

**Nano.gov**

U.S. National Nanotechnology Initiative

# **Future Directions of the National Nanotechnology Initiative – NNI 2.0**

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Director**

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**www.Nano.gov**

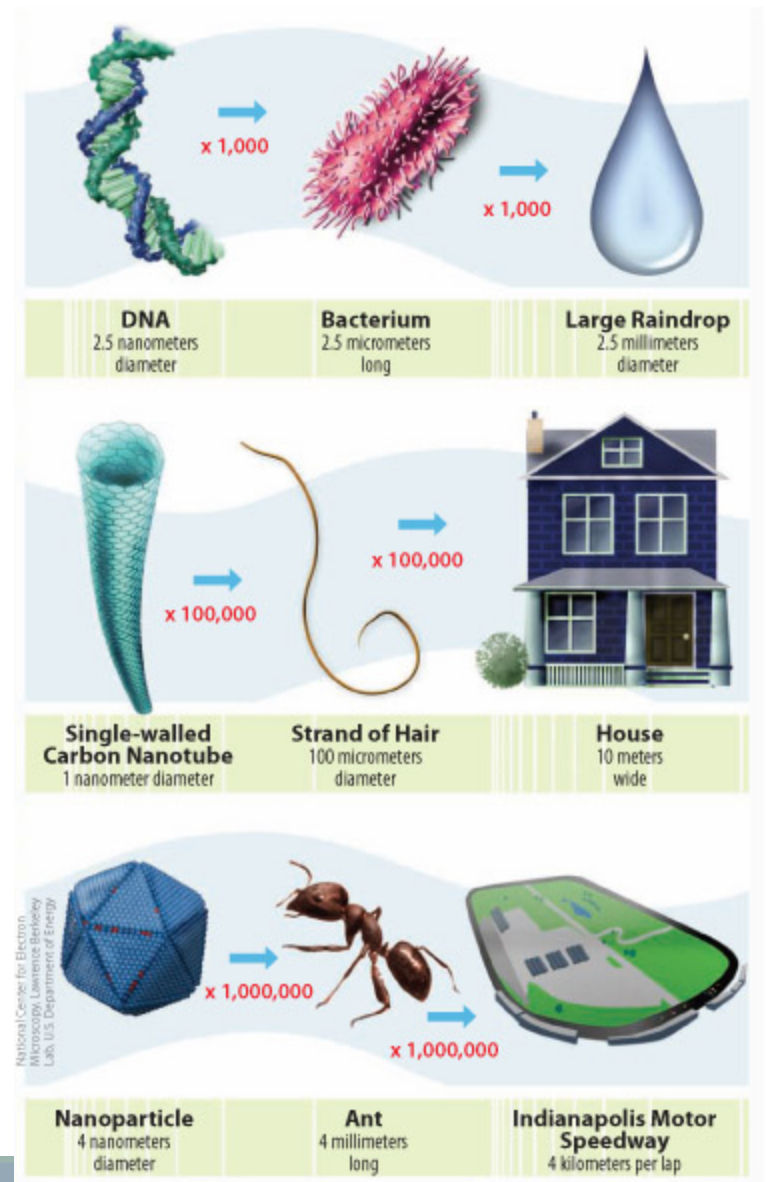
# Overview

- What's so special about nanotechnology
- National Nanotechnology Initiative
  - Investments in nanotechnology
  - NNI Signature Initiatives
- Clinton Challenges
- Other NNI progress
- The future - NNI 2.0
- Summary

# What is Nanotechnology?

- Control of matter and processes at the atomic and molecular level
  - Typically 100 nanometers in two dimensions
    - Nanometer is one billionth of a millimeter
      - Single sheet of paper is about 100,000 nm thick
- Conventional physics often breaks down at the nano-level
  - Affects electrical, optical, thermal and mechanical properties

Source: National Nanotechnology Initiative  
([www.nano.gov](http://www.nano.gov))



# Nanotechnology is Nothing New



**Lycurgus Cup**  
*(British Museum)*



Damascus Steel

# NNI Vision

A future in which the ability to understand and control matter at the nanoscale leads to *a revolution in technology and industry that benefits society.*



# Large Surface Areas Cause Higher Chemical Reactivity



# AIICE Propellant

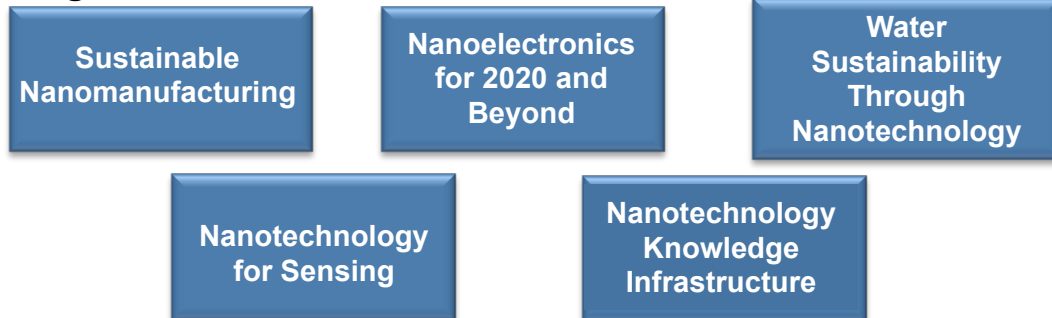


# The National Nanotechnology Initiative (NNI)

- Established in 2000 by President Bill Clinton
- Intent of the NNI is to provide a framework for member agencies to work together to:
  - Advance world-class nanotechnology research
  - Foster the transfer of technologies into products for commercial and public benefit
  - Develop and sustain educational resources, a skilled workforce and the supporting infrastructure and tools to advance nanotechnology
  - Support the responsible development of nanotechnology
- The NNI is a coordinated initiative not a distinct funding program



## Signature Initiatives

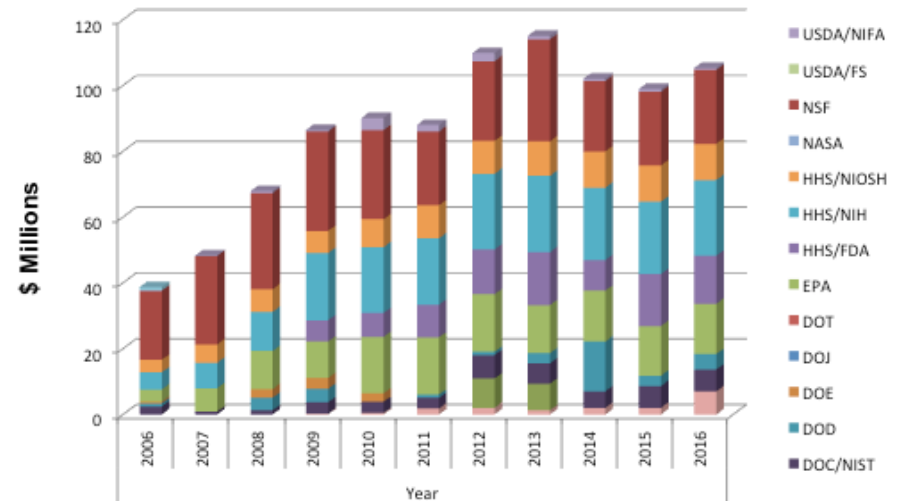




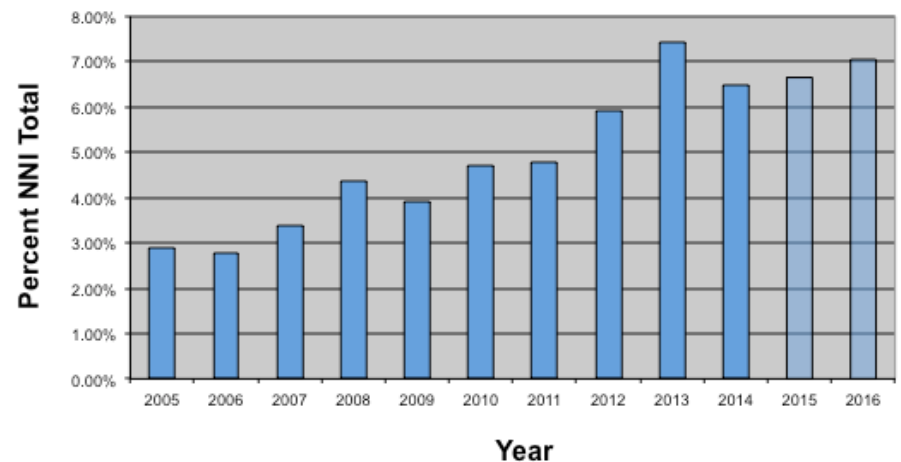
# NNI EHS Priorities

- Federal agencies continue to target and accelerate nanoEHS research by
  - Prioritizing nanomaterials
  - Establishing standard measurements, terminology, nomenclature, and assay methods
  - Developing informatics and predictive modeling tools
  - Stratifying knowledge for risk assessment
  - Partnering to achieve the NNI EHS research goals, both domestically and internationally

EH&S Investments by Agency



Percentage of NNI Budget Invested in EH&S



# Quantifying Exposure to Engineered Nanomaterials in Consumer Products (QEEN)

- Workshop co-sponsored by CPSC and the NNI to identify knowledge gaps and technology needs in understanding effects of exposure to engineered nanomaterials to humans and the environment
- Major findings:
  - Significant progress has been made, especially over the past decade, in our ability to quantify ENM exposure
    - New characterization tools
    - Exposure assessment methodologies
    - Simulation and modeling
    - Ability to detect NPs well below known toxicity levels
  - Techniques needed for more rapidly estimating exposure risk, including alternative testing models and high throughput methods
  - Studies need to better replicate real world conditions
    - Concentrations
    - Changes to ENMs through product life cycle
  - New focus on determining biomarkers linked to disease

**Quantifying Exposure to Engineered Nanomaterials (QEEN) from Manufactured Products**  
Addressing Environmental, Health, and Safety Implications

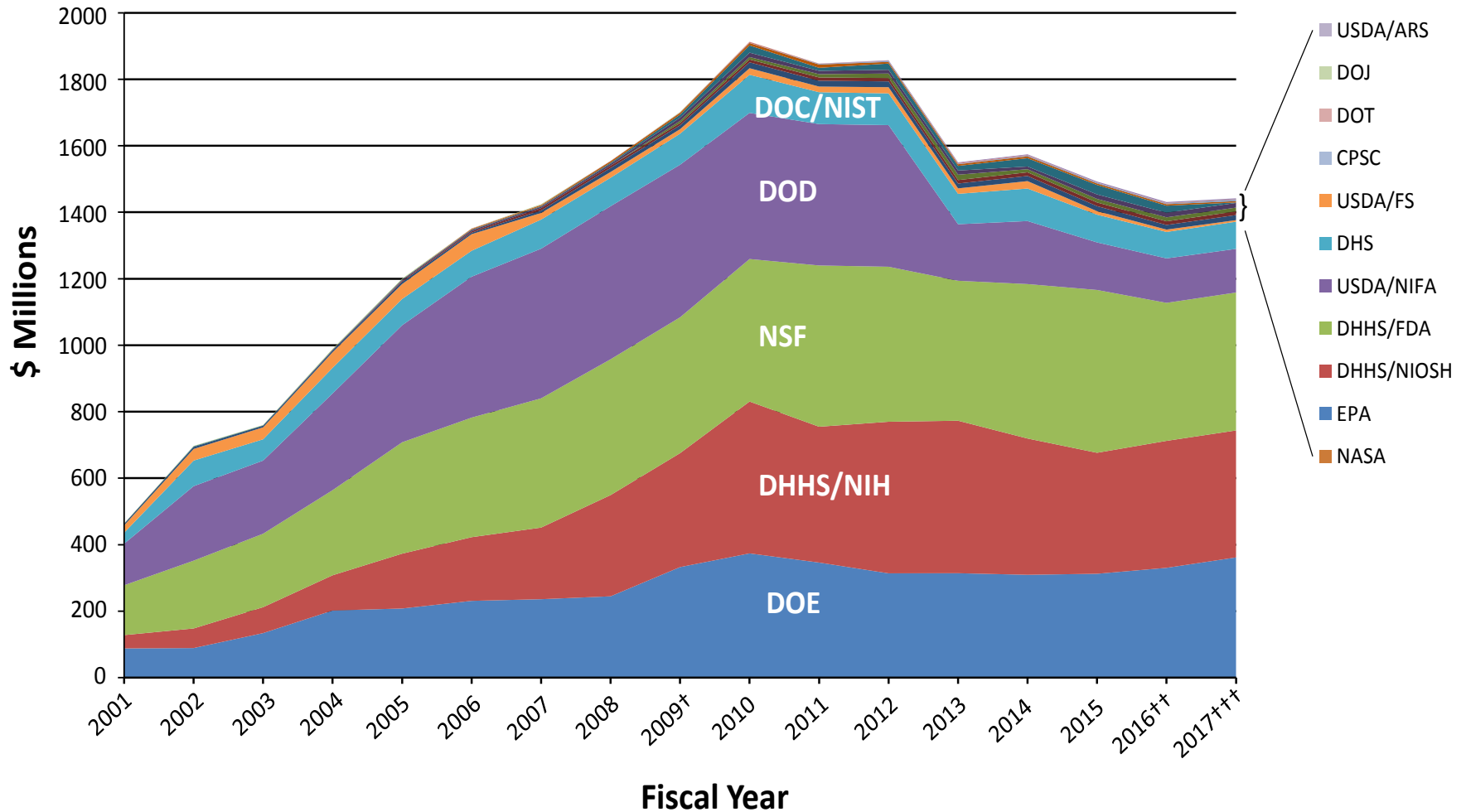
**Workshop Proceedings**  
July 7–8, 2015

Sponsored by the  
**Consumer Product Safety Commission**  
in collaboration with the  
**National Nanotechnology Initiative**

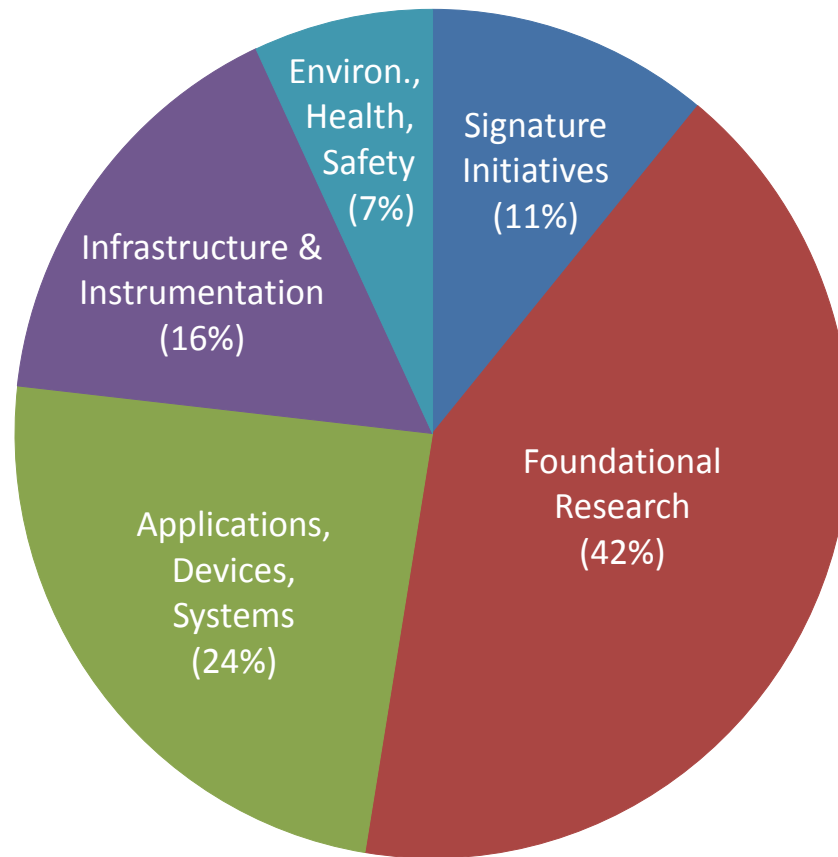
The diagram illustrates the equation for exposure:  $Exposure = \int (Concentration) \times (Exposure\ Factors) dt$ . Arrows point from the following factors to the equation:

- Substance fate and transport
- Substance matrix interactions
- Population characteristics
- Population behavior
- Integrated over time

# Total NNI Investments Exceed \$23B



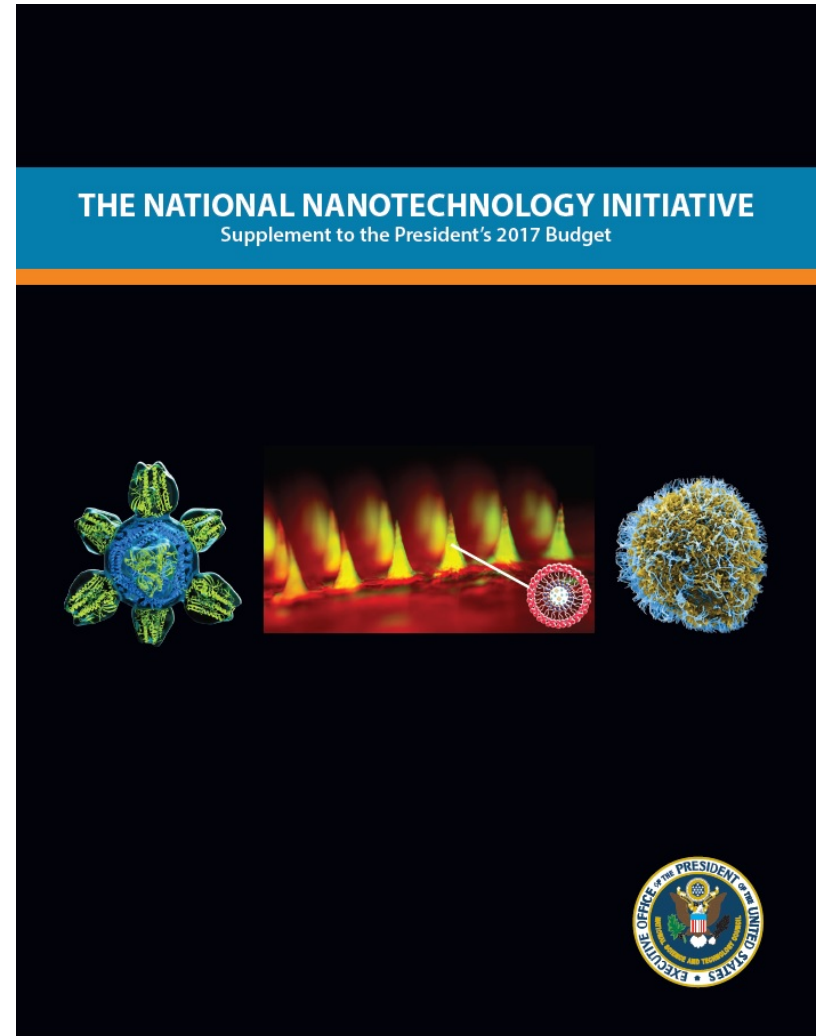
# NNI Has a Balanced Portfolio of Investments



# NNI Reporting

The NNI Supplement to the President's Budget:

- Funding information by agency/department and PCA for prior, current FY and requested amount for budget year
- Accomplishments from prior FY
- Plans for current FY and budget year
- Available on [www.nano.gov](http://www.nano.gov)



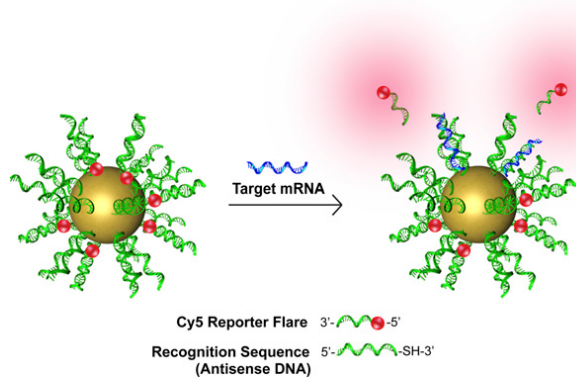
# The National Nanotechnology Initiative (NNI)

“ Just imagine, materials with 10 times the strength of steel and only a fraction of the weight; shrinking all the information at the Library of Congress into a device the size of a sugar cube; detecting cancerous tumors that are only a few cells in size. Some of these research goals will take 20 or more years to achieve. But that is why—precisely why there is such a critical role for the Federal Government.”

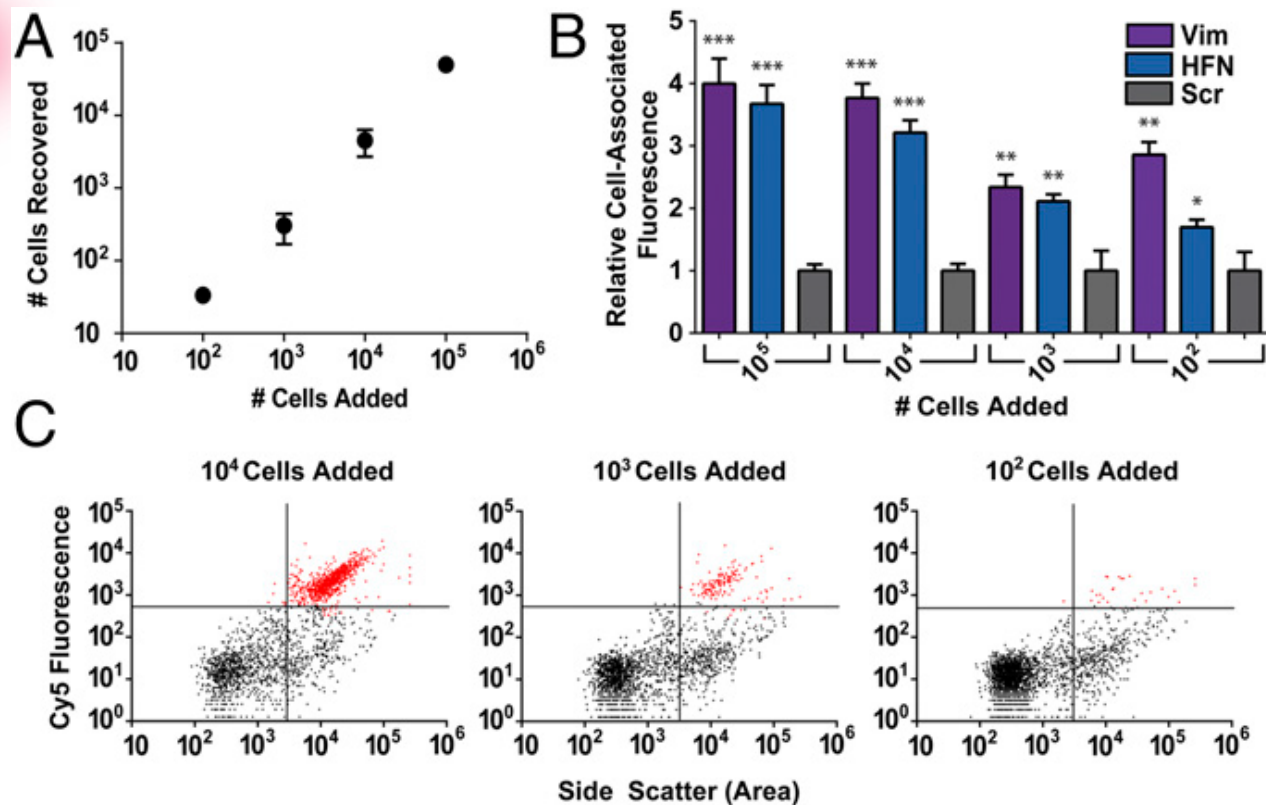
President Clinton, July 21, 2000



# NanoFlares Can Detect as Few as 100 Cancer Cells per mL of Blood



- Gold NPs decorated with a monolayer of antisense DNA and fluorophore containing reporter flare
- Binding of target mRNA releases fluorophore



T.L. Halo et al *PNAS* **2014**, *111*, 17104-17106

# The National Nanotechnology Initiative (NNI)

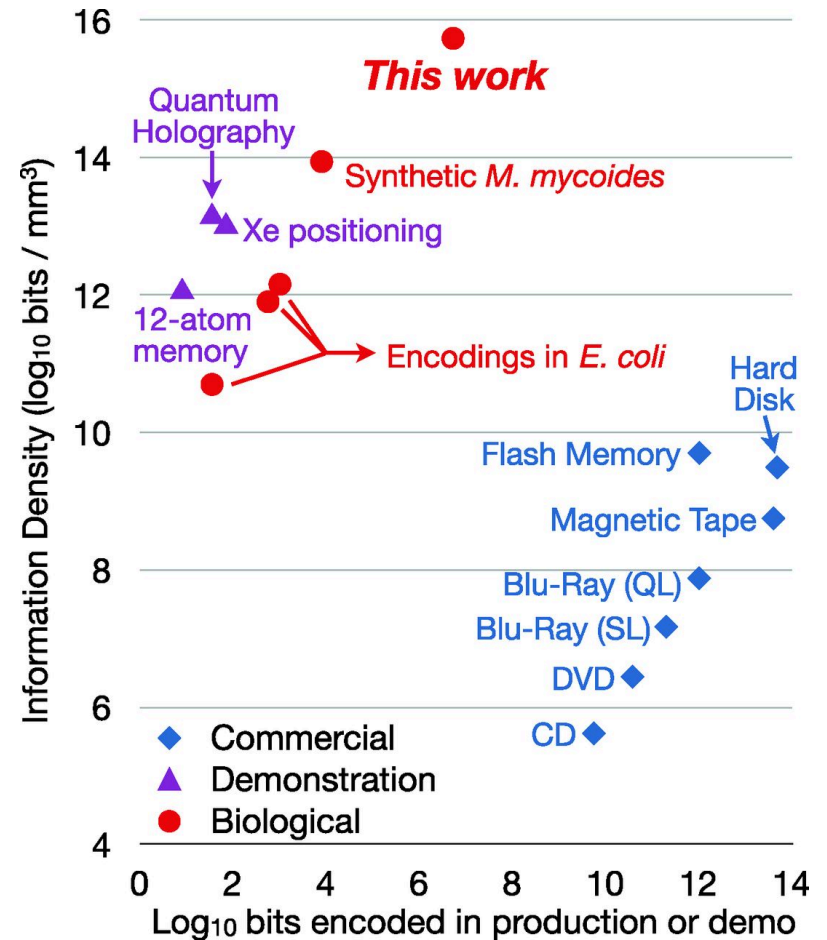
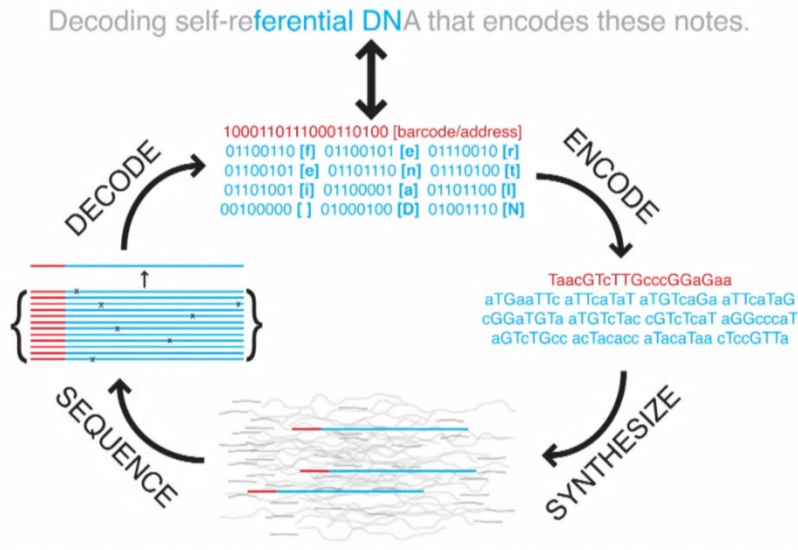
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*President Clinton, July 21, 2000*





# DNA Encoding Provides a Route to High Density Data Storage



G.M. Church, Y. Gao, S. Kosuri *Science* **2012**, 337, 1628

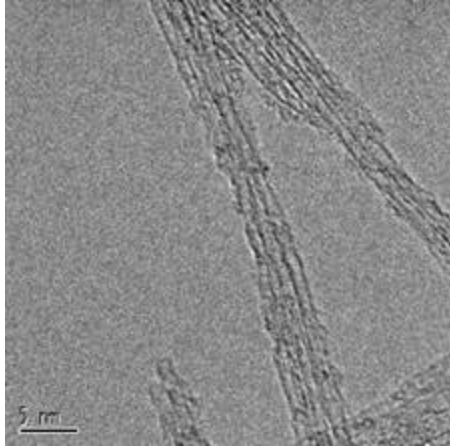
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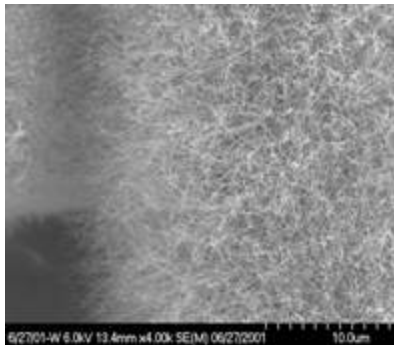
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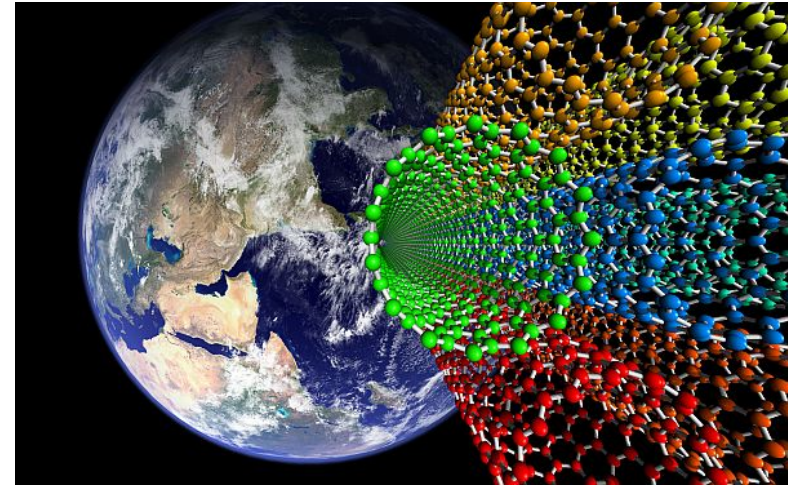
# Carbon Nanotube Based Materials



**Purified Single Wall  
Carbon Nanotubes**



**Nanotube Modified  
Substrates**



**Carbon Nanotube Space Elevator**

Nanotubes have remarkable properties-

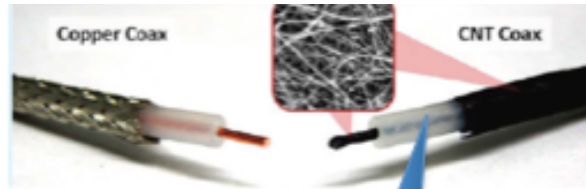
- Specific strength 150X that of conventional carbon fibers, 100X aluminum
- Elongation 10X that of conventional carbon fibers
- Electrical and thermal conductivities ~10X that of high conductivity carbon fibers

Because of these properties, carbon nanotubes have been proposed for disruptive applications such as a space elevator cable

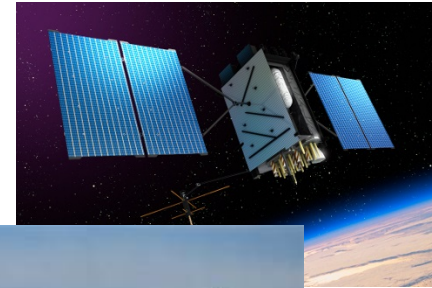
# Carbon Nanotube Yarns in Production



# Replacement of Metallic Conductors with CNTs Can Reduce Data Cable Weight by 30-70%



Polyimide  
Aerogel  
Insulation



**NORTHROP GRUMMAN**

**LOCKHEED MARTIN**

**BOEING**

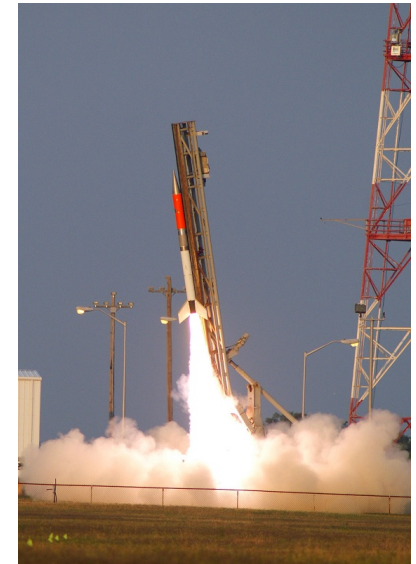
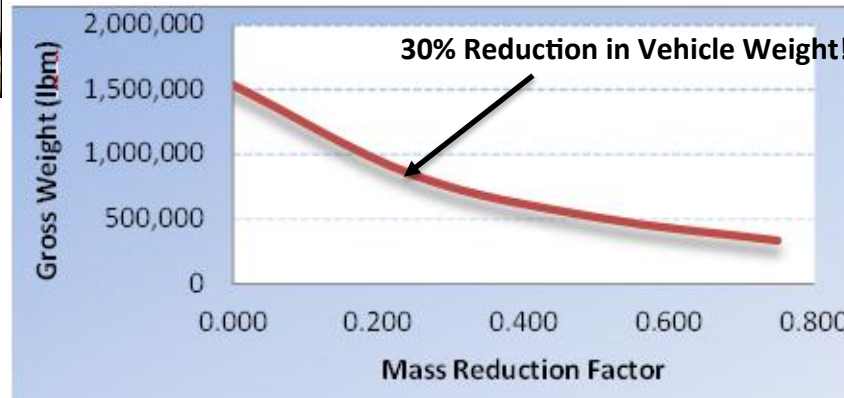
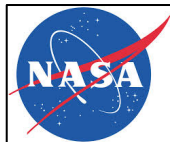
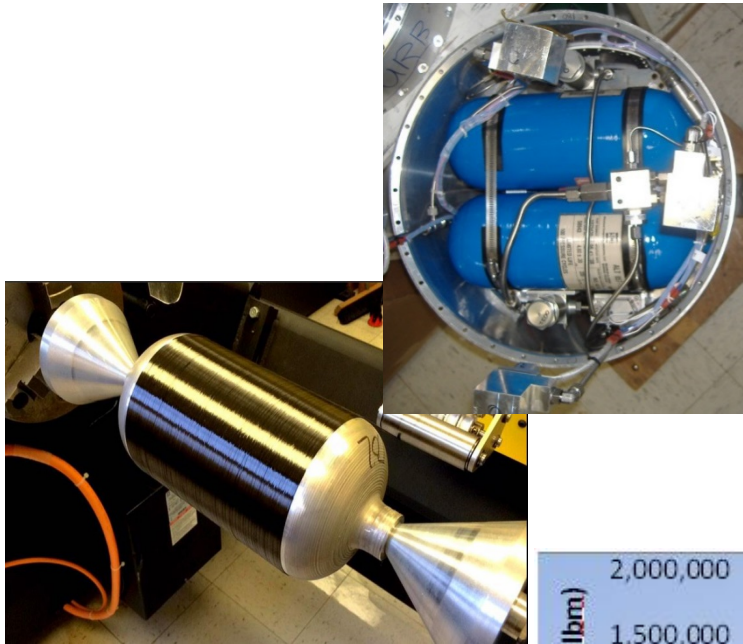


**nanocomp**  
TECHNOLOGIES, INC.

**MINNESOTA WIRE**  
Life Saving Connections

**MICRO-COAX**  
Leading the way in transmission line solutions.

# CNT Reinforced Composites to be Demonstrated in a Structural Component



Flight Test 2016



# Nanotechnology is Now



<http://www.smt.sandvik.com/nanoflex>



Eddie Bauer with NanoTex



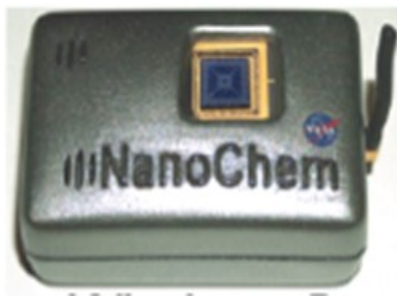
<http://www.bmc-racing.com>

# Nanotechnology Has Made it into Space

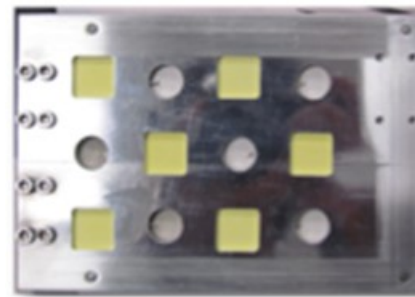


Silica Aerogels

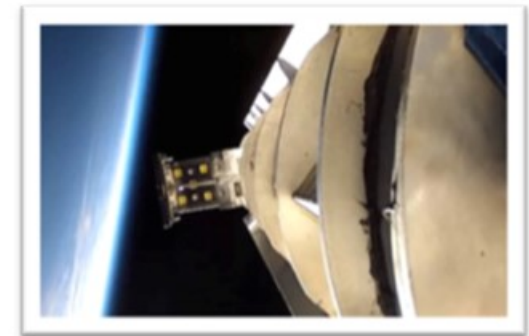
## CNT Nanocomposites for Charge Dissipation



CNT "Electronic Nose"



Polyimide Aerogels

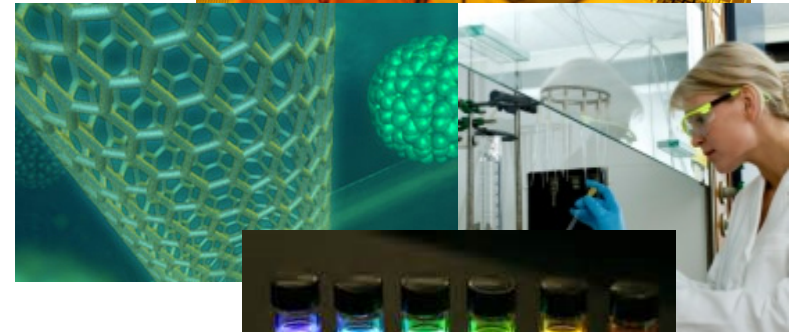
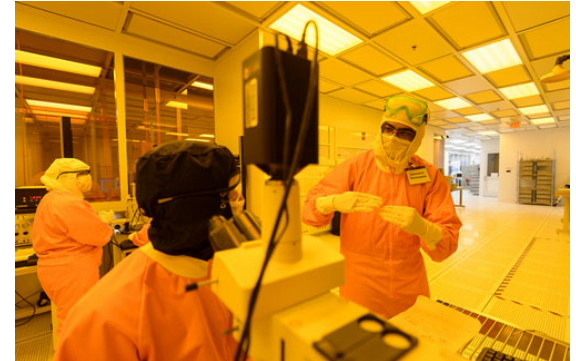




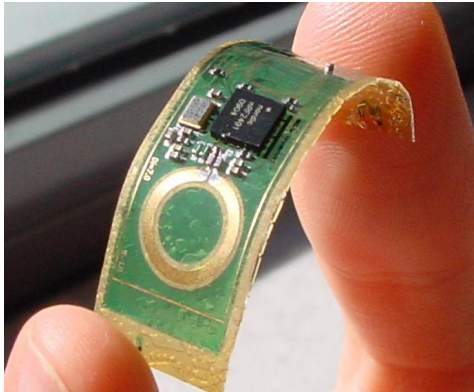
# Some Nano-Factoids

Lux Research, February 2016

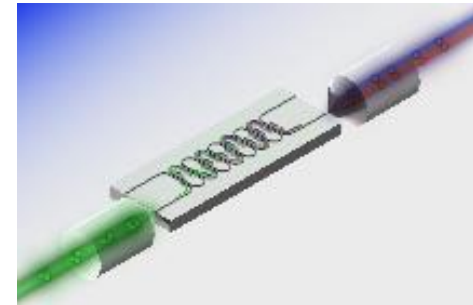
- Worldwide governments, corporations and VCs invested **\$18.1 billion in 2014** (8% increase over 2010)
  - The **U.S. contributed 33%** of this amount – leads in government and corporate spending
  - Corporate spending in the US in 2014 was \$4.0 billion, government spending was \$1.67 billion
- **Global value of nano-enabled products is predicted to reach \$3.7 trillion by 2018.**
  - The **revenue** from nano-enabled products globally grew from \$339 billion in 2010 to **\$1.6 trillion in 2014.**
    - US revenues grew from \$109M to \$370M
  - The **revenue** from nanomaterials increased 35% over 2012 to \$2.12 billion in 2014



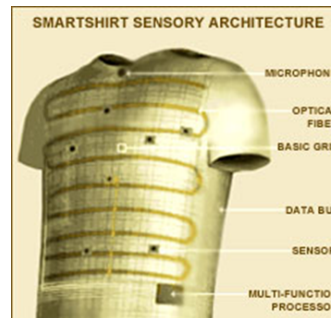
# Nanotechnology and Innovative Manufacturing Institutes



**Flexible Hybrid Electronics  
Manufacturing Innovation  
Institute (*Flex-Tech Alliance*)**



**American Institute for  
Manufacturing Integrated  
Photonics (*U of Rochester*)**



**Advanced Functional Fabrics of  
America(*MIT*)**

# NNI 2.0


- Pivotal year for the NNI
  - NNI celebrated it's 15<sup>th</sup> anniversary last year – what should the NNI look like in the future?
  - NNI Strategic Plan Update
  - Election Year
- Some issues:
  - Nanotechnology as a focus area vs. as an enabling technology
  - Transition of nanotechnology discoveries from lab to market
  - Role of nanoEHS
- Elements Necessary for Continued Vitality and Growth of the NNI
  - Bold and compelling vision for the future
    - Grand Challenges
    - NNI Strategic Plan
  - Impactful accounting of the accomplishments – telling the NNI story
    - Education and Outreach
  - Broad community support for continuation
    - Nanotechnology business community
    - Technical and professional societies

# Grand Challenges

- Recommended by PCAST in their 2014 review of the NNI
- Definition derived from Administration's Innovation Policy
- Attributes of Grand Challenges are:
  - ✓ Require advances in fundamental scientific knowledge, tools, and infrastructure for successful completion.
  - ✓ Drive the need for collaboration between multiple disciplines, some of which do not normally interact, to come together, collaborate and share resources and information to solve the challenge .
  - ✓ Span efforts from discovery and fundamental science to engineering demonstration and commercialization, i.e., catalyze the transition of technologies from lab to market.
  - ✓ Be too big to be undertaken by one or even a few organizations.
  - ✓ Be exciting enough to motivate decision makers to provide funding and resources and multiple organizations to collaborate, share resources, and information to solve the challenge.
  - ✓ Have a measurable end-point and clear intermediate milestones that are measurable and valuable in their own right

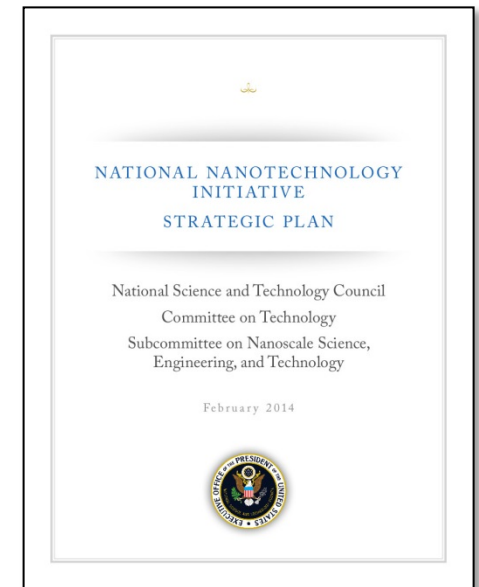
# 1<sup>st</sup> Nanotechnology Grand Challenge

**Create a new type of computer that can proactively interpret and learn from data, solve unfamiliar problems using what it has learned, and operate with the energy efficiency of the human brain**

- Announced on 10-20-2015 by the WH Office of Science and Technology Policy
  - Moving beyond conventional (von Neumann) computing architectures to make computers that can solve problems faster than conventional computers and require much less energy
  - Capability enables:
    - Modeling of complex phenomena, e.g., turbulence
    - Processing large amounts of data, e.g., satellite mapping of resource utilization
    - Autonomous robots and vehicles
    - Intelligent prosthetics
- 
- White paper written by Federal agency participants identified several research areas to address this challenge
    - Advanced materials
    - Improved devices and interconnects
    - Computing architectures
    - Brain-inspired approaches
    - Fabrication/Manufacturing
    - Software, Modeling and Simulation
  - Other Grand Challenge topics are under consideration

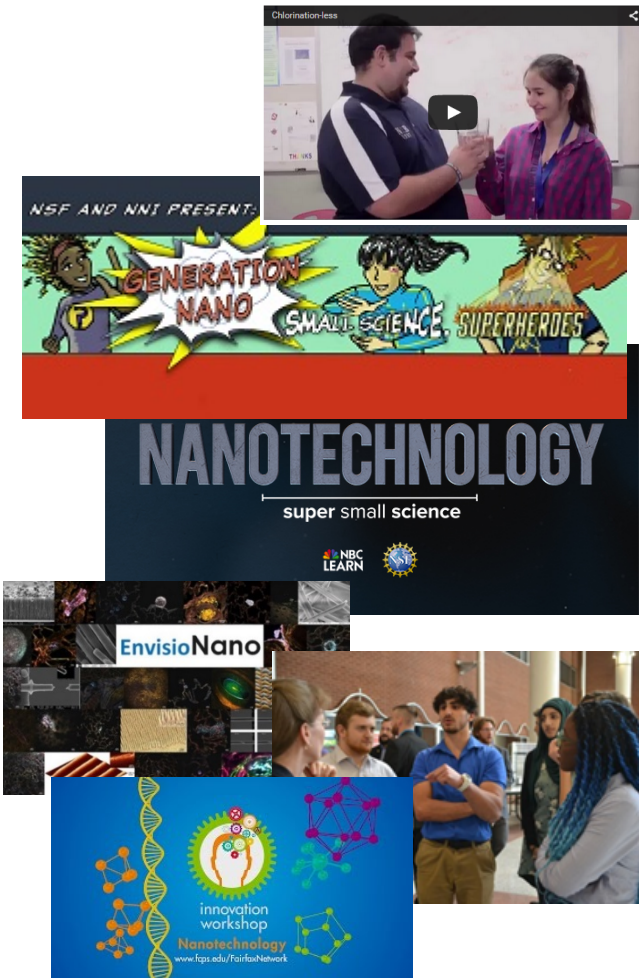
# NNI Strategic Plan

- Describes vision and goals, strategies to achieve the goals, and investment strategy
- Identifies specific objectives toward collectively achieving the vision
- Currently undergoing an update (every 3 years)
  - Input from NNI member agencies and broader nanotechnology community
  - NNI Strategic Plan Stakeholders' Workshop held in Washington on May 19 and 20
    - Very worthwhile discussion that will help shape the new Plan
    - Workshop summary as an appendix to the Plan
- Draft released for public comment from 9/12 to 9/25
- Final approval by OSTP is underway



# Educating the Next Generation

- Utilized contests to challenge students, highlight their research and the accomplishments of the NNI
  - EnvisioNano
  - Nano Film
  - GenerationNano
- Collaborated on the development of high quality videos to educate the students and the public
  - NSF/NBC Learn - *Nanotechnology Super Small Science* – 9 million students, >200 NBC affiliates
  - West Carolina State U (animations) – airing on PBS stations in Central VA (190K households) + potential distribution to 356 stations nationally
  - Fairfax County, VA Schools – Innovation Workshop: Nanotechnology (classroom videos) – Telly and Emmy (local) awards
- Engaging educators – NSTA, Teachers' Network and webinar, NSF-funded workshop *Nanoscale Science and Engineering Education (NSEE) – The Next Steps*
- Established Network of Emerging Tech Student Groups and annual Student Conference at TechConnect World (students from 11 schools across U.S.)



# National Nanotechnology Day

An event led by the U.S. nanotechnology community to raise awareness of nanotechnology, how it is currently used in products that enrich our daily lives, and the challenges and opportunities it holds for the future.

- 1<sup>st</sup> ever on October 9<sup>th</sup>
- Technical societies (e.g. ASM, ASME, ACS, IEE, AVS) are:
  - ✓ Publishing perspective articles and op-ed pieces on future directions for nanotechnology
  - ✓ Dedicating October issue of their journal to nanotechnology
  - ✓ Hosting nanotechnology workshops and symposia throughout October
  - ✓ Featuring nanotechnology activities on their society's website
- Universities (e.g. Cornell, MIT, Penn, Rice, NC State, U of Nebraska) conducting education and outreach activities
- NNCO is:
  - ✓ Sponsoring 100 Billion Nanometer Dash
  - ✓ Recording and posting NanoNuggets
  - ✓ Hosting a website with links to National Nanotechnology Day activities by technical societies, universities, National labs and Federal agencies

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## Nanomaterials: A Foundational Building Block to Nanotechnology Breakthroughs Past and Future

Daniel S. Gianola and Kevin J. Hemker

### Opinion: For Your Consideration

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Daniel S. Gianola



Kevin J. Hemker

The National Nanotechnology Initiative (NNI) was launched in 2001 to promote a broad interagency goal of understanding and controlling materials at the nanoscale to produce disruptive advances in technology.

NNI's 15 in October opportunity future pri

It is ov of NNI's nanotech by (an igh medical computer efficiency devices. I articles on the nanite trend has nanotech now com For most the story year has a recent champion equipment enhanced of carbon and suffic still in its questio of mater nanotech societal i Table 1 inspired)

National Academy of Sciences, a response to the call for arms from the White House Office of Science and Technology Policy: (1) Increase the five-year survival rates by 50 percent for the most difficult to

## How fast can YOU run 100 BILLION NANOMETERS???



Upload a picture or video of yourself running  
#100BillionNanometers for National Nanotechnology Day.

#NationalNanoDay is October 9th!



What's the big deal about something so small?

Cool things happen at the nanoscale resulting in new materials and devices with amazing properties that are already changing our way of life.

Nanotechnology is already in:

- Phones that are really pocket-sized super computers
- Odor-resistant fabrics so our running and workout clothes don't stink
- Displays for our tablets and flat screen TVs with more vibrant pictures

Nanotechnology will soon be in:

- Metamaterials that can be turned into invisibility cloaks
- Better drugs to treat infectious diseases and cancer
- Gecko-inspired gloves so that you can literally climb walls

Want to learn more? Go to [Nano.gov](http://Nano.gov)



#NationalNanoDay | #100BillionNanometers | #100BNM



# Summary

- The NNI has been a highly successful initiative
  - 16 + years of US leadership in nanotechnology R&D
  - Enabled the development of unique nanofabrication and characterization facilities
  - Facilitated the commercialization of nanotechnology products – US accounted for 23% of global revenues in nanotechnology-enabled products
  - Promoted the responsible development of nanotechnology based products
- Nanotechnology has become pervasive in commercial products
  - Automotive
  - Health Care
  - Cosmetics
  - Sporting Goods
  - Consumer Electronics
- It's time to start talking about the next era of the NNI – NNI 2.0
- We want your input
  - Where do you see nanotechnology advancing globally – what are the opportunities and challenges over the next 10 years?
  - What can and should the NNI do to address these and maintain US leadership?
  - What should the broader nanotechnology community do to insure the continued vitality and success of the NNI?