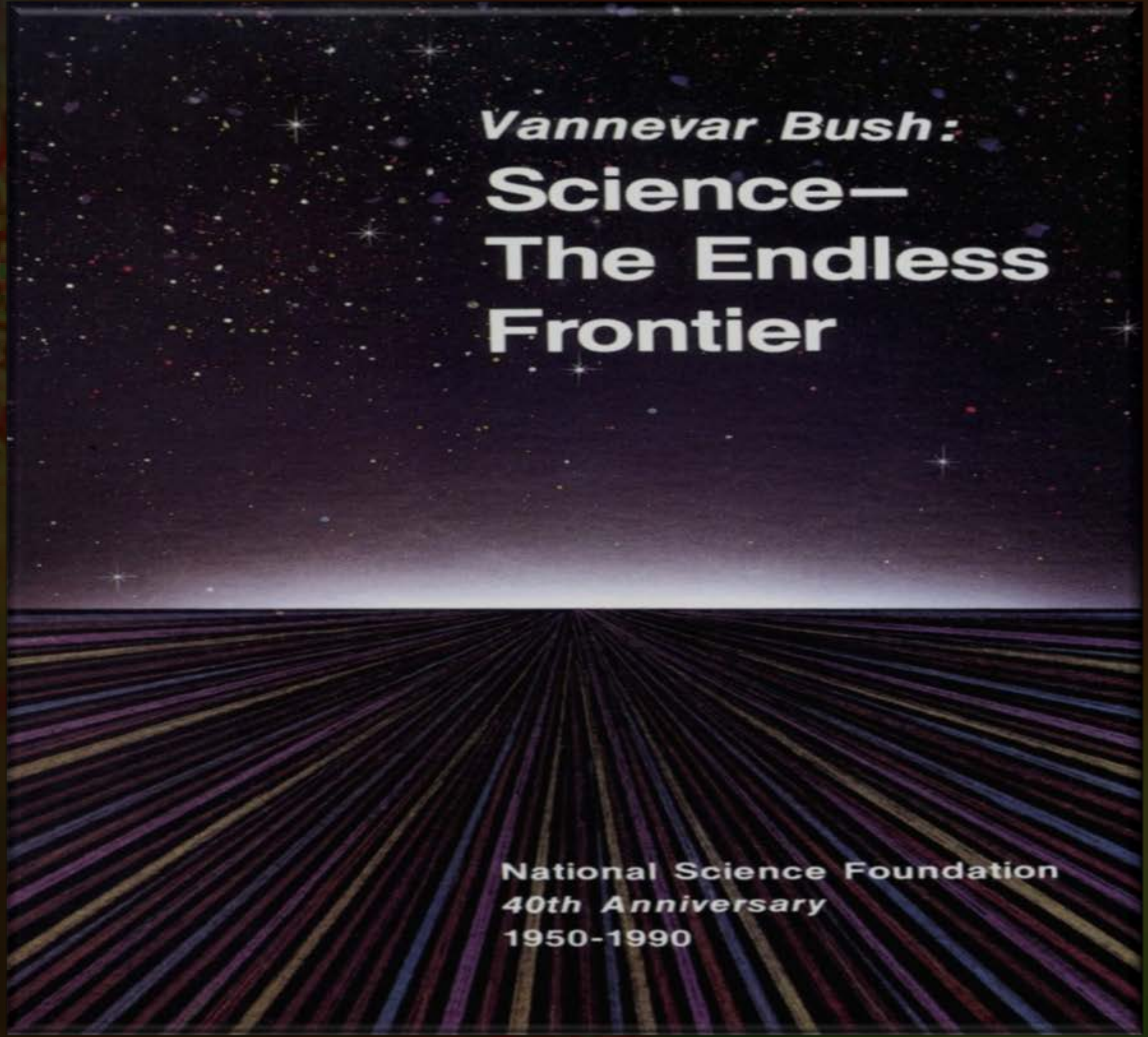
Opportunities and Challenges in Engineering Research and Education – *A View from NSF*

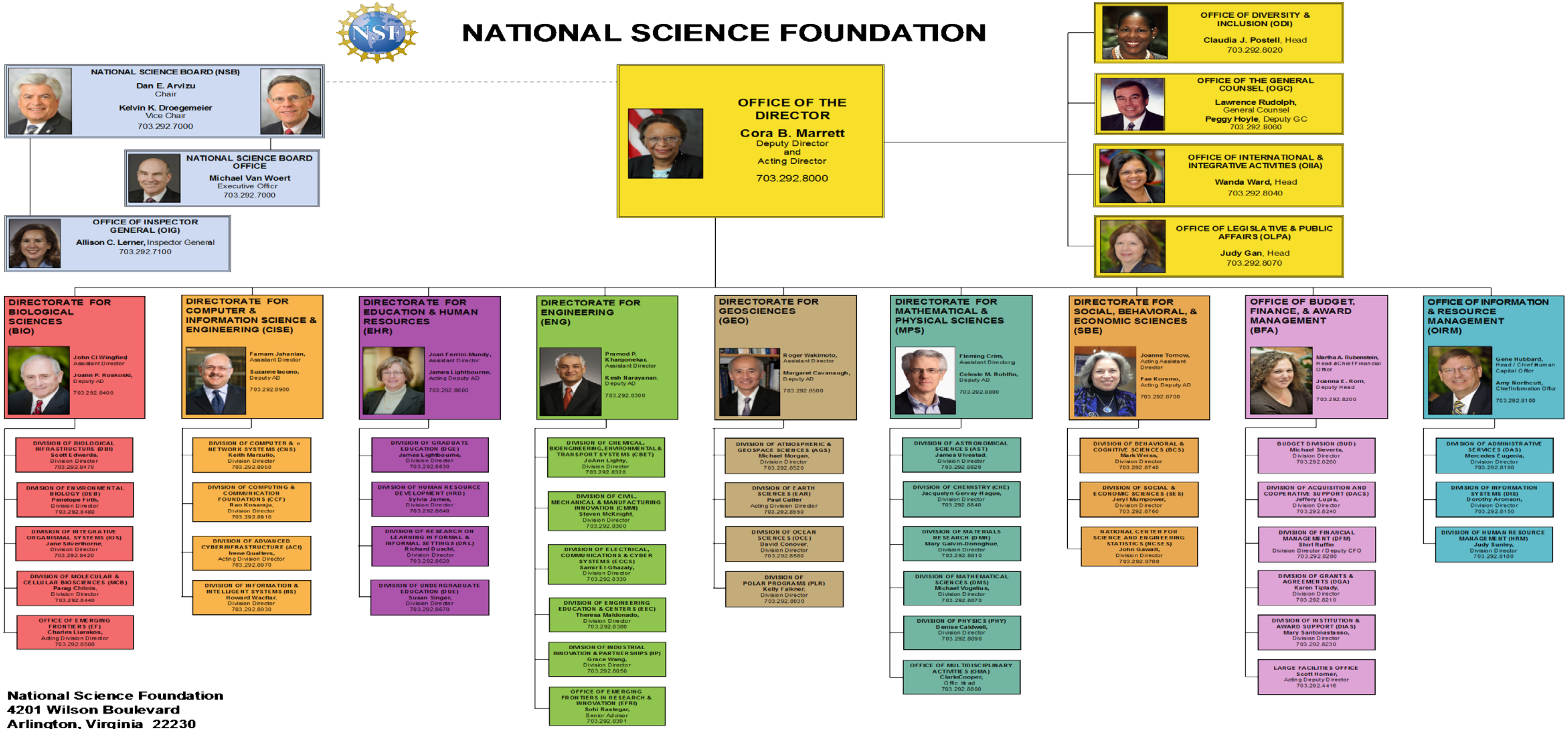
Pramod Khargonekar
Assistant Director for Engineering
National Science Foundation

Fowler Distinguished Lecture
Texas A & M
March 26, 2014



"to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF Act, 1950

NATIONAL SCIENCE FOUNDATION



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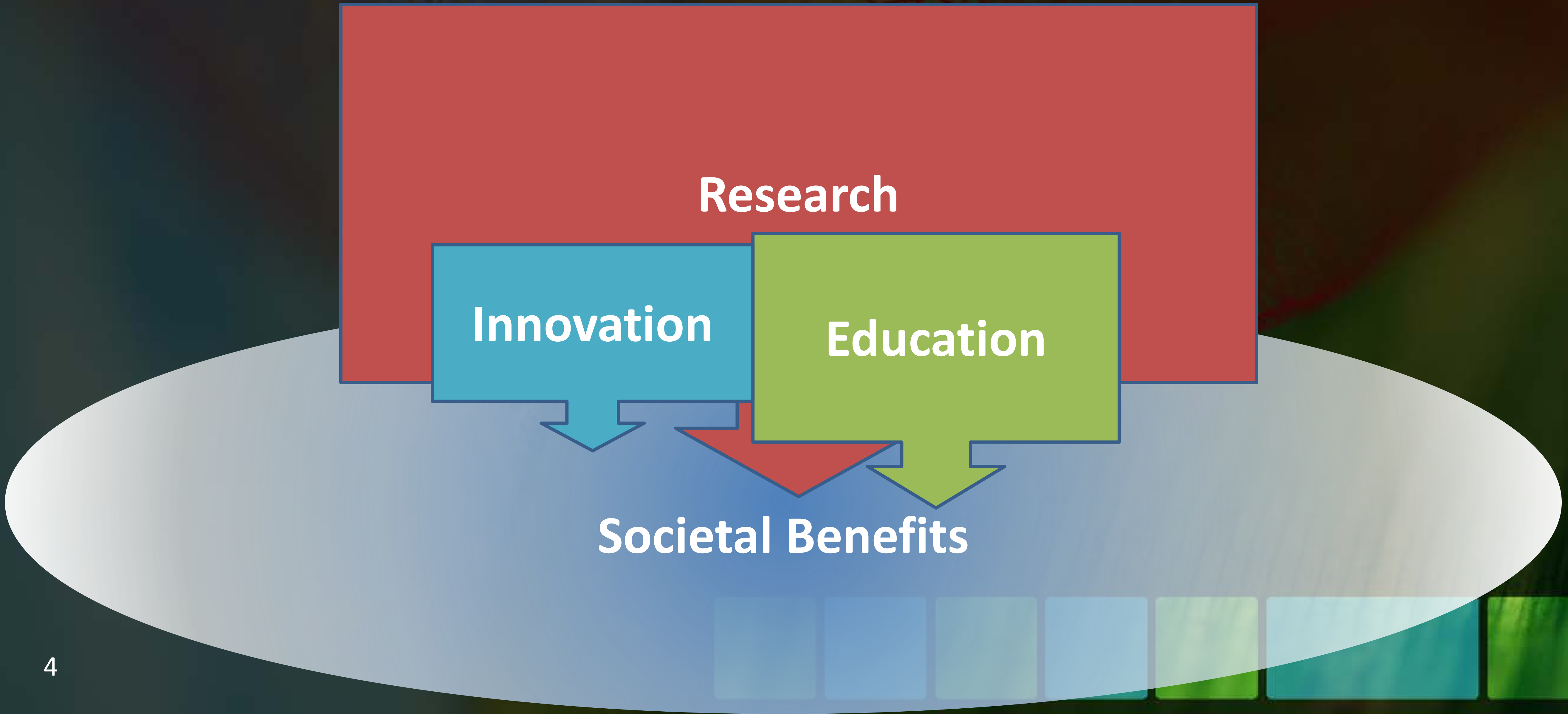
February 2014

NSF ENG: *Investing in transformative research and education to foster innovations for benefits to society*



Larger Context

- Economic growth, competitiveness, employment, and sustainability imperatives
- Mega problems: food, health, energy, water, security, education, infrastructure, …
- Stubborn long-standing issues in STEM talent, diversity, and education
- Global flows of components, products, services, knowledge, and people
- Federal support of research funding and public policy issues

Imagining Future of Engineering

- Vital and essential role for engineering to enable a prosperous, exciting, secure, healthy and sustainable society
- Ambitious, specific, but achievable grand challenges to stimulate the imagination, creativity, and ingenuity of the engineering community leading to dramatic advances
- Seamless transitions and feedback loops between research and practical realizations leading to great innovations
- Engineering education innovations have overcome stubborn, long-standing problems in retention, diversity, and K-12 and attract highly talented people to the profession

Key Scientific Drivers

- Nano –
  - Improving understanding and new tools at the atomic and molecular scales
  - Systems and design
- Bio/Med –
  - Interaction of engineered systems and biology at all scales – DNA to cells to organisms to eco-systems
  - Convergence of life sciences, physical sciences, and engineering
- Computing –
  - Computational modeling, simulation, optimization, pervasive in all fields of engineering
  - Networks and computation deeply integrated into engineered systems
- Behavioral/economic/cognitive
  - Human behavior in engineered systems and technology
  - Regulatory issues
- Systems science –
  - Multi-scale analysis, design, and optimization
  - Integration of engineered components (including cyber)
  - Range from nano to micro to macro
  - Few to billions
- *Design, creativity, aesthetics, …*

NSF ENG Strategy

- Attract, stimulate, catalyze and challenge research communities to think big, enable transformational research advances, and expand national innovation capacity
- Portfolio balance between fundamental, applied and translational as well as small, medium and large projects
- New approaches to address engineering education challenges
- Collaborate and partner within and outside NSF to maximize opportunity for the engineering research and education community to address major national priorities

Objective: *Maximize long term societal benefit*

Directorate for Engineering

Fundamental

EFRI

CBET

- Chemical, Biochemical, and Biotechnology Systems
- Biomedical Engineering and Engineering Healthcare
- Environmental Engineering and Sustainability
- Transport and Thermal Fluids Phenomena

CMMI

- Advanced Manufacturing
- Mechanics and Engineering Materials
- Resilient and Sustainable Infrastructure
- Systems Engineering and Design

ECCS

- Electronics, Photonics, and Magnetic Devices
- Communications, Circuits, and Sensing Systems
- Energy, Power, and Adaptive Systems

EEC

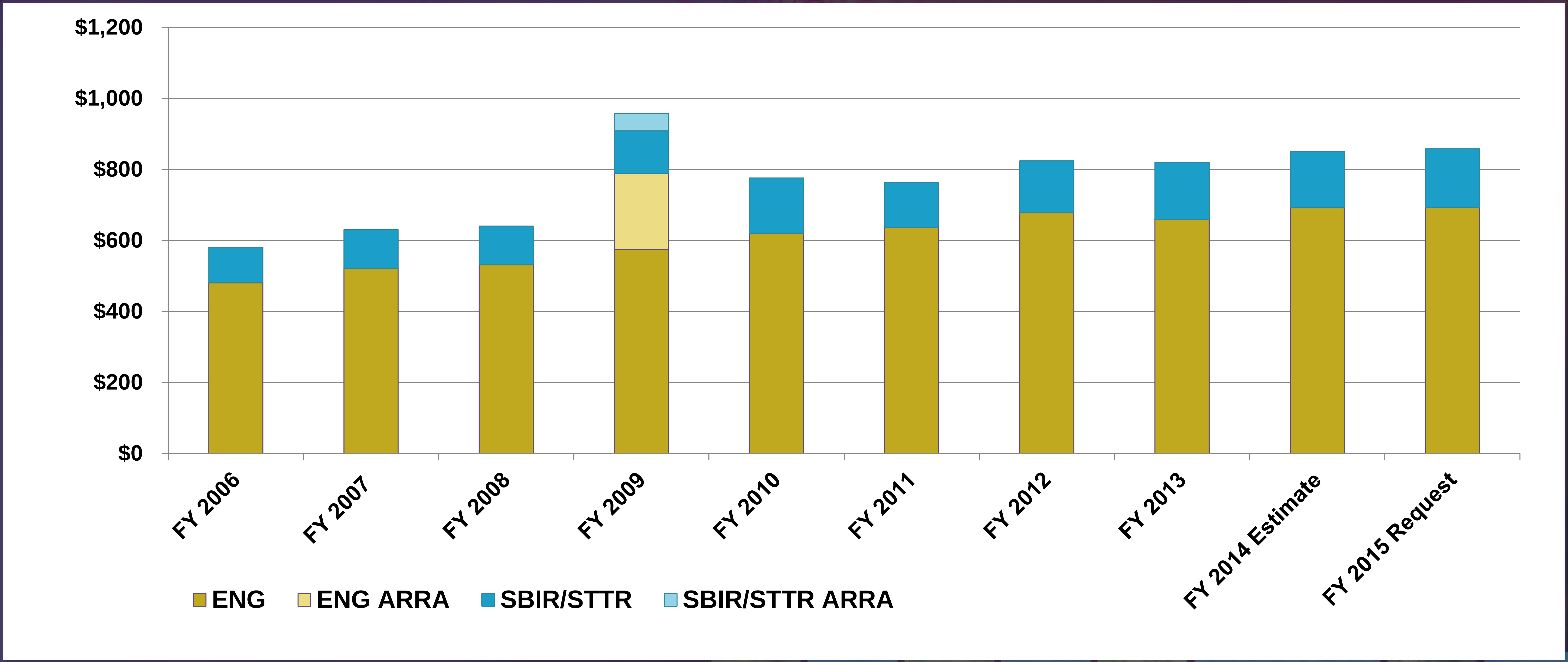
- Engineering Research Centers
- Engineering Education
- Engineering Workforce

Translational

IIP

- Academic Partnerships
- Small Business Partnerships

ENG and SBIR/STTR R&RA Budgets ($M)



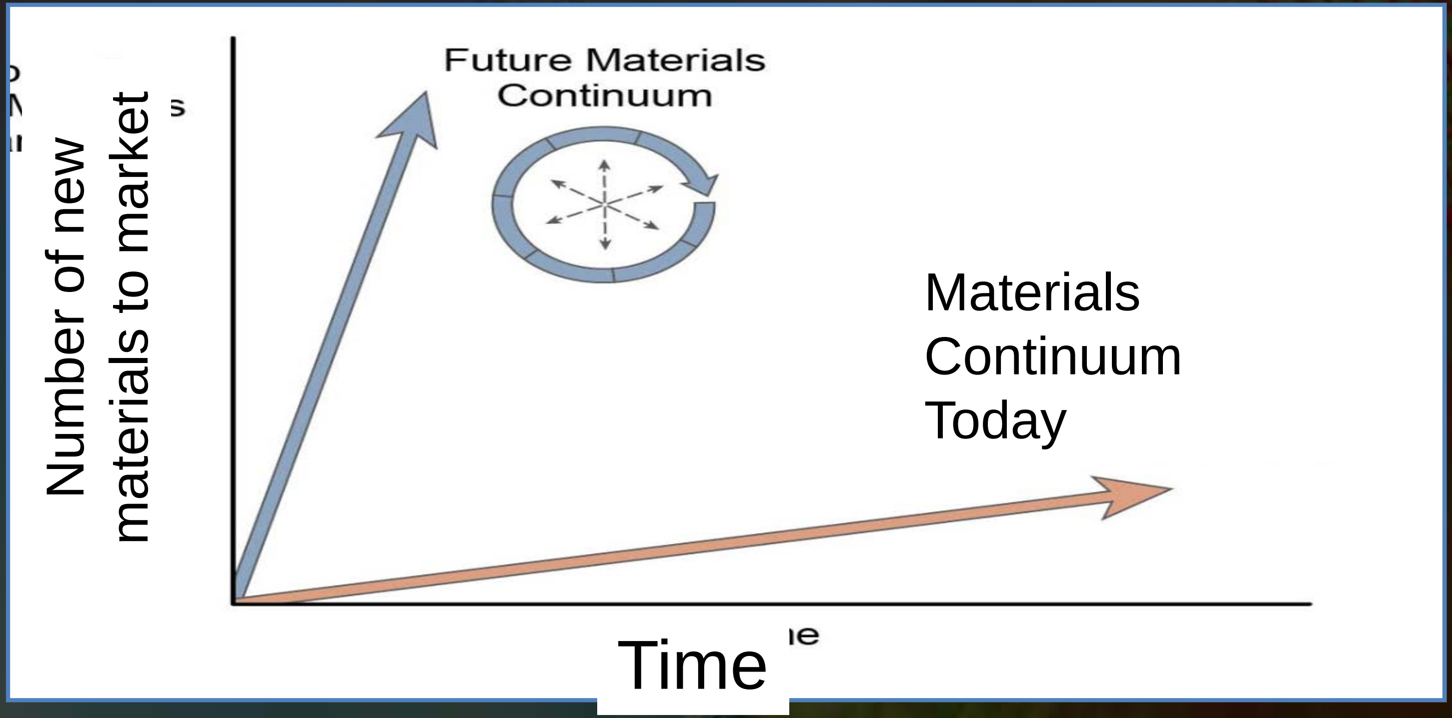
Engineering prioritizes research critical to the Nation’s Challenges

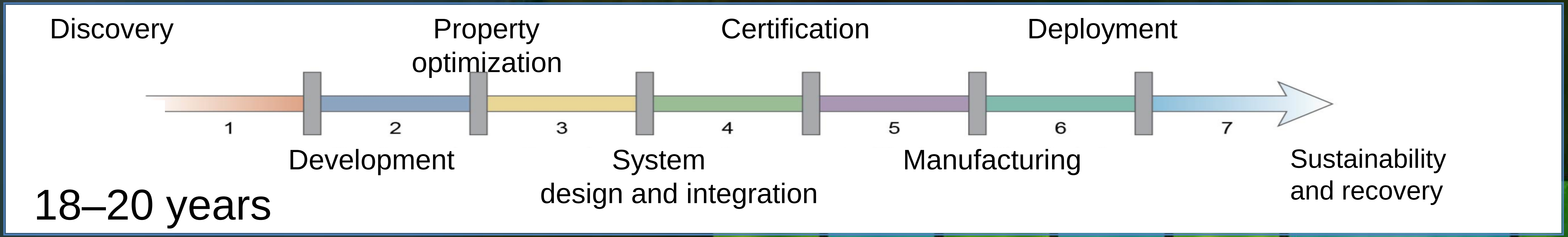
- National Initiatives
  - Advanced Manufacturing
  - Clean Energy
  - National Nanotechnology Initiative
- NSF Cross-cutting Priorities
  - Cognitive Science and Neuroscience
  - Communications and Cyberinfrastructure
  - Cyber-Enabled Materials, Manufacturing, and Smart Systems (CEMMSS)
  - Science, Engineering, and Education for Sustainability (SEES)
  - Education and Career Development
  - Interdisciplinary Research
  - Research Centers
  - Innovation Corps

Advanced Manufacturing

- Historically NSF has supported frontier research that has led to transformational advances in manufacturing
  - Additive manufacturing grew out, in part, from basic research investments in the 70’s and 80’s
  - MEMS enabled by fundamental research in late 80s (NSF & DARPA)
- Present research extends traditional advances and builds upon convergence of trans-disciplinary advances
  - National Robotics Initiative (NRI): towards autonomous systems
  - Cyber-Physical Systems (CPS): smart manufacturing
  - Digital design and manufacturing methods
  - Scalable Nano-manufacturing – moving forward on NNI discoveries
  - Bio-manufacturing
  - Novel semiconductor design and manufacturing
- Looking forward
  - Internet enabled, distributed, personalized, dynamic, digital, …
  - Energy and materials efficient sustainable manufacturing
  - Integration of services into manufacturing and servitization of products

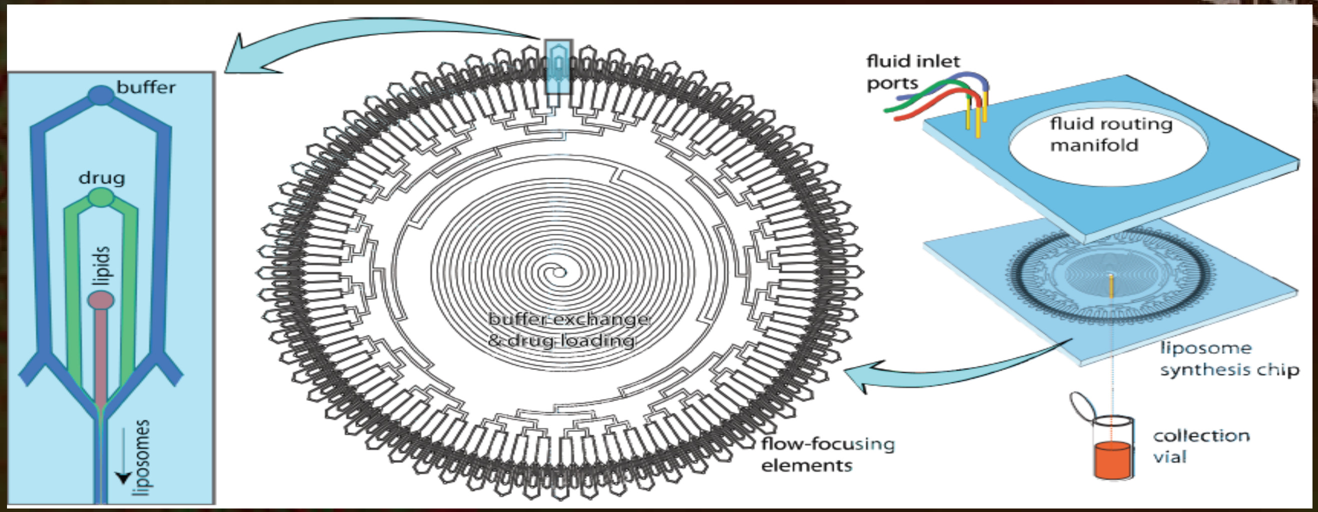
Materials Genome Initiative





Bio-manufacturing

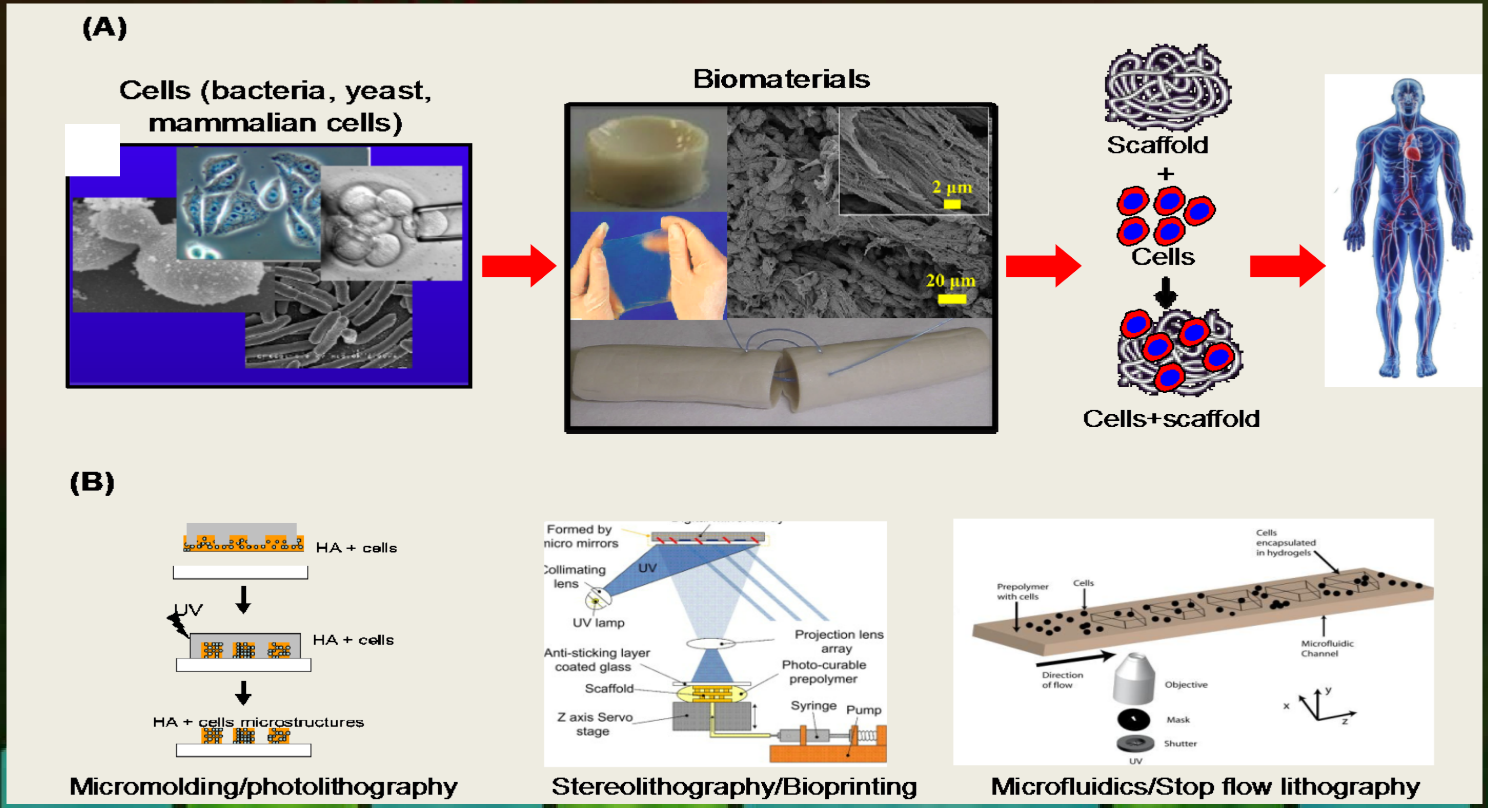
The use of biological systems comprised of biomolecules, cells and biomaterials, or the products of biological systems, to generate new devices and constructs with a view towards scalability and industrialization



Production of liposomal pharmaceuticals in a microfluidic system

Vision: To combine advances in biology with innovative design to engineer the next generation of biologically inspired products

Objective: To advance research in biomanufacturing as an emerging discipline in the academic and industrial communities, as well as a technological opportunity to spur research and industry growth



Fabrication of complex, biologically active, three-dimensional constructs

Mapping and Engineering the Brain

Neuroscience & Cognitive Science

Bioimaging & Biosensing

Nanomedicine & Nanofabrication

Neuro-engineering

Biophysics & Control

Genetic & Molecular Cell Biology

Computation & Bioinformatics

Integration

Noninvasive Brain Activity Mapping

Deciphering

- mechanisms underlying the brain adaptation to changing environment, and genetic and epigenetic landscape
- mechanisms underlying dynamic decisions and communication within and across scales
- neural representations and coding, and principles of brain organization and decision making
- neural circuits and signal pathways that regulate the regrowth, repair of nerve tissues and cells

Engineering

Impact

Intelligent Systems

Brain Circuit Control Network

Artificial Intelligence

Intelligent Robotics

President Obama

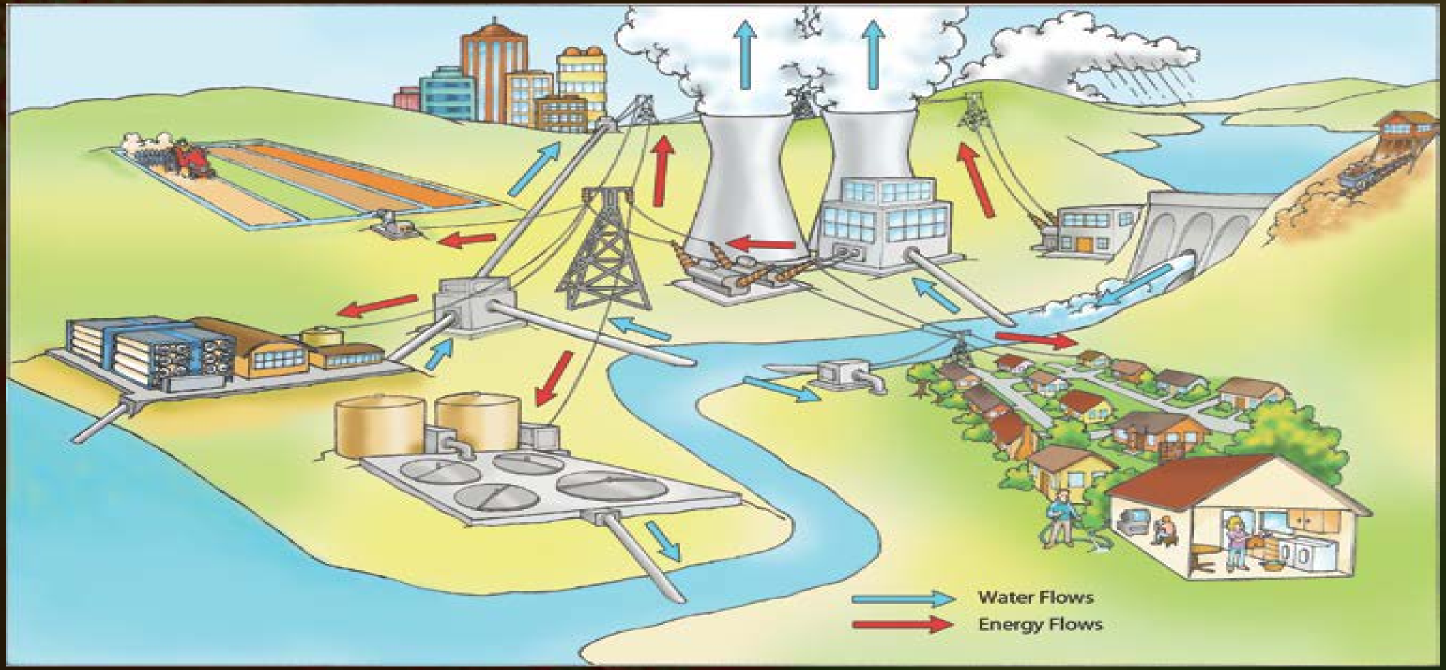
WH, April 2, 2013

"BRAIN" Initiative—a bold new research effort to revolutionize our understanding of the human mind and uncover new ways to treat, prevent, and cure brain disorders like Alzheimer's, schizophrenia, autism, epilepsy, and traumatic brain injury.

"… the BRAIN Initiative will change that by giving scientists the tools they need to get a dynamic picture of the brain in action and better understand how we think and how we learn and how we remember."

Partnership with EPRI on Energy-Water Nexus

- About 90% of power plant fresh water is used for cooling; wasteful consumption.
- EPRI Office of Innovation recently started an annual solicitation on innovations in power plant cooling for reduced water usage
- Advanced cooling is a priority for appropriate NSF CBET Programs. Relevant technologies include electronic cooling, HVAC.
- Goal: promote integration of fundamental advances in condensation, and heat exchangers for wet, dry and hybrid power plant cooling.



ELECTRIC POWER RESEARCH INSTITUTE

Emerging theme:

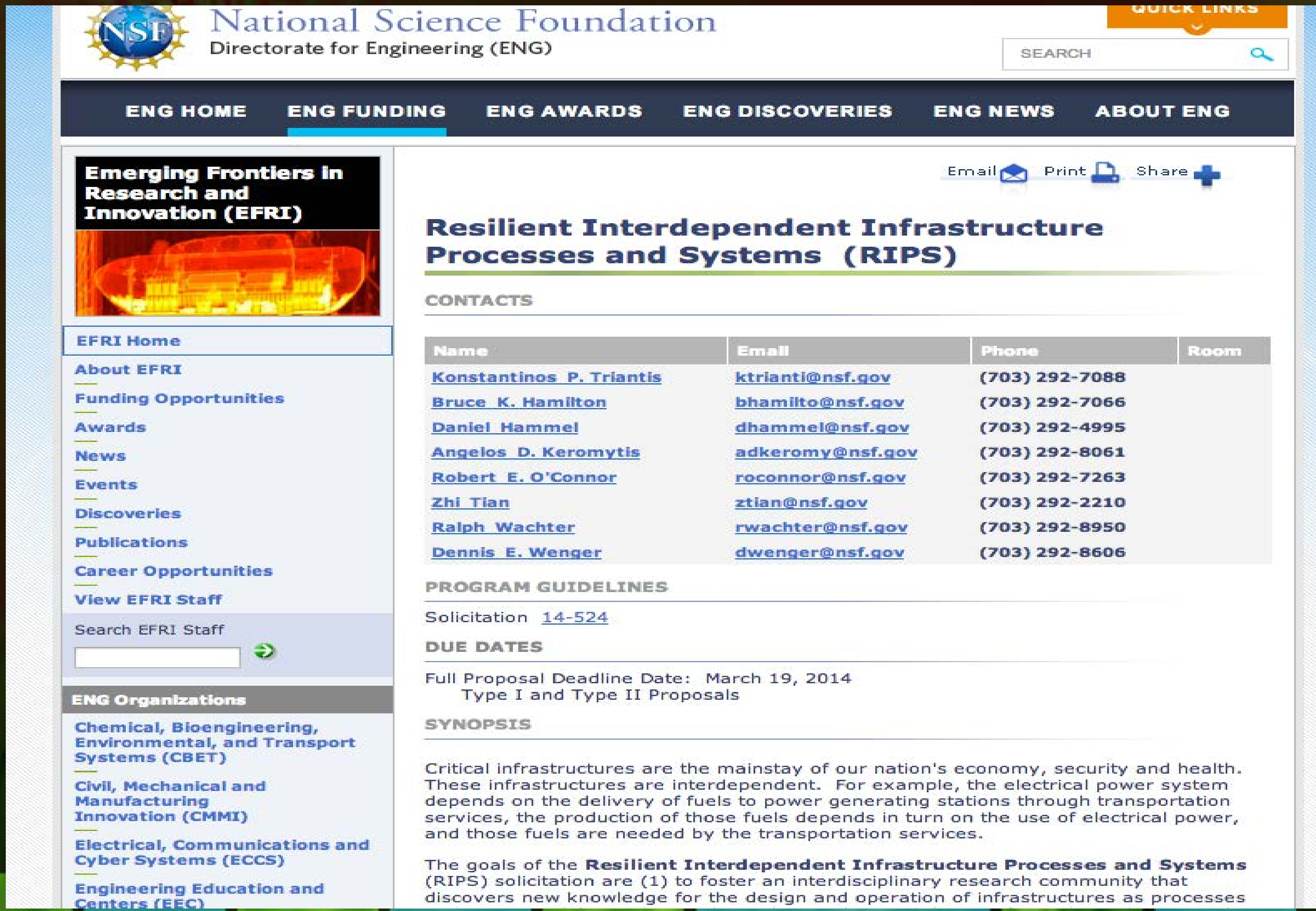
Energy-Water-Food nexus

Infrastructure Systems

- Fundamental research to enable design of resilient and sustainable infrastructure systems
- Historical approaches and successes
  - Earthquake resistant structures (e.g. base isolation, novel materials, improved building codes)
  - NEES – unique national facilities "at scale"
  - Integration of engineering and social sciences for infrastructure management and hazard mitigation
  - RAPIDs: Learning from real-world examples
- Looking forward
  - Protecting from multi-hazard threats and evolving trends (climate change, demographics, etc.)
  - Design of infrastructure systems as processes and services vs. discrete "things"
  - Interdependency of existing and emerging infrastructure – challenges and opportunities
  - Ubiquity and availability of real-time data

A New Opportunity - RIPS

- Resilient Interdependent Infrastructures Processes and Systems
- Under the Emerging Frontiers in Research and Innovation (EFRI) Program
- FY 15: CRISP: Critical Resilient Interdependent Infrastructure Systems and Processes


National Science Foundation
Directorate for Engineering (ENG)

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- Civil, Mechanical and Manufacturing Innovation (CMMI)
- Electrical, Communications and Cyber Systems (ECCS)
- Engineering Education and Centers (EEC)

Email Print Share

Resilient Interdependent Infrastructure Processes and Systems (RIPS)

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PROGRAM GUIDELINES

Solicitation 14-524

DUE DATES

Full Proposal Deadline Date: March 19, 2014
Type I and Type II Proposals

SYNOPSIS

Critical infrastructures are the mainstay of our nation's economy, security and health. These infrastructures are interdependent. For example, the electrical power system depends on the delivery of fuels to power generating stations through transportation services, the production of those fuels depends in turn on the use of electrical power, and those fuels are needed by the transportation services.

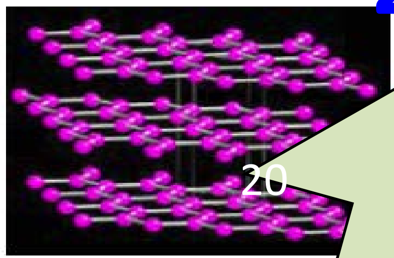
The goals of the **Resilient Interdependent Infrastructure Processes and Systems** (RIPS) solicitation are (1) to foster an interdisciplinary research community that discovers new knowledge for the design and operation of infrastructures as processes

Rapid Growth of Graphene Science & Technology

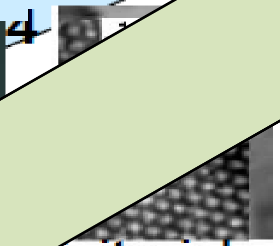
> 5000 papers per year!

2004

Graphite sp²

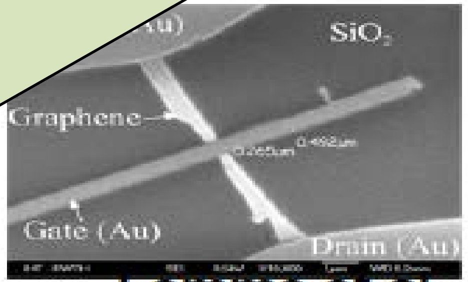


Novoselov et al., Science, 2004



Epitaxial graphe
Berger et al., 2004

2007

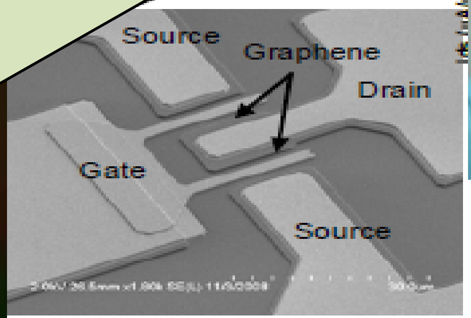


Lemme et al., EDL, 2007
Ion/Ioff < 3

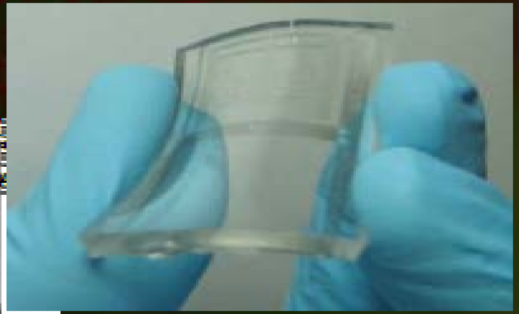
2008

A world's first 2" graphene MOSFET

2009



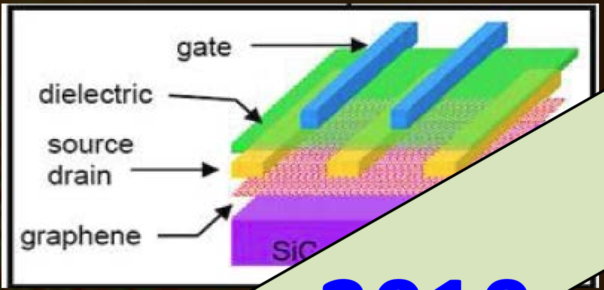
A world's first Epitaxial graphene RF-FET (HRL, Dec, 2008)



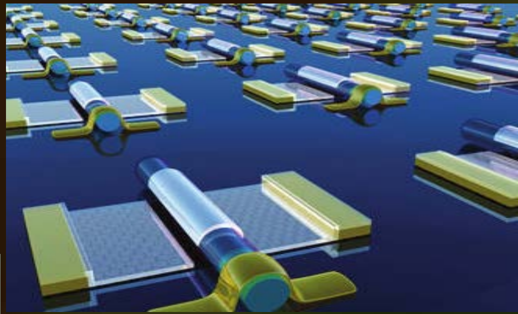
Stretchable transparent electrodes - Kim et al. *Nature* 2009 (SKKU , Samsung, Columbia)

2010

IBM's 100 GHz RF-FET
Avouris, *Science* 2010



2012



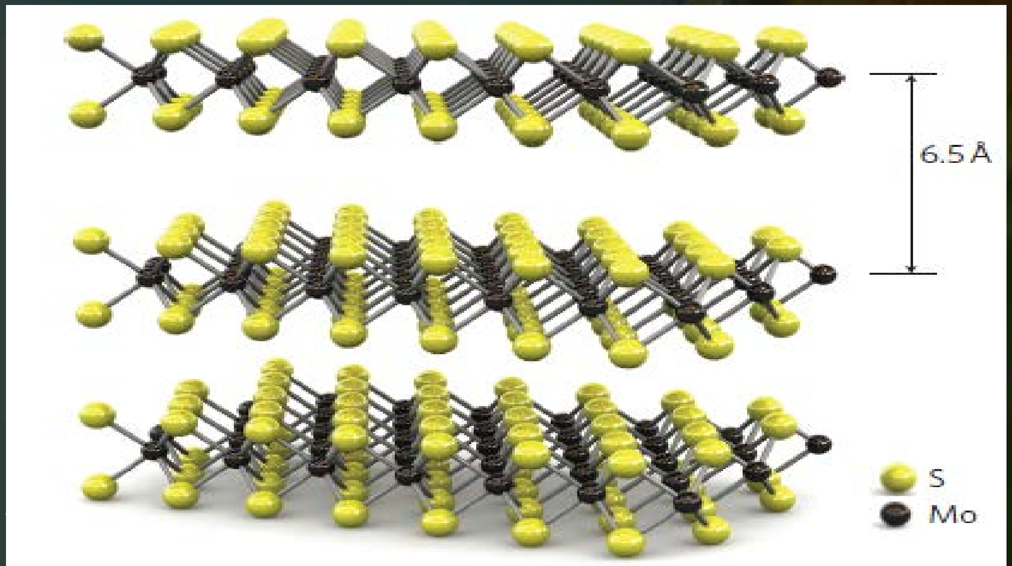
Graphene circuits/mixers
Duan et al. *Nano Lett* 2012

Other 2-D Layered Materials

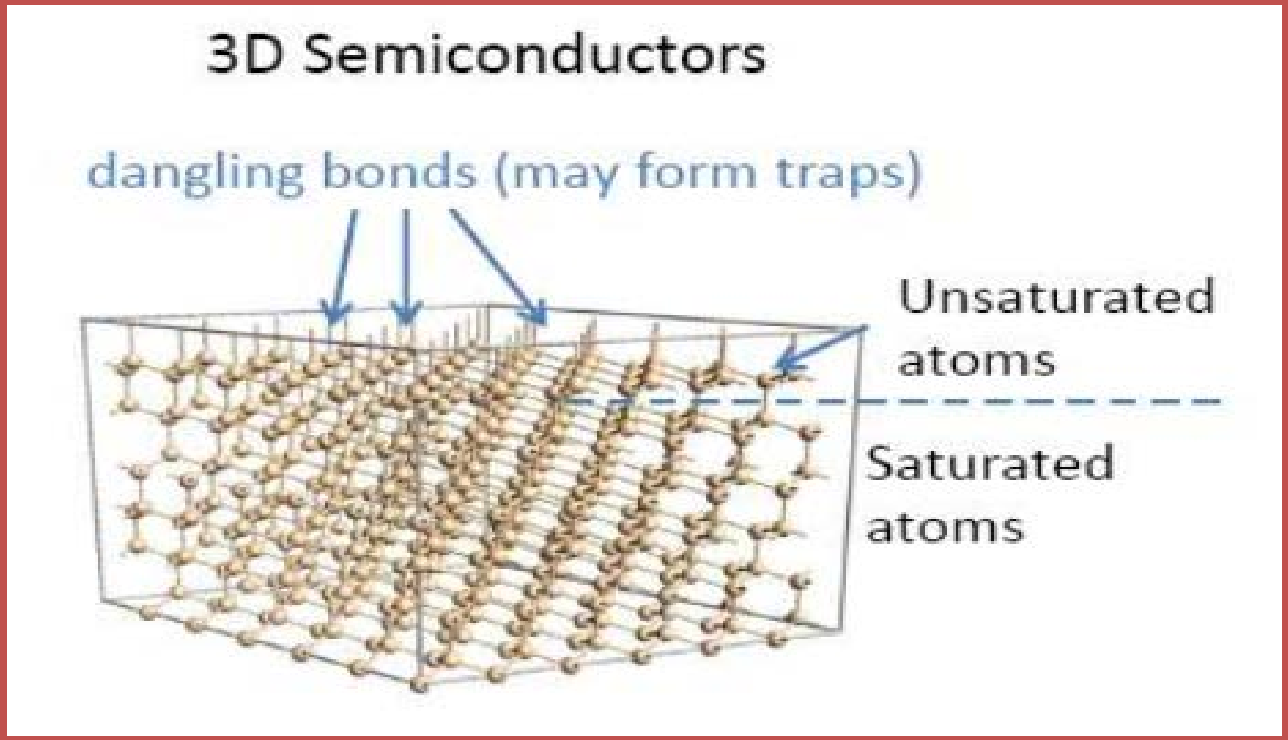
Graphene opened our eyes to an entire new world of 2-D layered materials

Bulk MoS2 crystal, looks and feels graphite – Molybdenite – earth abundant

- Other layered 2D materials exist: oxides, nitrides, sulfides
- Van der Waals solids: e.g. 2D MoS2
- Interesting properties: MoS2 turns from indirect band-gap semiconductor to direct band-gap



Scaled 3D Semiconductors



Two-Dimensional Atomic-layer Research and Engineering – 2-DARE

- Under our EFRI program
- Three themes:
  - Exploration of Materials Properties and Device Applications
  - Synthesis and Nanomanufacturing
  - Theory and Modeling
- 159 pre-proposals submitted
- 42 full proposals invited
- Again in FY 2015

Network for Computational Nanotechnology (NCN)

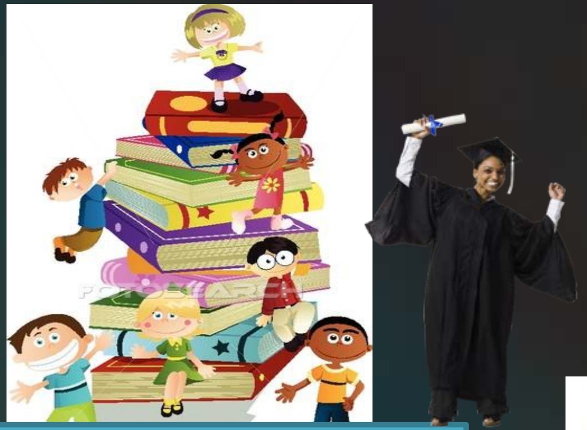
"nanoHUB builds an extraordinary community among different disciplines and industries involved in nanotechnology and allows them to collaborate more efficiently. It's a virtual community that shows there are more solutions than there are problems."

-Jack Uldrich

Author of "The Next Big Thing is Really Small"

- NCN provides a global community of researchers, educators, and learners.
- In FY 2012, NSF re-competed the NCN cyberplatform and two content nodes
  - Nano-Engineered Electronic Device Simulation Node (NEEDS) (Nano-SPICE)
  - Nano-bio

New ERC Competition in Underway



Education

Interdisciplinary Research

Innovation Ecosystem

Engineered Systems Vision

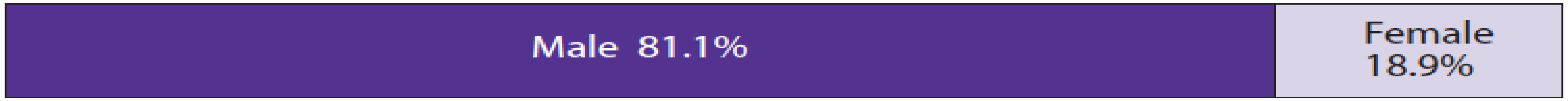
Infrastructure

- 188 pre-proposals received
- 18 invited for full proposals
- Deadline ~ June 2014
- Awards in FY15

Engineering Education

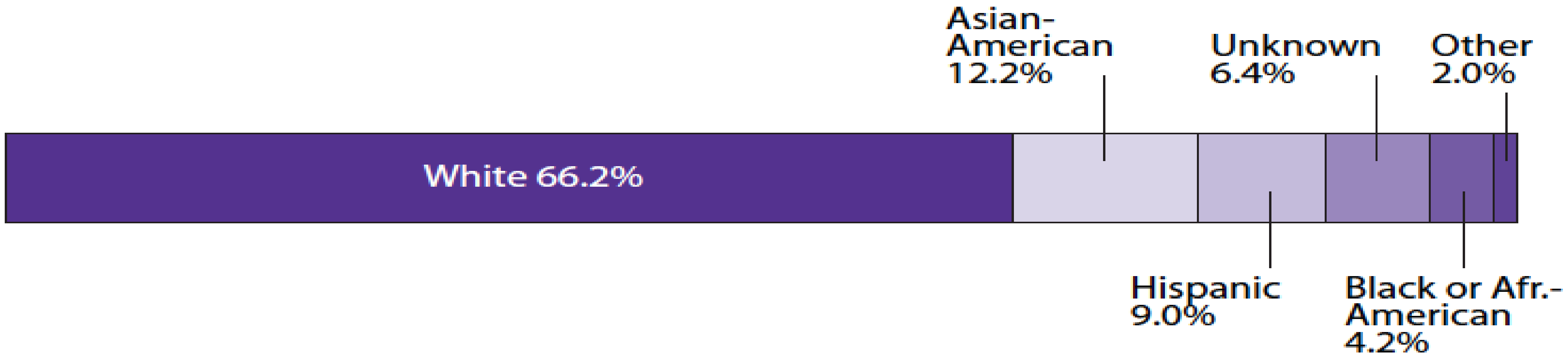
Engineering Degrees

Bachelor's Degrees by Gender, 2012



	2003	2004	2005	2006	2007	2008	2009	2010	2011
Female	20.4%	20.3%	19.5%	19.3%	18.1%	18.0%	17.8%	18.1%	18.4%
Male	79.6%	79.7%	80.5%	80.7%	81.9%	82.0%	82.2%	81.9%	81.6%

Bachelor's Degrees by Ethnicity, 2012*



	2003	2004	2005	2006	2007	2008	2009	2010	2011
Black or African American	5.1%	5.1%	5.3%	5.0%	4.9%	4.7%	4.6%	4.5%	4.2%
Hispanic	5.4%	5.6%	5.8%	6.0%	6.2%	6.5%	6.6%	7.0%	8.5%
Other	7.2%	8.0%	8.6%	8.5%	8.3%	8.9%	11.0%	1.2%	1.6%
Asian American	14.0%	14.2%	14.1%	13.8%	13.3%	13.0%	12.4%	12.2%	12.2%
White	68.3%	67.1%	66.2%	66.7%	67.3%	66.9%	65.4%	69.8%	66.6%
Unknown								5.3%	6.9%

Source: ASEE, By the Numbers,11-4

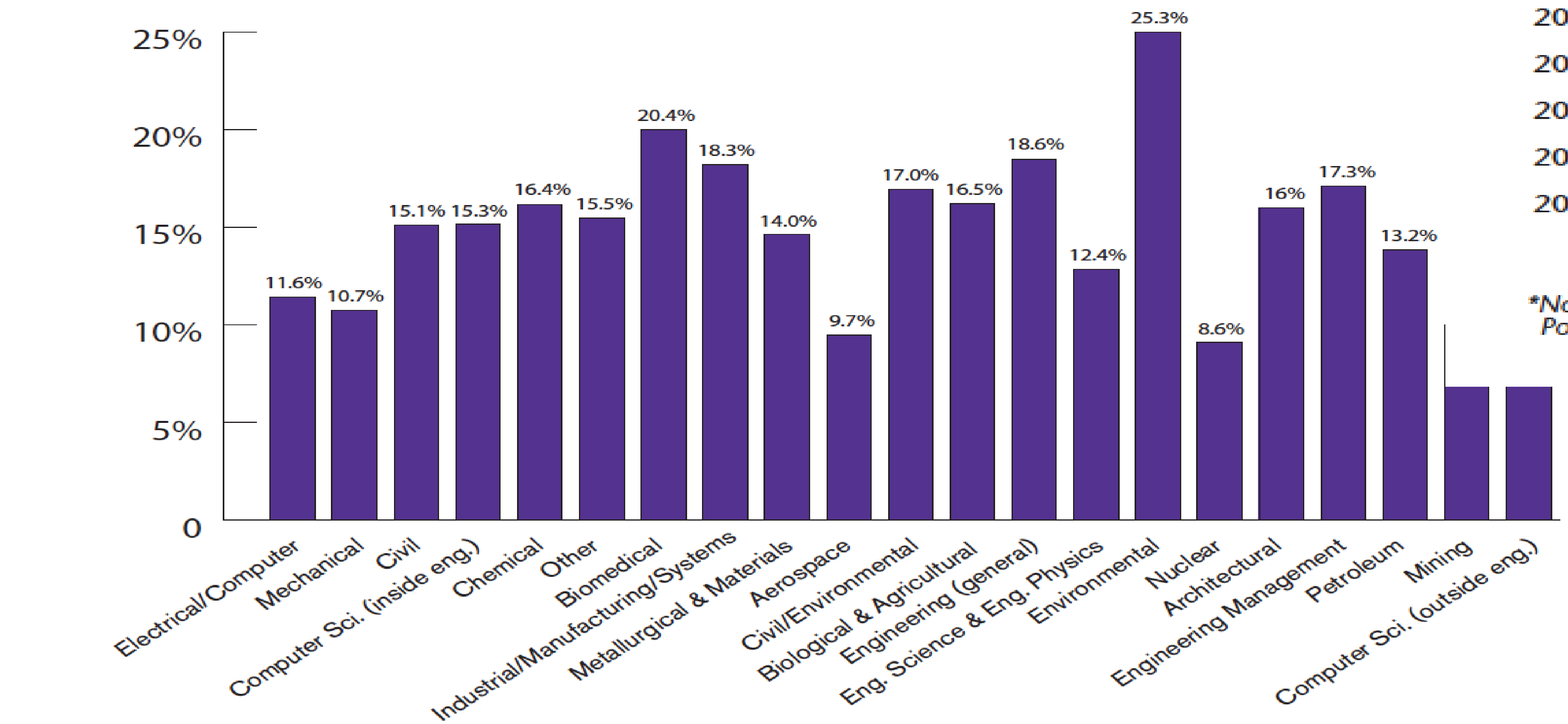
Source: ASEE, By the Numbers,11-47

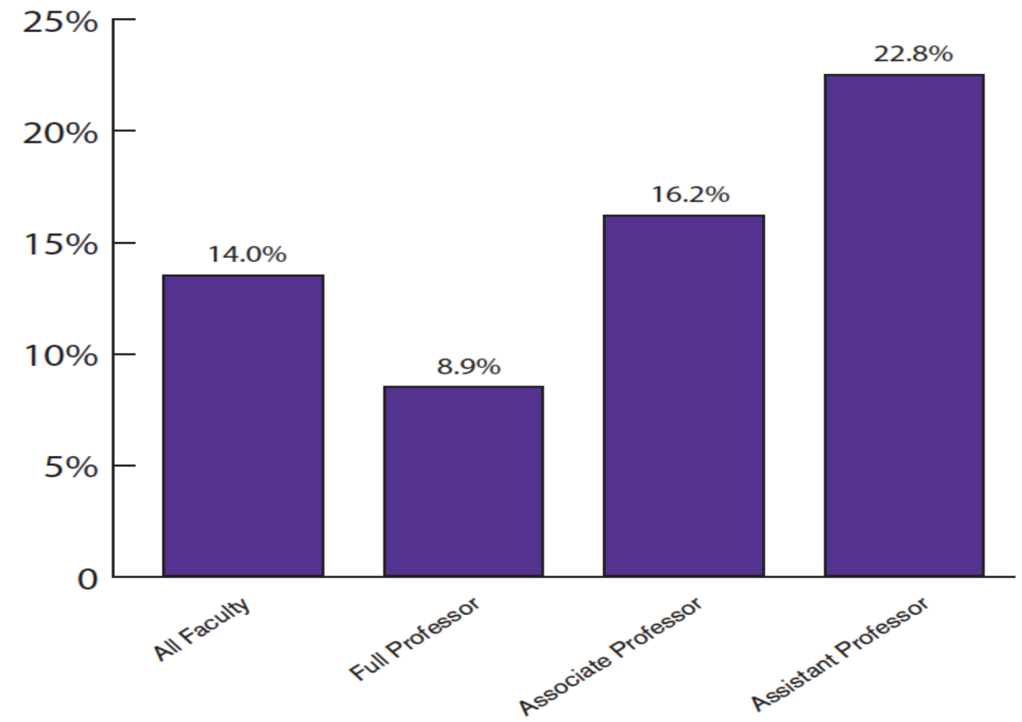
Faculty Diversity

	Women	African-American	Asian	Hispanic
2003	9.9%	2.2%	19.2%	3.1%
2004	10.4%	2.3%	20.2%	3.2%
2005	10.6%	2.4%	20.9%	3.2%
2006	11.3%	2.4%	22.0%	3.3%
2007	11.8%	2.5%	22.6%	3.4%
2008	12.3%	2.5%	22.7%	3.5%
2009	12.7%	2.5%	23.3%	3.5%
2010	13.2%	2.5%	23.9%	3.6%
2011	13.8%	2.5%	21.6%	3.7%

**Note: Includes faculty data from University of Puerto Rico, Mayaguez, Polytechnic University of Puerto Rico and Turabo University*

ERCENTAGE OF WOMEN TENURED/TENURE-TRACK FACULTY BY DISCIPLINE: 14.0%





Source: ASEE, By the Numbers,11-47

Observations

- Engineering continues to have major issues with attracting women and URMs
  - It is trailing certain other fields of science
  - There are significant differences among engineering disciplines
- More progress wrt women at the doctoral level and junior faculty ranks
- Mechanical Engineering has become the largest major in engineering
  - ME lags engineering overall in diversity in % terms
  - Note: there has been an increase in raw numbers
  - ME shares this trait with EE, Comp Eng, Civil Eng, …

Can engineering as a field and profession have a great future if we do not address broadening participation issues?

"Demography is destiny"
Auguste Comte

Questions to Ponder

- Models: What are the most successful models for change?
- Transferability: How can success at one institution be used to achieve success at another?
- Culture: What is the role of culture – societal, academic, engineering, institutional – in rate of change?
- How can we make faster progress?

Where will the leadership for new visions and change in engineering education come from?

What we might we achieve together?

NSF IUSE Program
(Improving Undergraduate STEM Education)

- IUSE supports the improvement of the undergraduate STEM education enterprise through funding
  - research on design, development, and wide-spread implementation of effective STEM learning and teaching knowledge and practice
  - foundational research on student learning.
- Projects that build on available evidence and theory, and that will generate evidence and build knowledge.
- Led by Education and Human Resources (EHR) Directorate
  - Engineering collaborating with EHR

CAREER: Teacher-Scholar

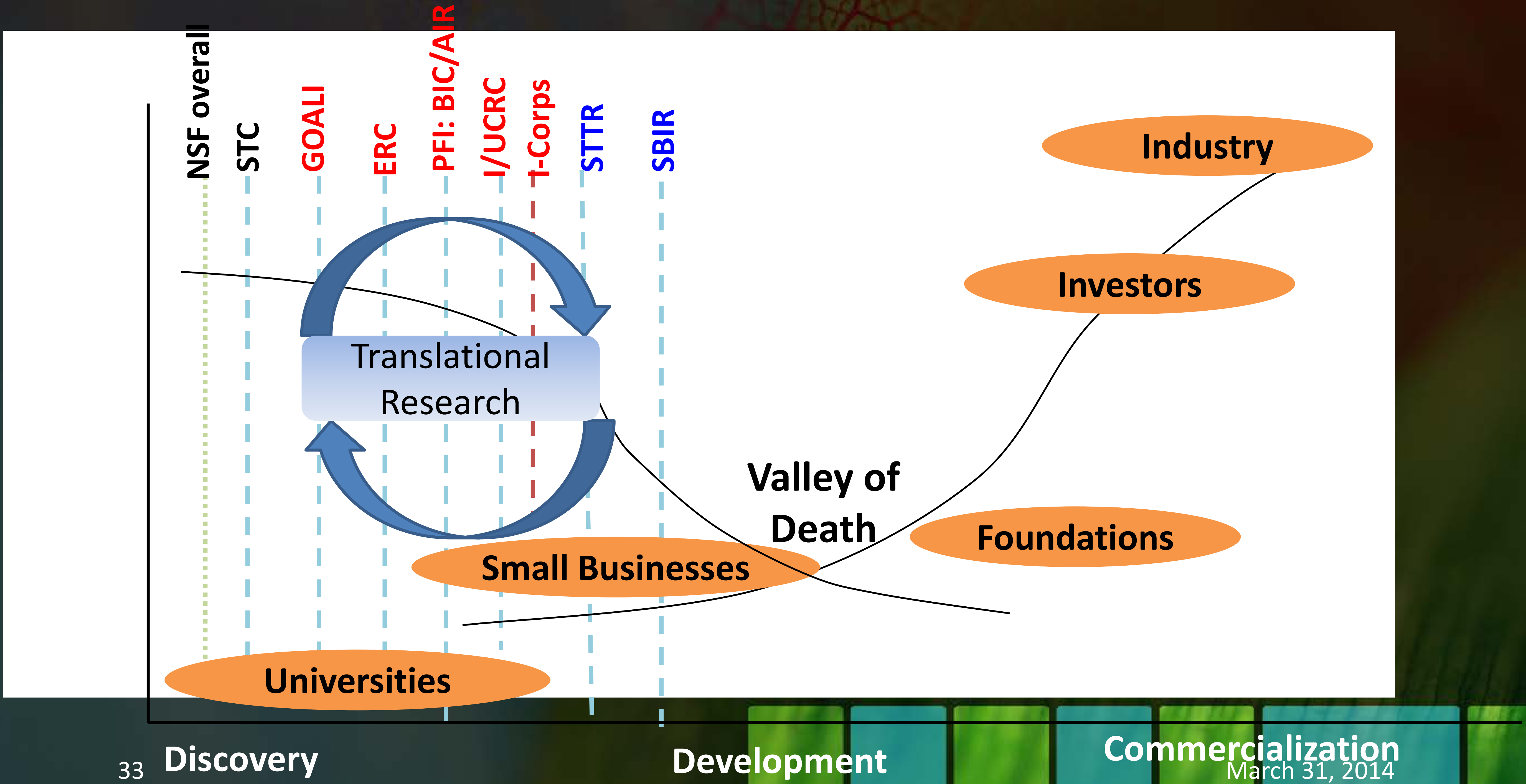
- "Successful applicants will propose creative, effective, **integrated** research and education plans, and indicate how they will assess these components."

CAREER Project Description:

- a description of the **proposed research project**, including preliminary supporting data where appropriate, specific objectives, methods and procedures to be used, and expected significance of the results;
- a description of the **proposed educational activities**, including plans to evaluate their impact on students and other participants;
- **a description of how the research and educational activities are integrated with one another**

NSF remains fully committed to supporting the junior faculty

Research to Commercialization: NSF Programs



The Service Economy

Last updated: January 24, 2013 6:27 pm

Xerox says shift to services is paying off

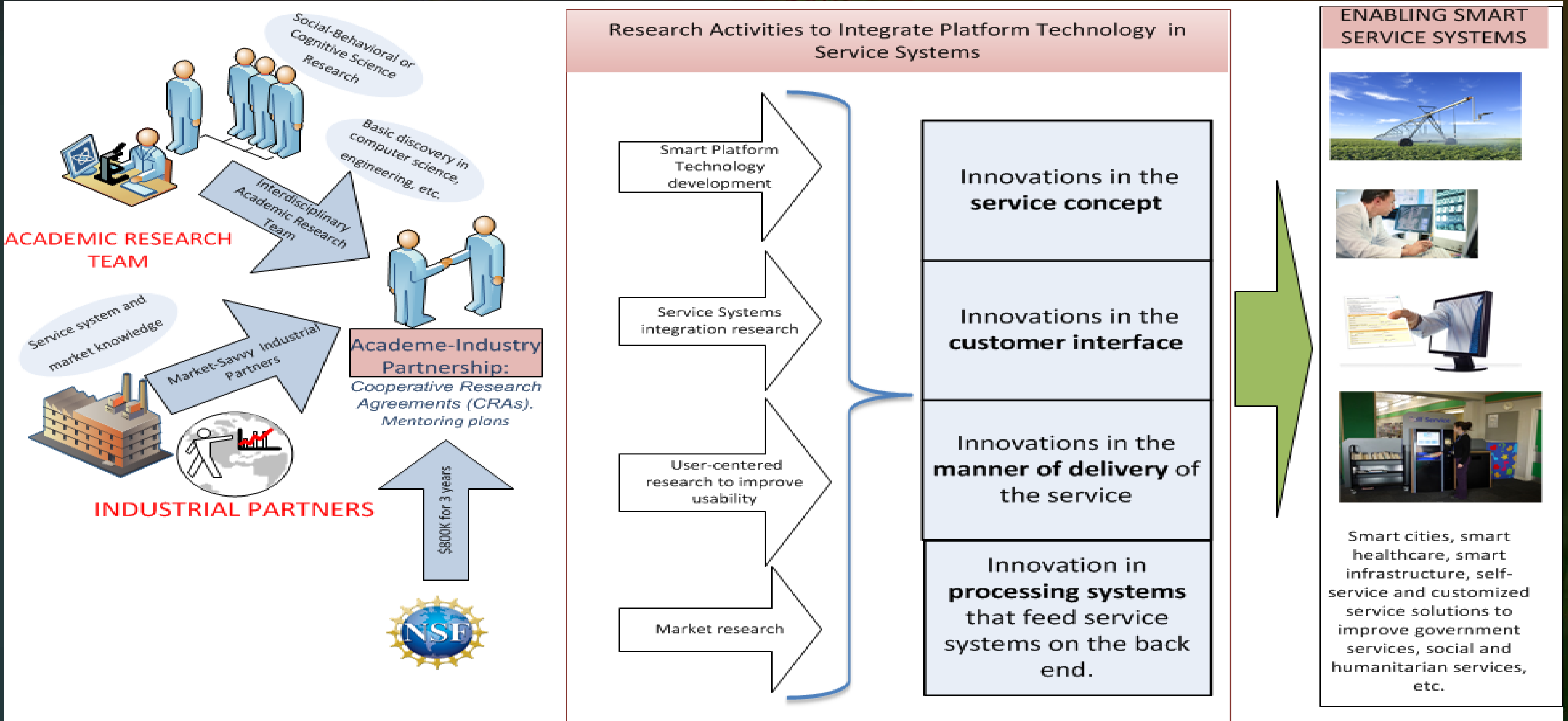
By Anjli Raval in New York

Medtronic's Ishrak outlines health services expansion plans

August 21, 2013 | By Mark Hollmer

- The U.S. service sector is responsible for:
  - Employing approximately 80% of workers
  - Creating approximately 80% of GDP
- Manufacturing (product) industries are increasingly incorporating value-added service components.
- The future market will need high-quality, low-cost, and highly personalized solutions in education, healthcare, manufacturing, transportation, and agriculture.

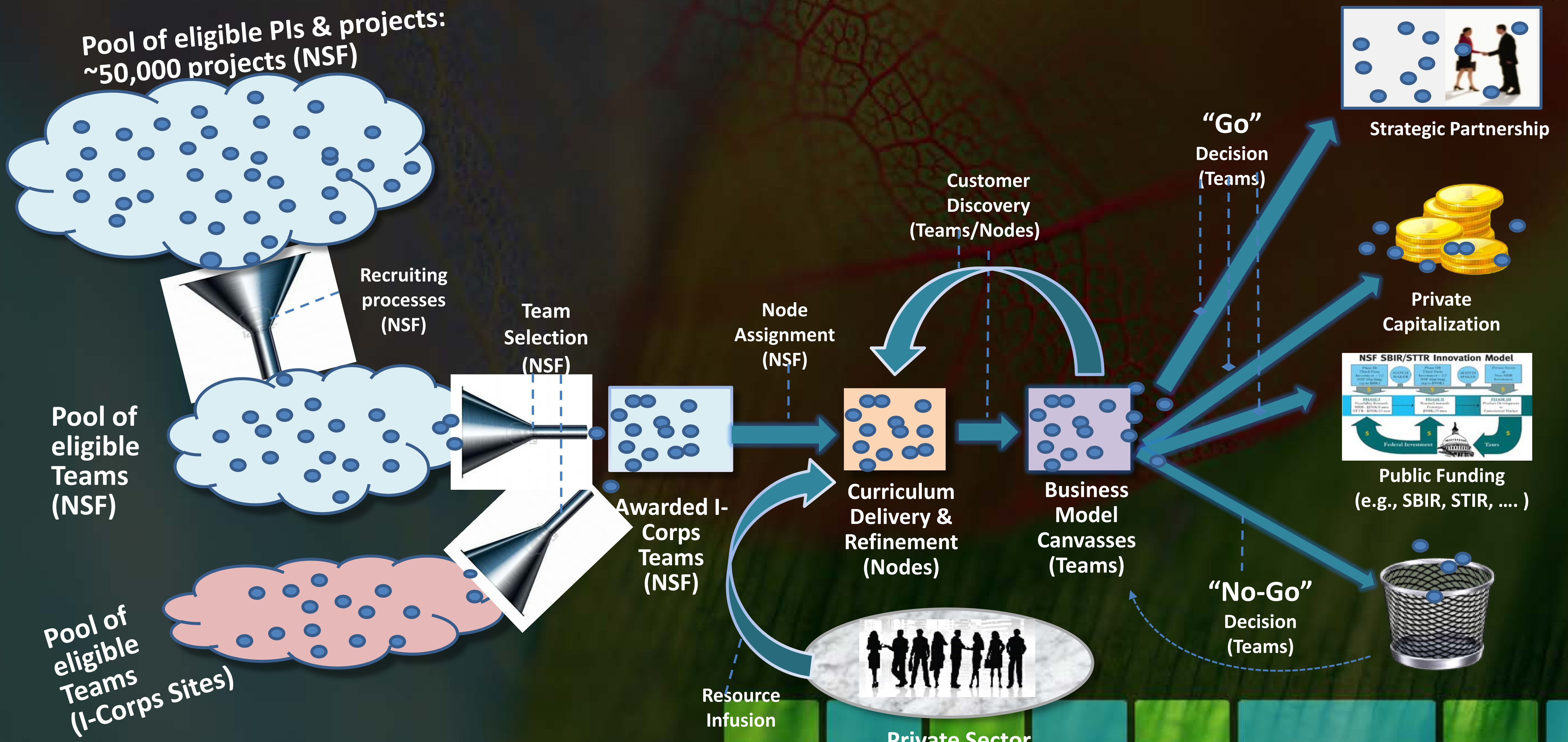
PFI:BIC – Smart Service Systems



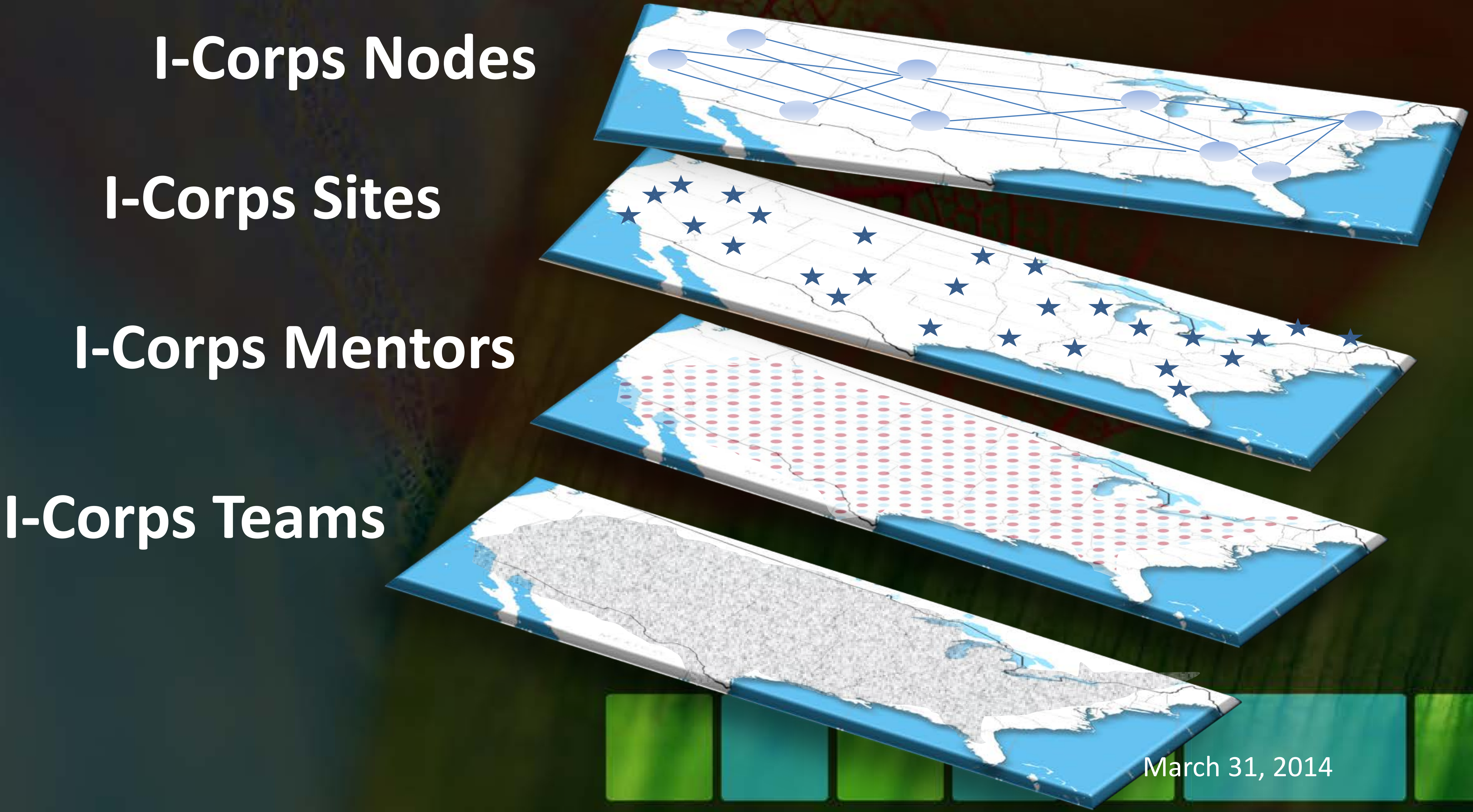
NSF I-Corps™

- Lab to Market program
- Aimed at customer discovery process
- Emphasizes experiential learning and feedback
- Challenges teams to create their own business model canvas
- Values revision and continual improvement of business development elements
- Full contact immersive class

I-Corps Process Flow



Building the Nation's I-Corps "Fabric"



anchovilabs

New way to organize, browse and share your photos.

Acquired by Dropbox

Developed software to annotate a large number of images quickly and accurately

Combining human input with an annotation algorithm

Facilitate image analysis

Founders

Serge Belongie

Professor at UC San Diego

Peter Welinder

Award-winning research in computer vision, machine learning and crowdsourcing.

Boris Babenko

Co-founder of @Anchovi Labs, Inc.

Disciplines in a World without Disciplines

- NSF ENG has a strong commitment to fundamental engineering research
- How should we think about discipline based fundamental research in the contemporary multi-disciplinary research environment?
- Think of disciplines as super-nodes in the knowledge network
- Major opportunity: robust, effective linkages among nodes to increase versatility of disciplinary research and solve tomorrow’s problems

Looking to the Future

- Are we in the midst of the emergence of a new research paradigm?
- Definition of *Paradigm*:

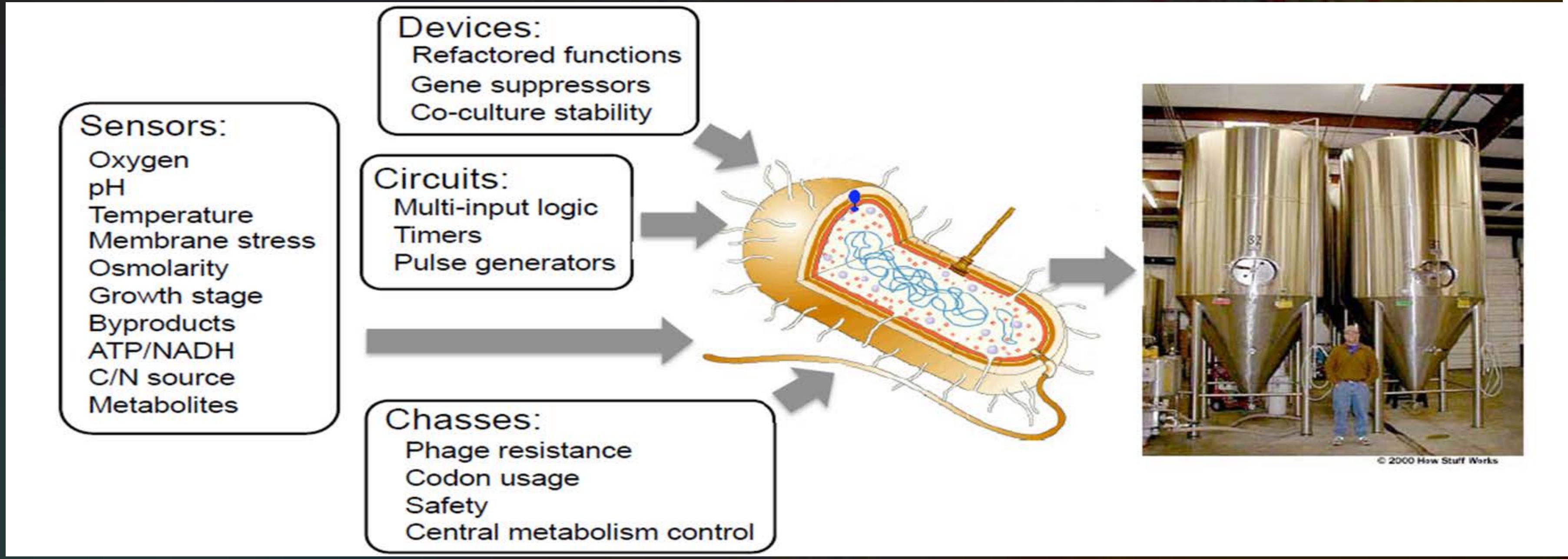
universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of practitioners

Thomas Kuhn

Convergence: Engineering Biology

- An emerging research paradigm: The convergence of engineering, physical sciences and life sciences
- Intellectual merit: deep integration of knowledge, ideas, tools, techniques for greater understanding and innovative designs
- Broader impacts:
  - Medicine, pharmaceuticals
  - Manufacturing (bio-products,
  - chemical intermediates)
  - Environment
  - Agriculture

Synthetic Biology ERC



VISION: engineer interchangeable biological tools that "repurpose" nature to benefit mankind.

- SynBERC engineers integrate foundational understanding of biology into computational tools to design new biological parts and devices *in silico.*

- New biological parts and devices are made *de novo* using engineered DNA that is expressed
- Parts and devices are assembled in circuits within living cells to manufacture specialty chemicals or test drug candidates
- SynBERC researchers work with stakeholders to minimize biorisks and environmental footprint.

Lead UC Berkeley (PI: Keasling); partners UC San Francisco, Stanford, Harvard and MIT

Images courtesy SynBERC

Research in a Broader Context

How do we leverage research for larger societal benefits?

Merit Review Criterion: *Broader Impacts*

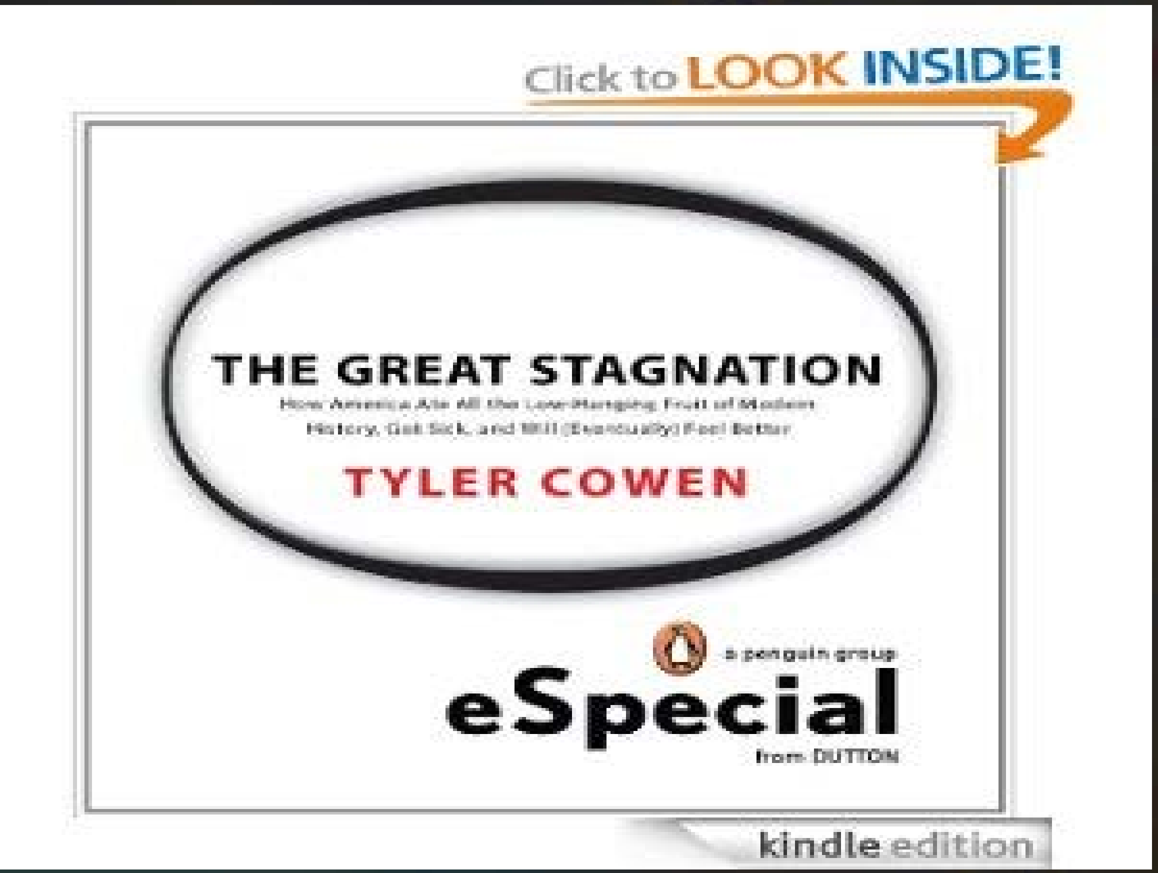
- The Broader Impacts criterion encompasses the potential to benefit society and contribute to achieving specific, desired societal outcomes, including:
  - increased participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM);
  - improved STEM education at all levels;
  - increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society;
  - development of a globally competitive STEM workforce;
  - increased partnerships between academia, industry, and others;
  - increased national security;
  - increased economic competitiveness of the United States;
  - and enhanced infrastructure for research and education.

NSB Recommendation

- “Just as institutions play an important role in facilitating research-related activities of their investigators, often in ways that align with strategic departmental and institutional (and possibly state-wide, regional, or national) priorities and investments, such a role can extend to activities directed toward the broader impacts of the project as well.”
- “… such efforts might be more effective if coordinated appropriately in ways that leverage particular institutional assets or strategic directions and even link investigators from multiple projects.”
- *NSF should encourage institutions to pursue such cooperative possibilities, which have the dual benefit of retaining the contributions of individual investigators while addressing national goals and yielding benefits broader than those within a given project.*
- *How can engineering colleges and departments respond to this opportunity?*

Role of Grand Challenges

- Grand challenges can be very useful in catalyzing major breakthroughs and advances
  - NAE Grand Challenges in Engineering
- Key characteristics:
  - Big impact
  - Ambitious yet achievable
  - Compelling vision
  - Right level of specificity
- How can the engineering research community use the grand challenge vehicle for big research achievements?



IS U.S. ECONOMIC GROWTH OVER? FALTERING INNOVATION CONFRONTS THE SIX HEADWINDS

Robert J. Gordon

Working Paper 18315
http://www.nber.org/papers/w18315

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Technological Forecasting an
Social Change

A possible declining trend for worldwide innovation

Jonathan Huebner*

The Economist

Innovation pessimism

Has the ideas machine broken down?

The idea that innovation and new technology have stopped driving growth is getting increasing attention. But it is not well founded

Jan 12th 2013 | From the print edition

An Invitation

- We encourage and invite the engineering research, education, and innovation communities to help us realize the vision for NSF Engineering Directorate
- Faculty, students, universities and industry are critically important partners for mutual benefits and successes
- We can work together to build a great engineering research and education ecosystem for societal benefits

QUESTIONS?

IDEAS, THOUGHTS!

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