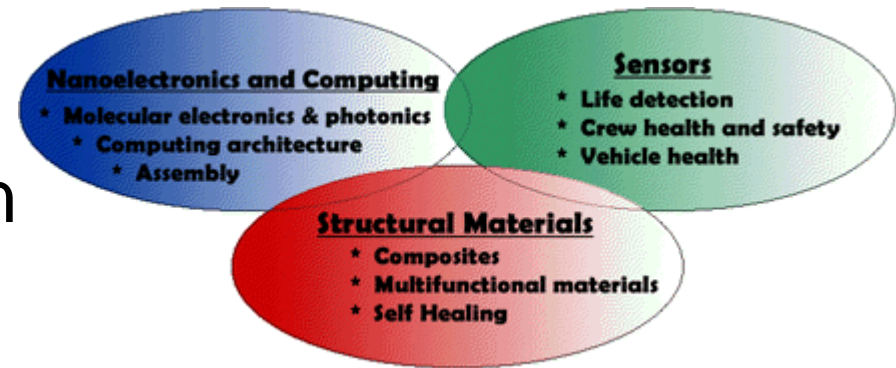
NASA

- Materials
 - \$11 million - controlled by NASA Langley Laboratory),
- Electronics and data processing
 - \$15 million, controlled by NASA Ames Laboratory,
- Sensors and Components
 - \$10 million, controlled by NASA Jet Propulsion Laboratory,
- Basic research



NASA

Nanotechnology Mission Needs



- Onboard computing systems for future autonomous intelligent vehicles
- High performance computing (Tera- and Peta-flops)
- Revolutionary computing technologies
- Smart, compact sensors, ultras-small probes
- Advanced miniaturization of all systems
- Microspacecraft
- Autonomous 'thinking' spacecraft
- Micro-, nano-rovers for planetary exploration

NASA Nanotechnology Roadmap

C A P A B I L I T Y

Multi-Functional Materials



High Strength Materials
(>10 GPa)



Reusable Launch Vehicle
(20% less mass, 20% less noise)



Revolutionary Aircraft Concepts
(30% less mass, 20% less emission, 25% increased range)



Autonomous Spacecraft
(40% less mass)

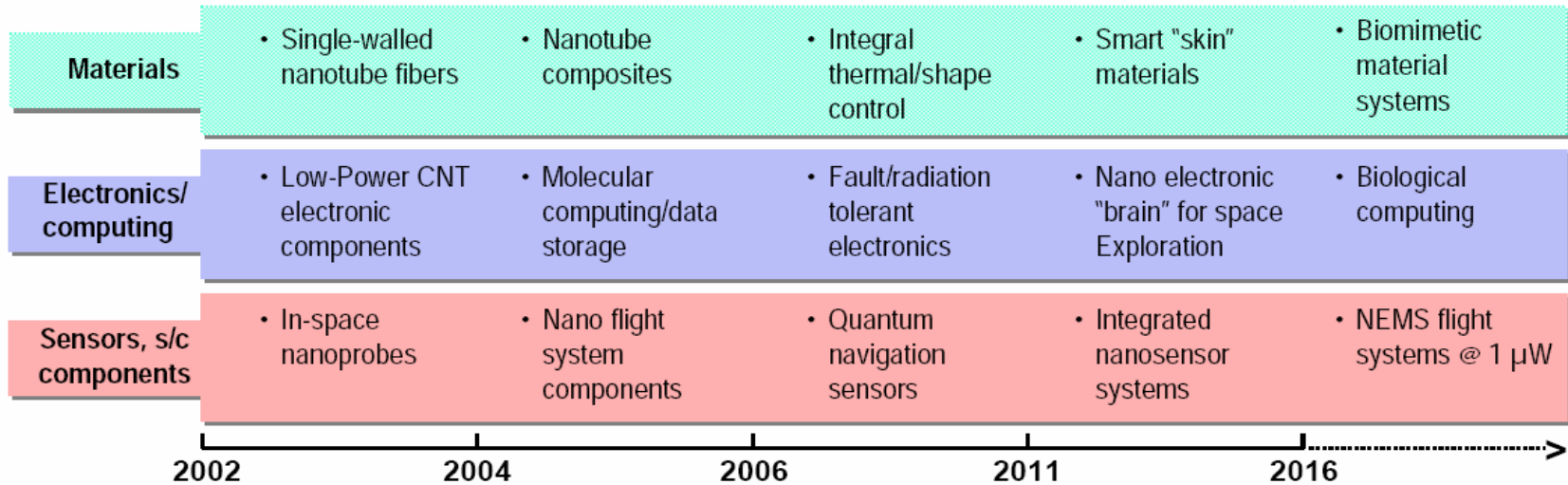
Bio-Inspired Materials and Processes



Adaptive Self-Repairing Space Missions



Increasing levels of system design and integration →



NASA Center for Nanotechnology

- Ames Research Center
 - To develop novel concepts in nanotechnology for NASA's future needs on electronics, computing, sensors, and advanced miniaturization of all systems;
 - To develop highly integrated and intelligent simulation environment that facilitates the rapid development and validation of future generation electronic devices as well as associated materials and processes through virtual prototyping at multiple levels of fidelity.

NIST

- Projects in the following areas were funded in 2007
 - Molecular electronics
 - Quantum computing
 - Nanomagnetodynamics
 - Nanotribology
 - Nanomanufacturing and Nanofabrication
 - Nanoimprint lithography
 - Particle metrology
 - Autonomous atom assembly
- About half of the total allocated funds were used to continue current internal efforts
- Half was used to leverage existing efforts with external partners.

NIST National Nanomanufacturing and Nanometrology Facility (N3F)

- Opened in Gaithersburg, MD, in 2005
 - Includes Center for Nanoscale Science and Technology (CNST)
 - Develop the necessary instrumentation, measurement science, and standards needed for the nanomanufacturing industry