Future Directions of the National Nanotechnology Initiative – NNI 2.0

Michael A. Meador
Director
U.S. National Nanotechnology Coordination Office
mmeador@nnco.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)
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
AlICE 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

- Sustainable Nanomanufacturing
- Nanoelectronics for 2020 and Beyond
- Water Sustainability Through Nanotechnology
- Nanotechnology for Sensing
- Nanotechnology Knowledge Infrastructure

National Nanotechnology Initiative

Collaborative research and development that will advance understanding and control of matter at nanoscale for:

- National economic benefit
  - National security
  - Improved quality of life
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
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
Total NNI Investments Exceed $23B
NNI Has a Balanced Portfolio of Investments

- Foundational Research (42%)
- Applications, Devices, Systems (24%)
- Infrastructure & Instrumentation (16%)
- Environ., Health, Safety (7%)
- Signature Initiatives (11%)
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
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, California Institute of Technology, January 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
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DNA Encoding Provides a Route to High Density Data Storage

Decoding self-referential DNA that encodes these notes.

This work

- Quantum Holography
- Synthetic M. mycoides
- Xe positioning
- 12-atom memory
- Encodings in E. coli

Information Density (log10 bits / mm²)

- Hard Disk
- Flash Memory
- Magnetic Tape
- Blu-Ray (QL)
- Blu-Ray (SL)
- DVD

Commercial
Demonstration
Biological

G.M. Church, Y. Gao, S. Kosuri *Science* **2012**, *337*, 1628
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Carbon Nanotube Based Materials

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%
CNT Reinforced Composites to be Demonstrated in a Structural Component

Flight Test 2016

30% Reduction in Vehicle Weight!
Nanotechnology is Now

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

Eddie Bauer with NanoTex

http://www.bmc-racing.com
Nanotechnology Has Made it into Space

CNT Nanocomposites for Charge Dissipation

Silica Aerogels

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 15th 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.
1st 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.

• 1st ever on October 9th
• 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
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?