Twenty Five Hundred Years of Small Science

What's Next?

Lloyd Whitman

Assistant Director for Nanotechnology

White House Office of Science and Technology Policy

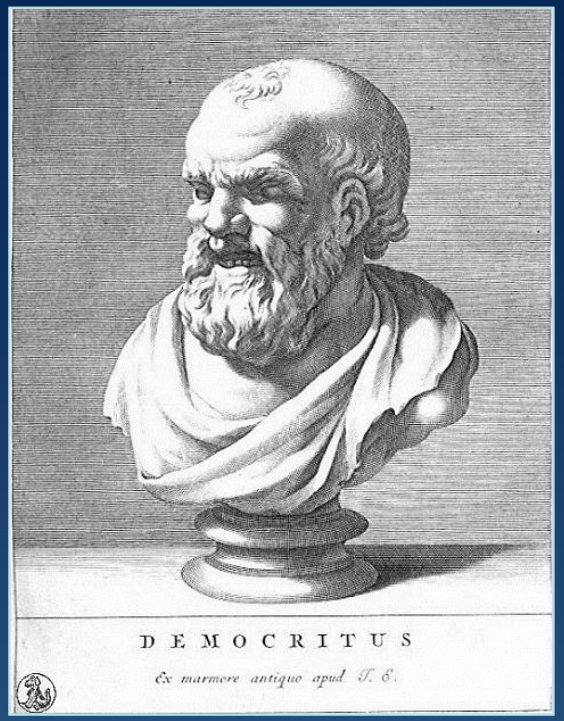
Workshop on Integrated Nanosystems for Atomically Precise Manufacturing

Berkeley, CA, August 5, 2015

Democritus (ca. 460 – 370 BC)

Everything is composed of “atoms”

Atomos (ἄτομος): that which can not be cut

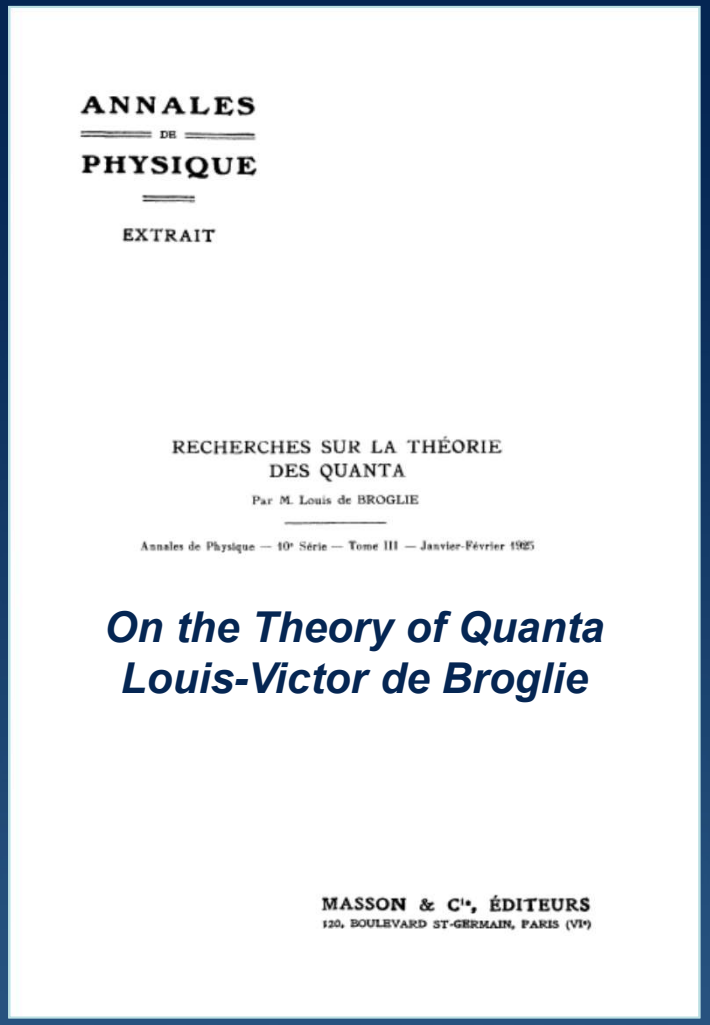


www.phil-fak.uni-duesseldorf.de/philo/galerie/antike/demokrit.html

Quantum Mechanics (1920s)

Max Planck *1918**
Albert Einstein *1921*
Niels Bohr *1922*
Louis de Broglie *1929*
Max Born *1954*
Paul Dirac *1933*
Werner Heisenberg *1932*
Wolfgang Pauli *1945*
Erwin Schrödinger *1933*

**Nobel Prizes in Physics*



ANNALES
DE
PHYSIQUE

EXTRAIT

RECHERCHES SUR LA THÉORIE
DES QUANTA

Par M. Louis de BROGLIE

Annales de Physique — 10e Série — Tome III — Janvier-Février 1925

On the Theory of Quanta
Louis-Victor de Broglie

MASSON & Cie, ÉDITEURS
120, BOULEVARD ST-GERMAIN, PARIS (VIe)

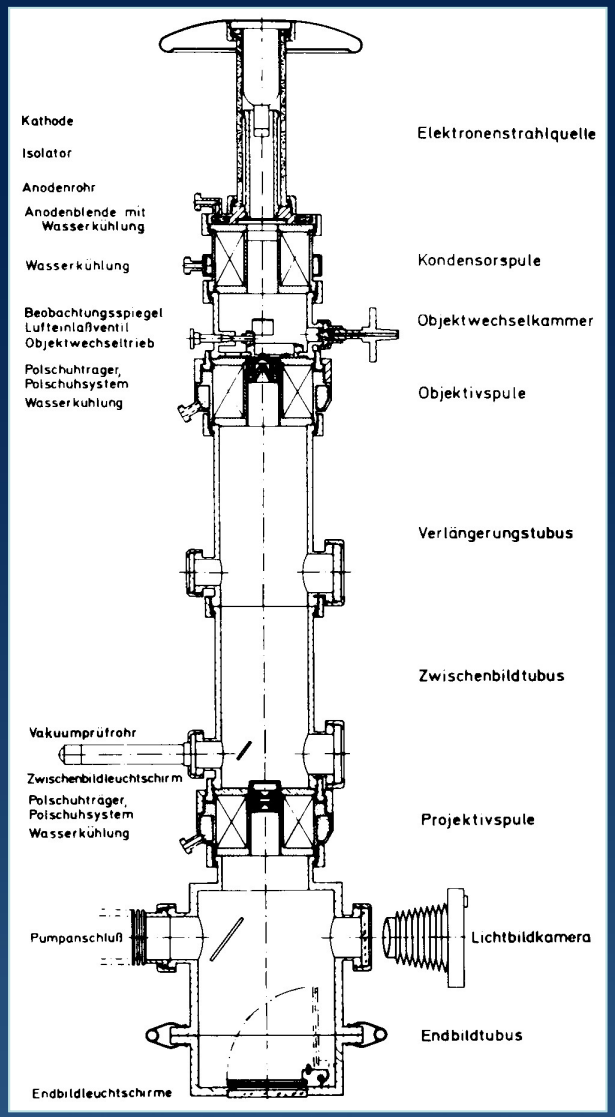
https://tel.archives-ouvertes.fr/tel-00006807

Ernst Ruska (1906 – 1988)

Electron Microscopy

Magnifying higher than the light microscope - 1933

Nobel Prize in Physics 1986



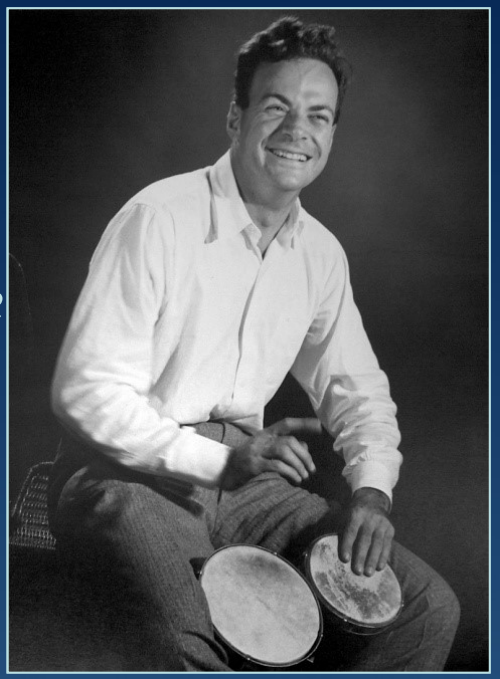
www.nobelprize.org/nobel_prizes/physics/laureates/1986/ruska-lecture.pdf

Richard Feynman (1918-1988)

There's Plenty of Room at the Bottom, An Invitation to Enter a New Field of Physics

What would happen if we could arrange the atoms one by one the way we want them…?

December 29, 1959



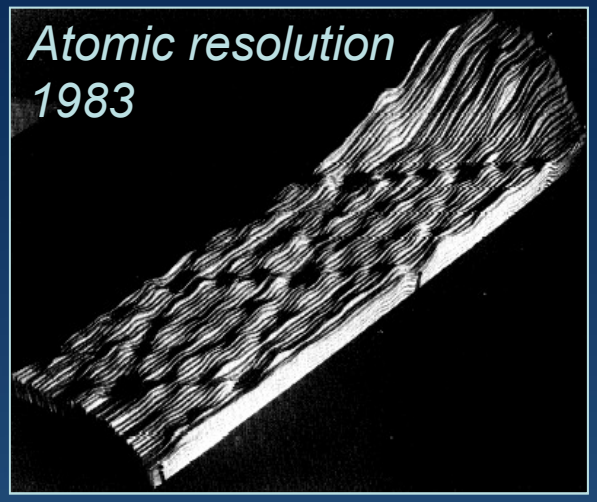
richard-feynman.net

Heinrich Rohrer (1933 – 2013)
Gerd Binnig

Scanning Tunneling Microscopy - 1981

I could not stop looking at the images. It was like entering a new world.

Gerd Binnig, Nobel lecture



Binnig, *et al.*, *PRL* **50**, 120 (1983)

Nobel Prize in Physics 1986

C60: Buckminsterfullerene

Kroto, Heath, O'Brien, Curl and Smalley - 1985

...a remarkably stable cluster consisting of 60 carbon atoms...a truncated icosahedron.

Nature ***318****, 162 (1985)*

http://www.acs.org/content/acs/en/education/whatischemistry/landmarks/fullerenes.html

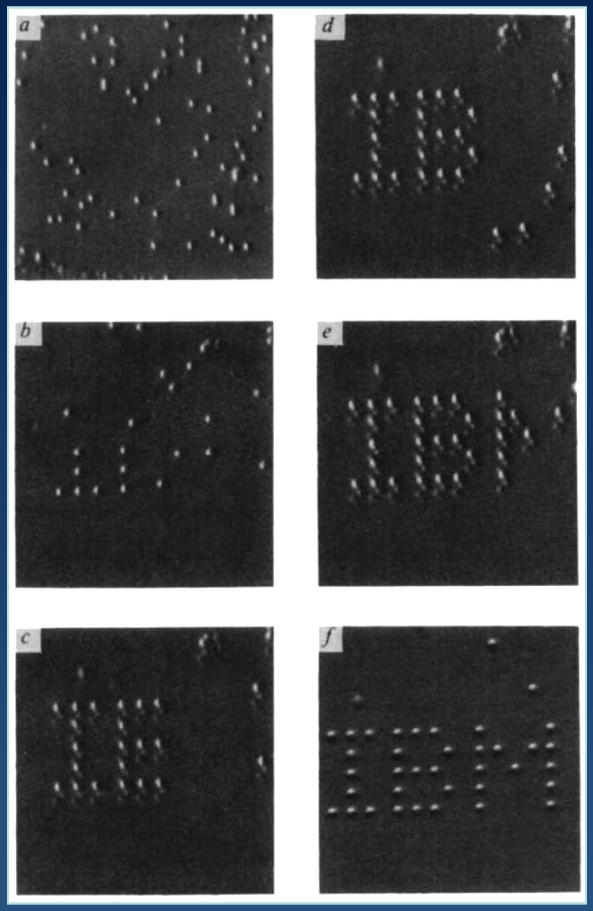
Nobel Prize in Chemistry 1996

Curl, Kroto, and Smalley

Positioning Single Atoms with a Scanning Tunnelling Microscope

Eigler and Schweizer - 1990

...fabricate rudimentary structures of our own design, atom by atom.



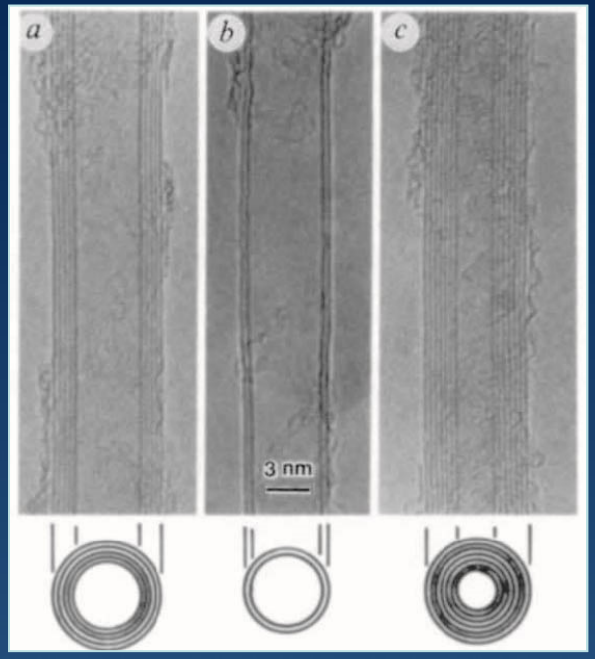
Nature **344**, 524 (1990)

Helical Microtubules of Graphitic Carbon

aka, carbon nanotubes

Sumio Iijima - 1991

Here I report the preparation of a new type of finite carbon structure consisting of needle-like tubes.



Iijima, *Nature* **354**, 56 (1991)

Proposing a National Initiative

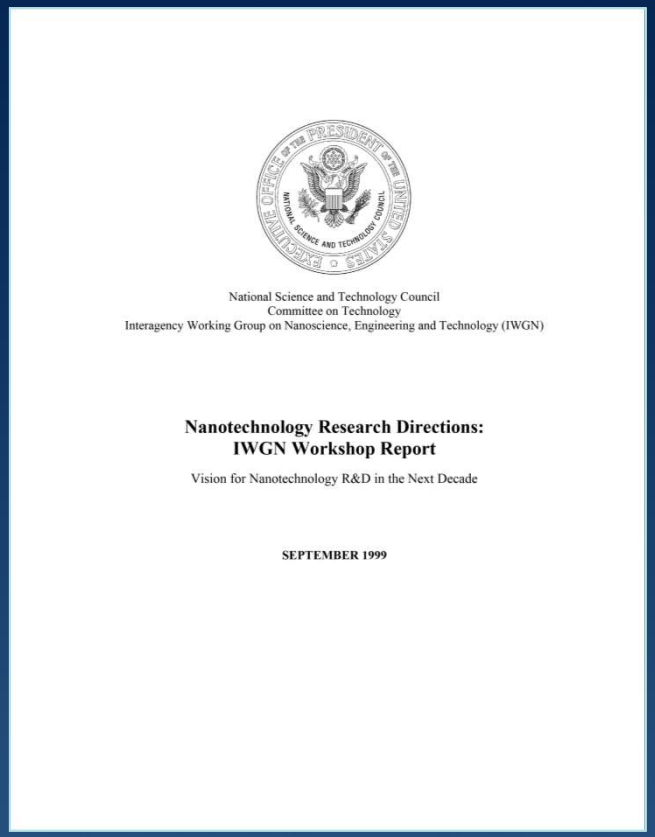
Interagency Working Group on Nanoscience, Engineering and Technology - 1999

Chair: M. C. Roco, NSF

White House IWGN Co-chair: T. A. Kalil

Vice-chair: R. Trew, DOD

Executive Secretary: J. S. Murday, NRL



National Science and Technology Council
Committee on Technology
Interagency Working Group on Nanoscience, Engineering and Technology (IWGN)

Nanotechnology Research Directions:
IWGN Workshop Report

Vision for Nanotechnology R&D in the Next Decade

SEPTEMBER 1999

President Clinton at CalTech

http://assets.kennislink.nl/system/files/000/082/771/large/ClintonNNI.jpg

Announcing the National Nanotechnology Initiative - January 21, 2000

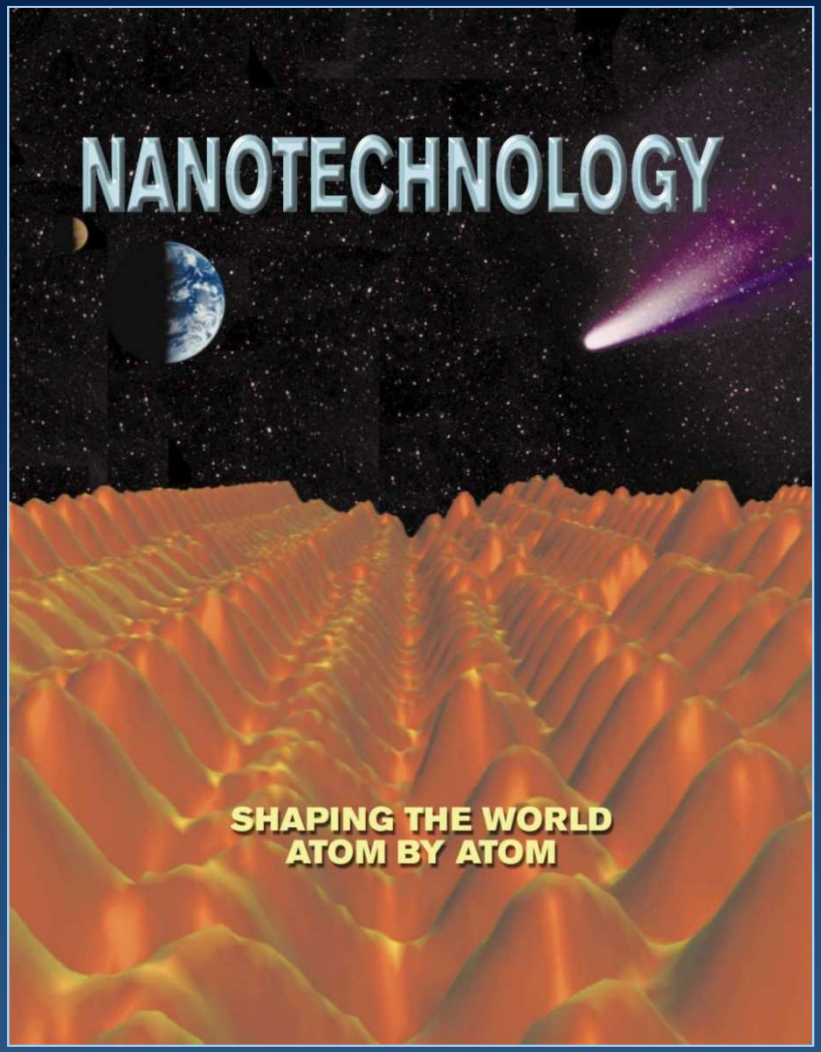
Some of these research goals will take 20 or more years to achieve. But that is why -- precisely why -- ...there is such a critical role for the Federal government.

National Nanotechnology Initiative (NNI)

20 Federal Departments and Independent Agencies
11 with nanotech budgets

2015 budget: $1.5 billion
$22 billion since 2001

www.nano.gov



NNI Brochure, 2000

How the NNI Functions

Management: White House and Federal agencies

Coordination: Nanoscale Science, Engineering, and Technology (NSET) Subcommittee

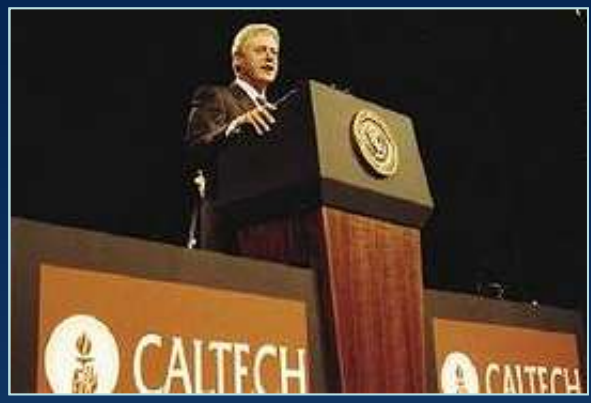
Reporting, Logistics, Outreach: NNCO

Nano.gov
U.S. National Nanotechnology Initiative

15 Years of Presidential Nanotechnology

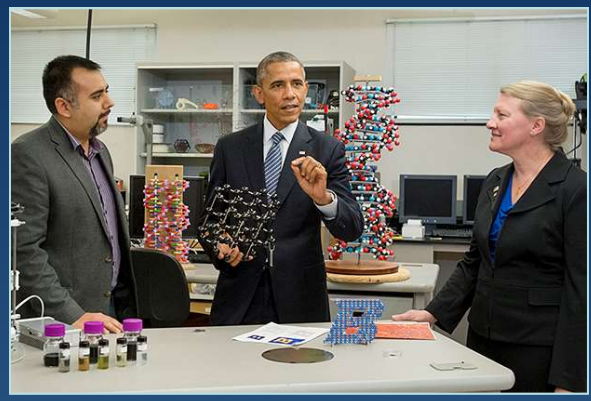
"Just imagine materials with 10 times the strength of steel and only a fraction of the weight… it was a real thrill for me to meet Dr. Moore, …even I knew what Moore's Law was."

President Clinton at CalTech, January 21, 2000



Discussing nanomanufacturing at Boise State, the President invoked Moore's law, and later remarked "Some of your faculty and students are working with next-generation materials like graphene, which is a material that's thinner than paper and stronger than steel."

President Obama at Boise State, January 21, 2015

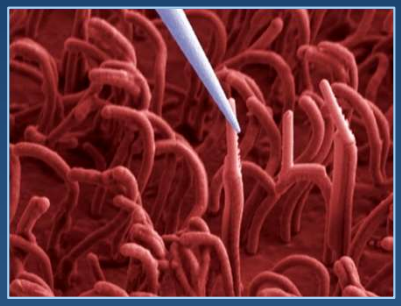


news.boisestate.edu

So, where is the NNI today?

Major R&D Thrusts in Nanotechnology

- Post-CMOS Electronics
- Photonics
- Energy
- Nanomanufacturing (including coatings, composites)
- Biotechnology and medicine
- Environment, Health, and Safety



NIST/CNST

Economic Impact is Growing

Project on Emerging Nanotechnologies

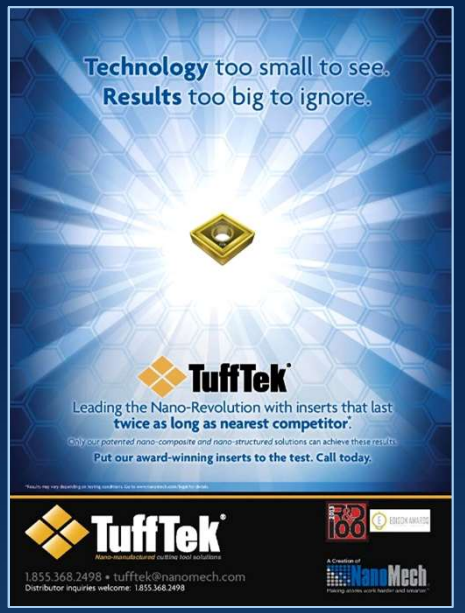
Consumer products grew from 380 in 2007 to 1628 in 2013

Lux Research

Global product revenue grew from $339 billion in 2010 to $731 billion in 2012

2014 estimate >$1 trillion

Most products involve nanoparticle additives and coatings



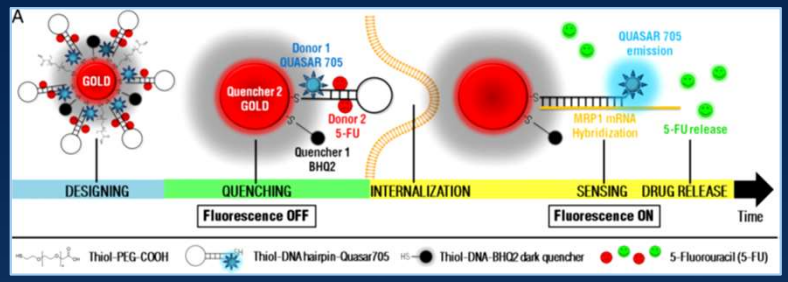
TCL Multimedia and QD Vision

So, where is the NNI today?

Should it continue?

Foundational NNI Justification Still Valid

Conde, Oliva, Artzi, *PNAS* 2015



Transcends disciplines

Requires deep integration across science and engineering fields

NIST/CNST

Fabrication and metrology is expensive

Requires shared infrastructure

Important for U.S. competitiveness

Federal investments key to encouraging sustained private sector investments

So, where is the NNI today?

Should it continue?

What's next?

Fifth Assessment of NNI by PCAST

NNI has delivered significant S&T progress

Healthy research should continue

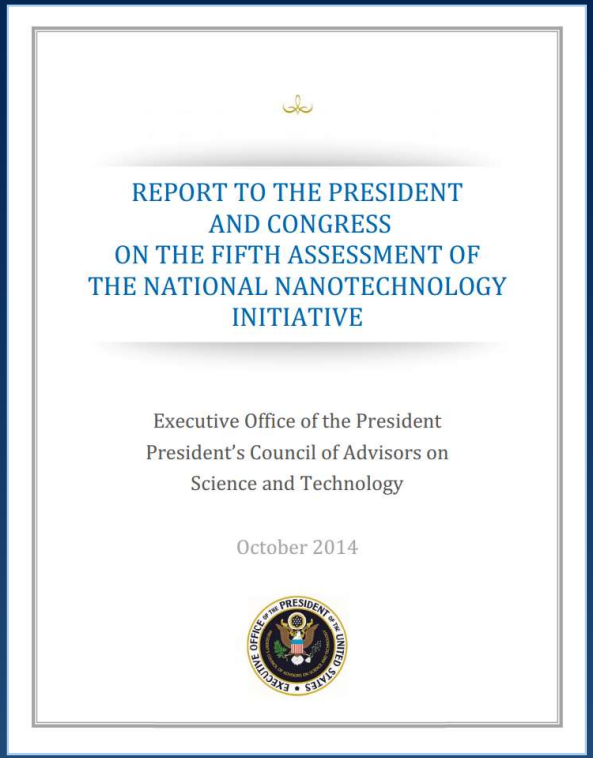
International competition has increased

U.S. now behind in infrastructure, workforce

"NNI 2.0" should focus on nano-systems and commercialization

Agencies should facilitate commercialization through Grand Challenges

Need formal system of metrics to track progress


REPORT TO THE PRESIDENT
AND CONGRESS
ON THE FIFTH ASSESSMENT OF
THE NATIONAL NANOTECHNOLOGY
INITIATIVE

Executive Office of the President
President's Council of Advisors on
Science and Technology

October 2014

Nanotechnology-Inspired Grand Challenges for the Next Decade

Ambitious but achievable goals that harness nanoscience, nanotechnology, and innovation…

- RFI posted on 6/17/2015, responses due 7/16/2015
  https://federalregister.gov/a/2015-14914
- Offers six examples developed by agencies, NNCO, & OSTP
- Looking for other challenges, variations on examples, comments on examples

The Future of the NNI

How can the NNI continue as a truly national initiative?

How do we broaden

awareness, participation, and cohesion

of the entire NNI ecosystem:

STEM-ed, R&D, societal acceptance, and commercialization?

The Future of the NNI

Is something holding back the high-value, higher-complexity products?

- *Manufacturing metrology*
- *EHS*
- *Design rules*
- *Life cycle assessment*

The Future of the NNI

Can we change the economics of nanotechnology?

Adapt nanotech tools & methods for new sectors

Make nanotech less capital intensive; i.e. "lean nanomanufacturing startup"


Thank you for your attention!
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www.ostp.gov