WHITE HOUSE 21ST CENTURY GRAND CHALLENGES

Ambitious but achievable goals

that harness science, technology, and innovation to solve important national or global problems

and have the potential to capture the public's imagination.

Lloyd Whitman
OSTP

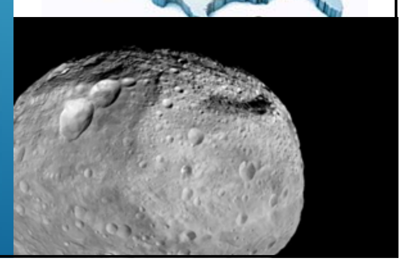
Nanotechnology-Inspired Information Processing Systems of the Future Workshop
8 ▪ 31 ▪ 2016

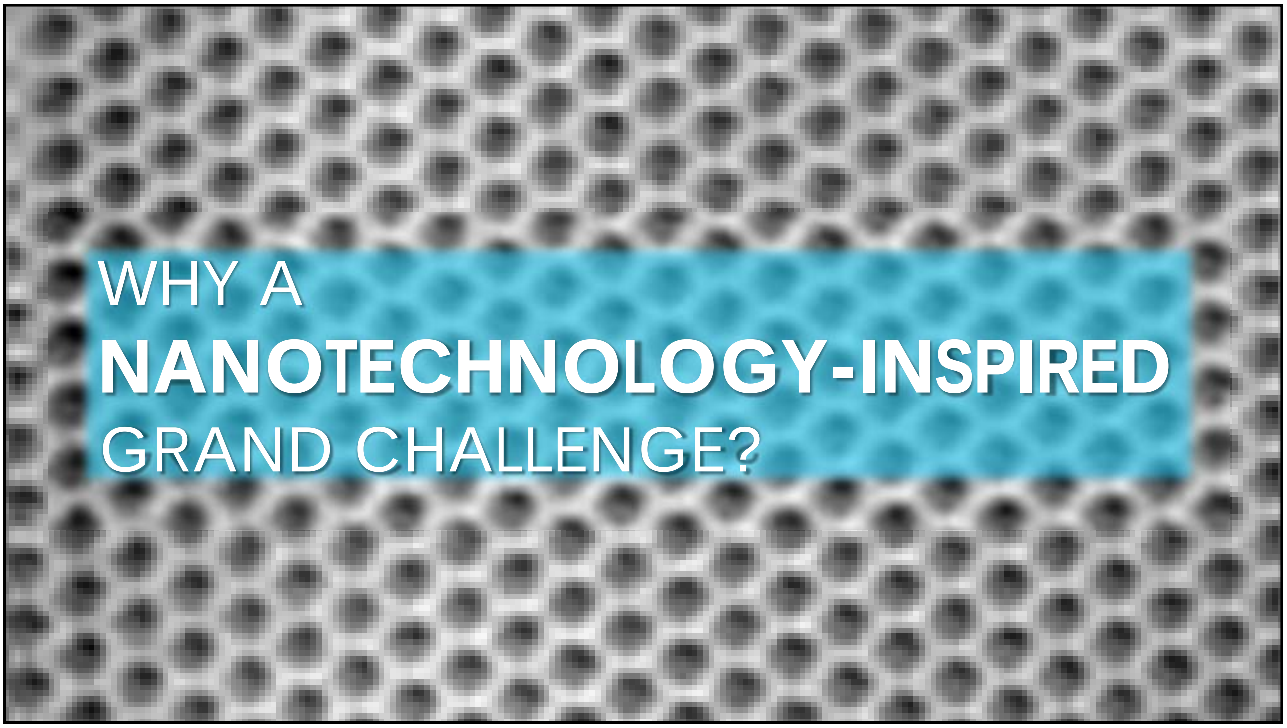
EXAMPLES

DOE SunShot Grand Challenge

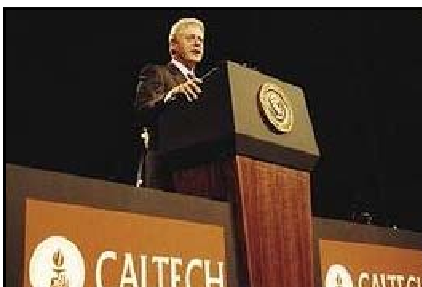
DOE EV Everywhere Grand Challenge

NASA Asteroid Grand Challenge





WHY A **NANOTECHNOLOGY-INSPIRED** GRAND CHALLENGE?



President Clinton
at CalTech
January 21, 2000

President Bush
signs NNI act
December 3, 2003

President Obama
at Boise State
January 21, 2015

NNI SUPPORTED BY **3 PRESIDENTS**

NNI TODAY

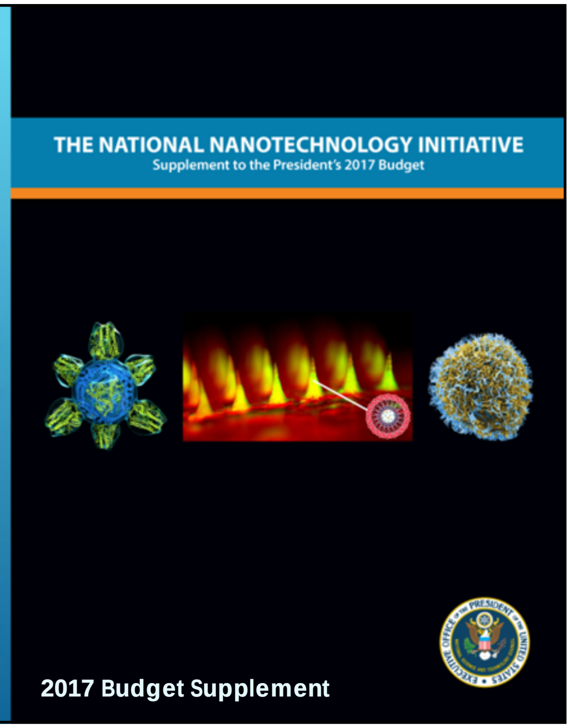
20 Federal Departments and Independent Agencies

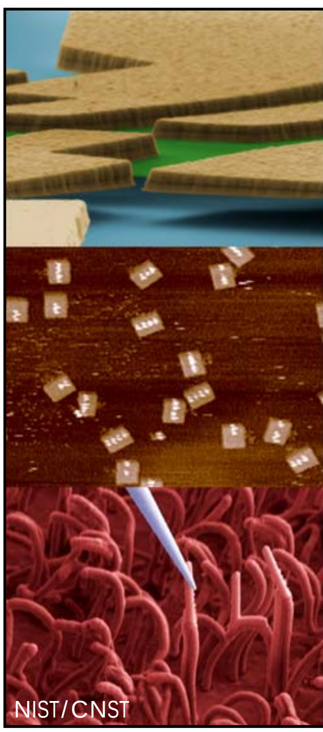
__11__ with nanotech budgets

$1.5 billion 2016 budget

$23 billion since 2001

Learn more: **www.nano.gov**





MAJOR **R&D THRUSTS** IN NANOTECHNOLOGY

Post-CMOS Electronics

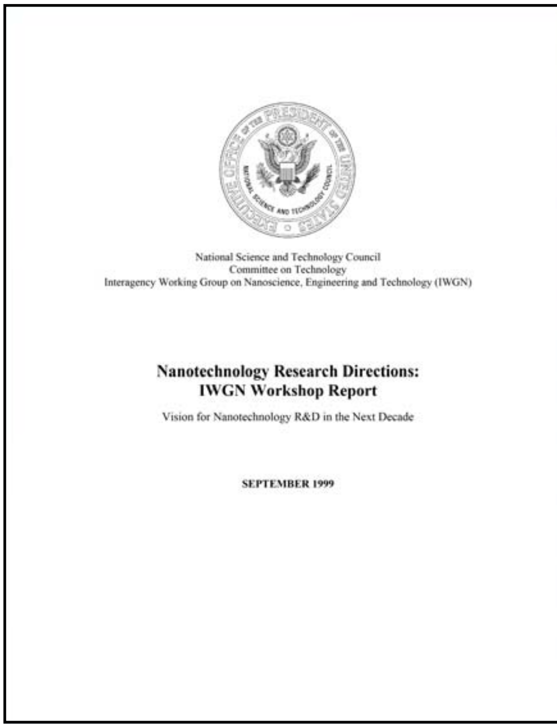
Photonics

Energy

Nanomanufacturing (incl. coatings, composites)

Biotech and medicine

Environment, health, and safety



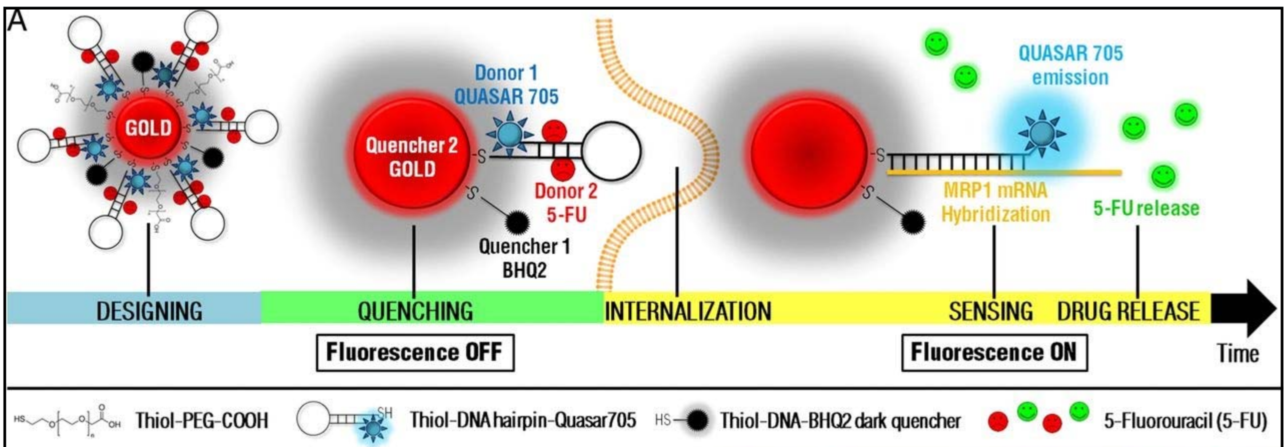
National Science and Technology Council
Committee on Technology
Interagency Working Group on Nanoscience, Engineering and Technology (IWGN)

Nanotechnology Research Directions:
IWGN Workshop Report
Vision for Nanotechnology R&D in the Next Decade

SEPTEMBER 1999

FOUNDATIONAL JUSTIFICATION OF NNI IS

STILL VALID

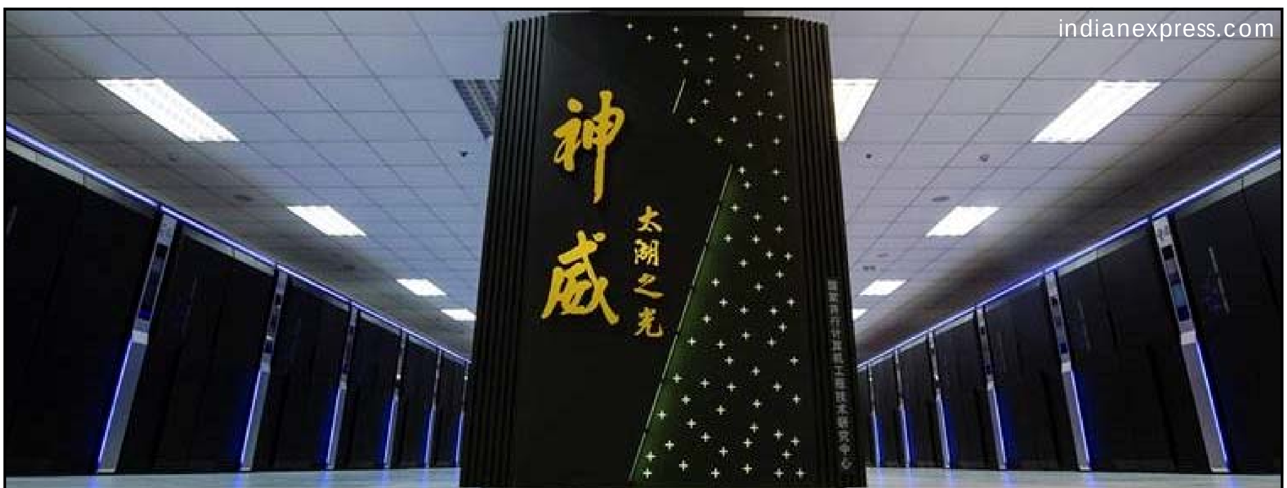


Conde, Oliva, Artzi, *PNAS 2015;112:E1278-E1287*

TRANSCENDS DISCIPLINES

NIST/CNST

INFRASTRUCTURE IS EXPENSIVE



IMPORTANT FOR U.S. COMPETITIVENESS

ECONOMIC IMPACT IS **GROWING**

Lux Research: Global nanotech product revenue

$3.7 trillion *by 2018*

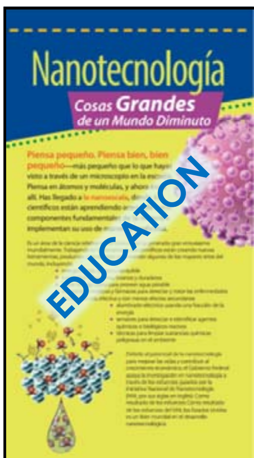
$1.6 trillion *in 2014*

$164 billion *in 2008*

www.nanosysinc.com

www.titanspine.com (photo: spinewards.com)

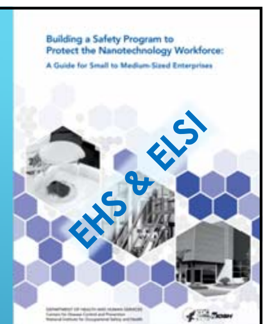
www.nanocomptech.com



FULFILLING THE PROMISE: NNI 2.0

Energize the ecosystem

Catalyze commercialization



NANOTECHNOLOGY -INSPIRED
GRAND CHALLENGES

Ambitious but achievable goals

that harness **nano**science, **nano**technology, and innovation to solve important national or global problems

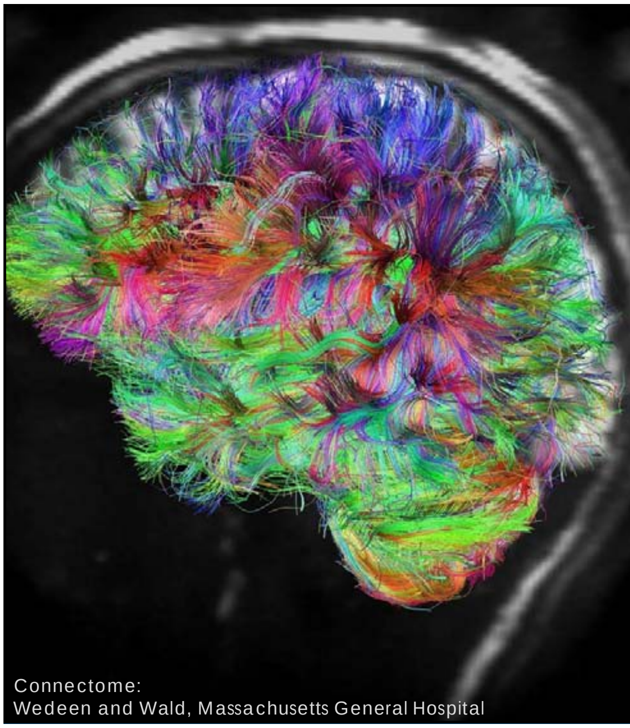
and have the potential to capture the public’s imagination.

THE PROBLEM

70 years of Von Neumann architecture

50 years of silicon transistor-based digital computers

Hitting the limits of size and power scaling



Connectome:
Wedeen and Wald, Massachusetts General Hospital

A DIFFERENT APPROACH

3-Dimensional
Fault tolerant
Adaptive

~10^{11} neurons

~10^{15} connections

Perception
Learning
Creative problem-solving

NANOTECHNOLOGY-INSPIRED GRAND CHALLENGE **FOR FUTURE COMPUTING**

DoD
DOE
IARPA
NIST
NSF

CCC
Moore Foundation
IEEE
Kavli Foundation
SRC

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.

The BRAIN Initiative®

Nano.gov
U.S. National Nanotechnology Initiative

The National Strategic Computing Initiative

CCC

Opportunities and Challenges for Next Generation Computing

Gregory D. Hager, Mark D. Hill, and Katherine Yelick

Oct. 19, 2015

Version 1

Computing has dramatically changed nearly every aspect of our lives, from business and agriculture to communication and entertainment. As a nation, we rely on computing in the design of systems for energy, transportation and defense; and computing fuels scientific discoveries that will improve our fundamental understanding of the world and help develop solutions to major challenges in health and the environment. Computing innovations "at the high end" tend to "trickle down," leading to increased performance and new applications of computing throughout the entire performance spectrum. These advances have relied on computing innovations in the broadest sense: faster algorithms, new mathematical and statistical models, powerful programming abstractions, ubiquitous high performance networks, and computing systems that have become smaller, faster, cheaper and more accessible over time.

Computing has changed our world, in part, because our innovations can run on computers whose performance and cost-performance has improved a million-fold over the last few decades. A driving force behind this has been a repeated doubling of the transistors per chip, dubbed Moore's Law. A concomitant enabler has been Dennard Scaling that has permitted these performance doublings at roughly constant power, but, as we will see, both trends face challenges.

Consider for a moment the impact of these two trends over the past 30 years. A 1980's supercomputer (e.g. a Cray 2) was rated at nearly 2 Gflops and consumed nearly 200 KW of power. At the time, it was used for high performance and national-scale applications ranging from weather forecasting to nuclear weapons research. A computer of similar performance now fits in our pocket and consumes less than 10 watts. What would be the implications of a similar computing/power reduction over the next 30 years – that is, taking a petaflop-scale machine (e.g. the Cray XK7 which requires about 500 KW for 1 Pflop (=10^{15} operations/sec) performance) and repeating that process? What is possible with such a computer in your pocket[1]? How would it change the landscape of high capacity computing? How would it change the landscape of personalized computing? Will such computing be general purpose and programmable in the same way we're accustomed, or will new paradigms need to emerge?

While such performance improvements do not guarantee the same revolutionary changes we've seen over the past 30 years, they dramatically change the landscape of possibilities for both

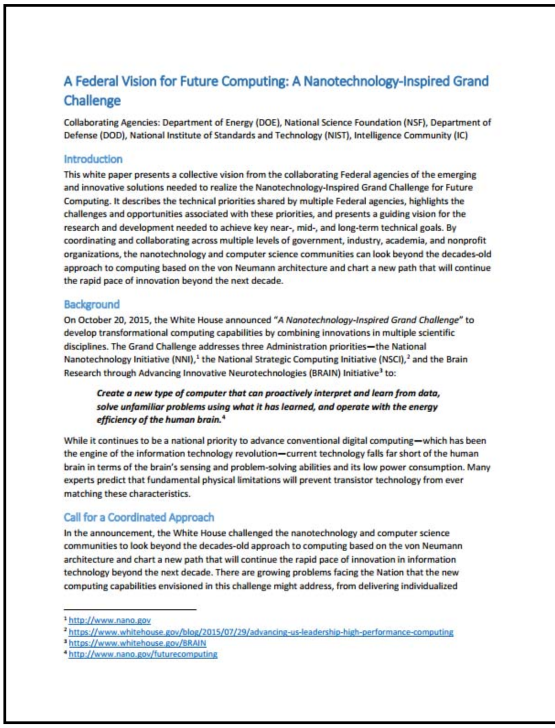
[1] One might also ask how such a computer compares to the one in your head! As a point of comparison, the human brain is estimated to contain around 8×10^{10} neurons and 10^{14} synapses. Neural circuits operate at firing rates of 100 to 1000 Hz. Although direct comparisons are hard to make, this could be viewed as 10-100 "petaspikes" of computation operating on around 20 watts of power.

1

cra.org/ccc/resources/ccc-led-whitepapers/

CCC WHITE PAPER SUPPORTING THE GRAND CHALLENGE

White paper released by CCC
October 19, 2015



A Federal Vision for Future Computing: A Nanotechnology-Inspired Grand Challenge

Collaborating Agencies: Department of Energy (DOE), National Science Foundation (NSF), Department of Defense (DOD), National Institute of Standards and Technology (NIST), Intelligence Community (IC)

Introduction

This white paper presents a collective vision from the collaborating Federal agencies of the emerging and innovative solutions needed to realize the Nanotechnology-Inspired Grand Challenge for Future Computing. It describes the technical priorities shared by multiple Federal agencies, highlights the challenges and opportunities associated with these priorities, and presents a guiding vision for the research and development needed to achieve key near-, mid-, and long-term technical goals. By coordinating and collaborating across multiple levels of government, industry, academia, and nonprofit organizations, the nanotechnology and computer science communities can look beyond the decades-old approach to computing based on the von Neumann architecture and chart a new path that will continue the rapid pace of innovation beyond the next decade.

Background

On October 20, 2015, the White House announced "*A Nanotechnology-Inspired Grand Challenge*" to develop transformational computing capabilities by combining innovations in multiple scientific disciplines. The Grand Challenge addresses three Administration priorities—the National Nanotechnology Initiative (NNI),[1] the National Strategic Computing Initiative (NSCI),[2] and the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative[3] to:

> ***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.***[4]

While it continues to be a national priority to advance conventional digital computing—which has been the engine of the information technology revolution—current technology falls far short of the human brain in terms of the brain's sensing and problem-solving abilities and its low power consumption. Many experts predict that fundamental physical limitations will prevent transistor technology from ever matching these characteristics.

Call for a Coordinated Approach

In the announcement, the White House challenged the nanotechnology and computer science communities to look beyond the decades-old approach to computing based on the von Neumann architecture and chart a new path that will continue the rapid pace of innovation in information technology beyond the next decade. There are growing problems facing the Nation that the new computing capabilities envisioned in this challenge might address, from delivering individualized

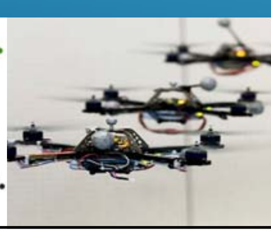
[1] http://www.nano.gov
[2] https://www.whitehouse.gov/blog/2015/07/29/advancing-us-leadership-high-performance-computing
[3] https://www.whitehouse.gov/BRAIN
[4] http://www.nano.gov/futurecomputing

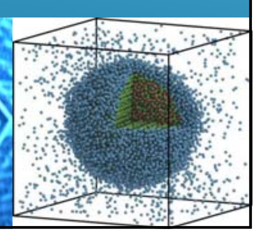
FEDERAL VISION
FOR THE
GRAND CHALLENGE

White paper released by
DOE, NSF, DoD, NIST, IC
July 29, 2016

GAME-CHANGING CAPABILITIES

- Intelligent big data sensors
- Online machine learning
- Technology for trust
- Autonomous platforms
- Machine intelligence for R&D
- Cybersecurity systems
- Low–power computing




Materials
Devices & Interconnects
Computing Architectures
Brain-Inspired Approaches
Fabrication/Manufacturing
Software, Modeling, & Sim.
Applications
SEVEN FOCUS AREAS