The Future of Center-Based Multidisciplinary Engineering Research

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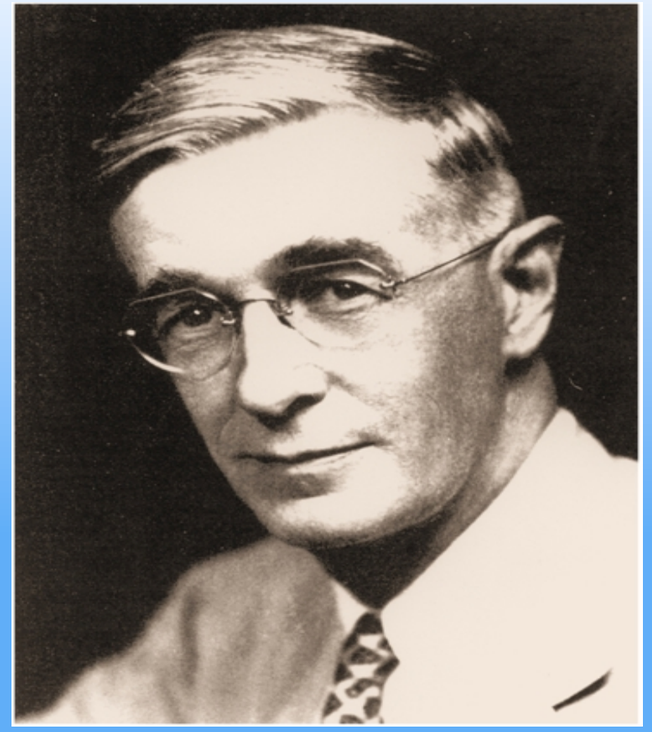
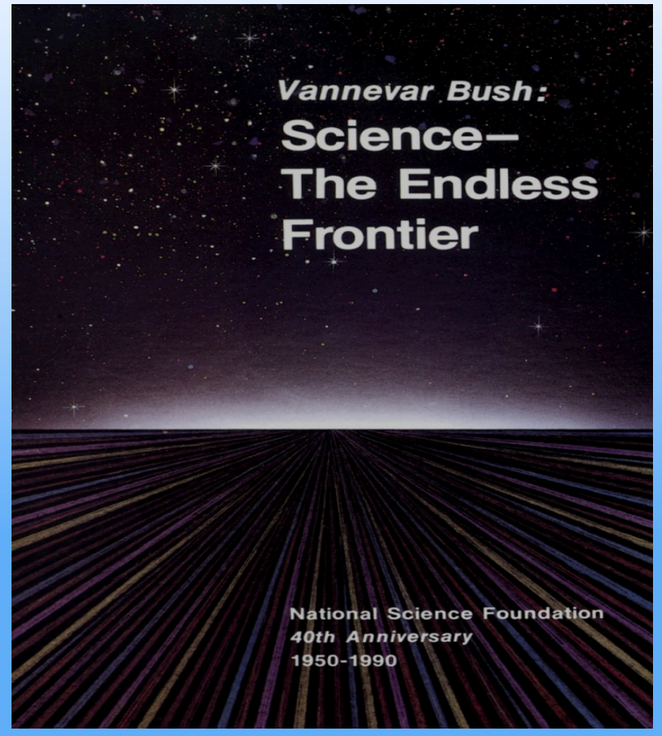
Assistant Director for Engineering
National Science Foundation

The National Academies
Committee on the Future of Center-Based,
Multidisciplinary Engineering Research
December 14, 2015





Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress.

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

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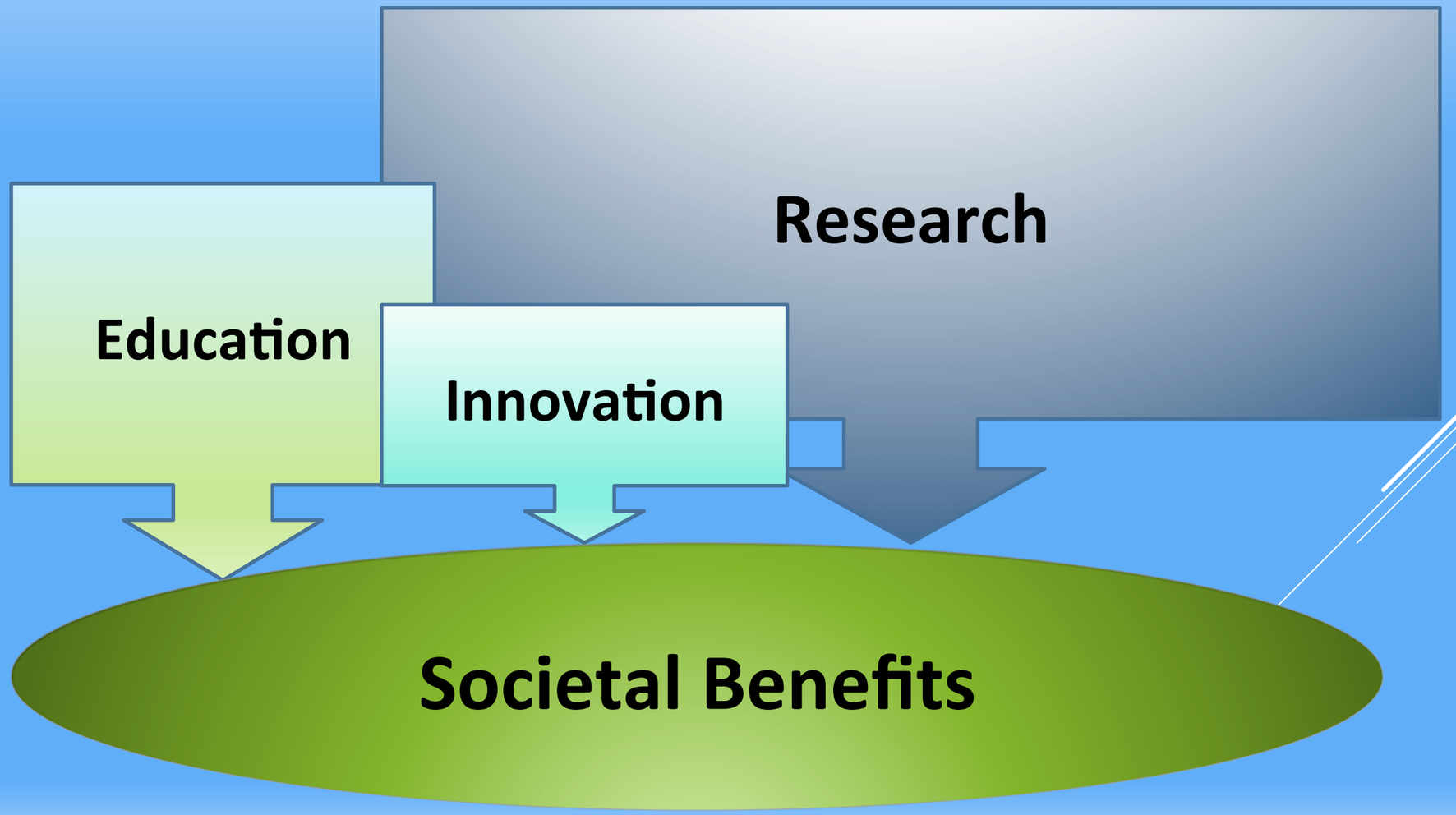
NSF ENG: Investing in engineering research and education and fostering innovations for benefit to society



Larger Context

- **Employment and wages**
  - Productivity, innovation, economic growth, sustainability, long-tem competitiveness
- **Mega problems**
  - Food, health, energy, water, security, education, infrastructure, …
- **Globalization**
  - Flows of components, products, services, knowledge, and people
- **People and talent**
  - Stubborn long-standing issues in STEM talent, diversity, and education
- **Accelerating pace of discovery and technology**
- **Federal support of research**

Top Engineering Achievements of the 20th Century

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

Source: National Academy of Engineering

What advances will be on the list for the 21st Century?

What will be the role of NSF/ENG in impacting items on that list?

Context for this NAE Study

- NSF established the Engineering Research Center program in 1984
- Focus on multidisciplinary engineering research, education, workforce development in partnership between academe and industry
- Much has changed since 1984
- *And, doubtless, much more will change in the next 30 years!*

Before We Think about the Future … First, Background on the ERC Program

Engineering Research Centers program was launched with the GOAL:

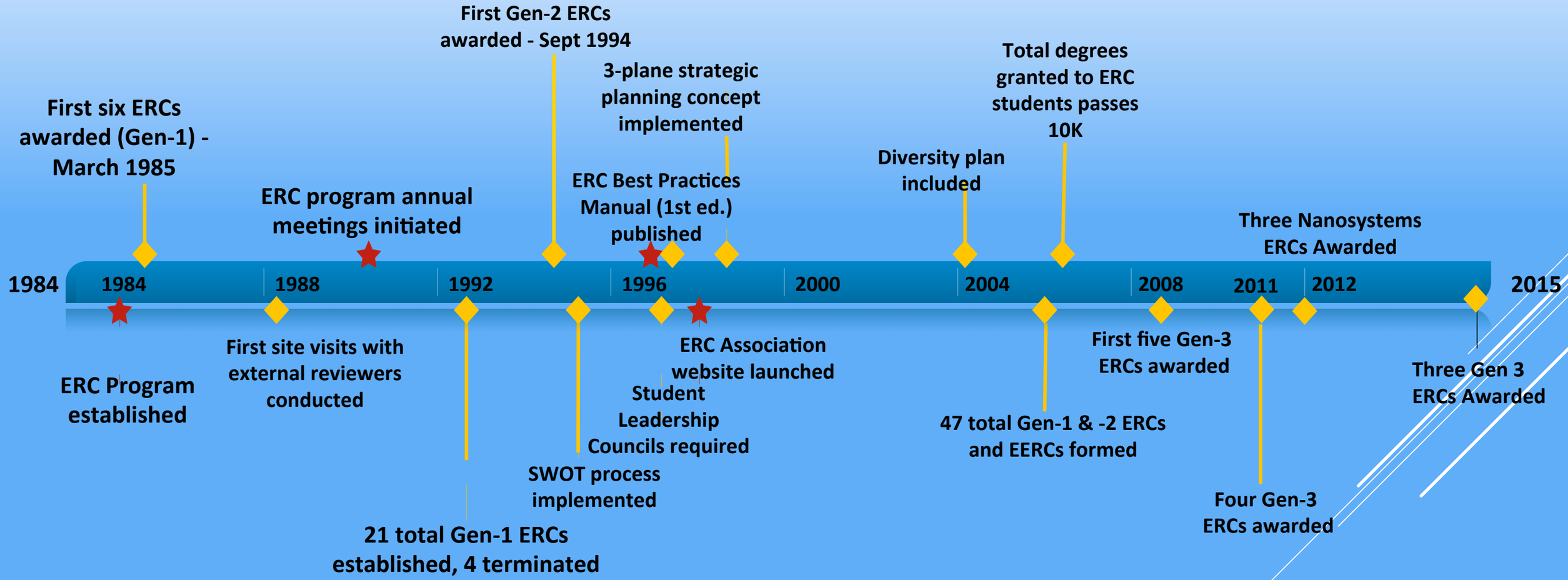
"to further the development of fundamental knowledge in engineering fields that will

- Enhance the competitiveness of the U.S. and
- Prepare engineers to contribute through better engineering practice."

Distinguishing Features of an ERC

- Compelling vision for an **engineered system** at the cusp of discovery and innovation for societal impact
- Integrated program from exciting fundamental research to proof-of-concept systems test beds
- A 10-year strategic plan that is driven by engineered systems barriers and powerful fundamental insights
- Innovative plan to develop engineering graduates with the skills to be highly effective in industrial practice and creative innovators in a global economy throughout their careers
- Innovative plan to accelerate the use of ERC-generated technology and processes in industry/practice

ERC Evolution Timeline



Gen 1 to Gen 2 Major Changes

- Lead + at least one academic core partner required from 1998
- Guiding strategic vision for transforming engineered systems and developing a globally competitive and diverse engineering workforce
- Strategic plans for research and education to realize the vision
- Cross-disciplinary research program from discovery to innovation
- Education program integrating research and education
- Outreach to precollege and other university students and teachers/faculty
- Partnership with industry to formulate and evolve the strategic plan, strengthen research and education, speed technology transfer
- Leadership infrastructure, cohesive interdisciplinary team, management systems
- Cross-institutional commitment to facilitate and foster the interdisciplinary culture and diversity of the ERC

Gen 2 to Gen 3 Major Changes

- Support translational research with small firms to speed innovation
- Partner with economic development organizations to foster entrepreneurship
- Develop engineers who are more creative & innovative
- Partner with foreign universities to provide cross-cultural, global research and education experiences
- Establish long-term pre-college partnerships to attract young students to engineering

Current ERC Solicitation (NSF 15-589)

Three Fundamental Questions

- *What is the compelling new idea and how does it relate to national needs?*
- *Why is a center necessary to tackle the idea?*
- *How will the ERC's infrastructure integrate and implement research, workforce development, and innovation ecosystem development efforts to achieve its vision?*

Specific Review Criteria

- Integrated Strategic Plans for Research, Workforce Development, Innovation
- Leadership: expertise in research, workforce development, and innovation
  - Diversity Director: experienced in activities proven to create culture of inclusion
- Research: impact, benchmarking, partnerships, system-at-scale
- Workforce Development: literature-based, inclusive, assessment
- Innovation: scalable, sustainable, community
- Infrastructure: plan for community of inclusion

ERC Program Evaluations and Reports

General

- 2007 Annual Meeting Report: Designing the Future ERC
- Post-Graduation Status of Engineering Research Centers - 2010
- Engineering Research Centers 2005-2006 Program Report
- Designing the Future Generation of NSF Engineering Research Centers: Insights from Worldwide Practice (report of the Science and Technology Policy Institute, 2007)
- The Impact of Engineering Research Centers on Institutional and Cultural Change in Participating Universities, 2001
- Documenting Center Graduation Paths, 2000
- The ERC Program: An Assessment of Outcomes and Benefits, 1997

ERC Program Evaluations and Reports

Education & Workforce Development

- Undergraduate and Graduate Education Activities of Current Engineering Research Centers - 2006
- Post-graduation Status of ERC Education Programs – 2002

Innovation & Industrial Collaboration

- IAB Role in ERCs: A SWOT - 2012
- Innovations: ERC-Generated Commercialized Products, Processes, and Startups - 2010
- Engineering Innovation: Strategic Planning in NSF-funded ERCs - 2007
- The Economic Impact on Georgia of Georgia Tech's Packaging Research Center - 2004
- The Impact on Industry of Interaction with Engineering Research Centers - 2004

All these reports are available at:

http://erc-assoc.org/content/erc-program-evaluations-and-case-studies-program-impact

Now, as We Look to the Future …

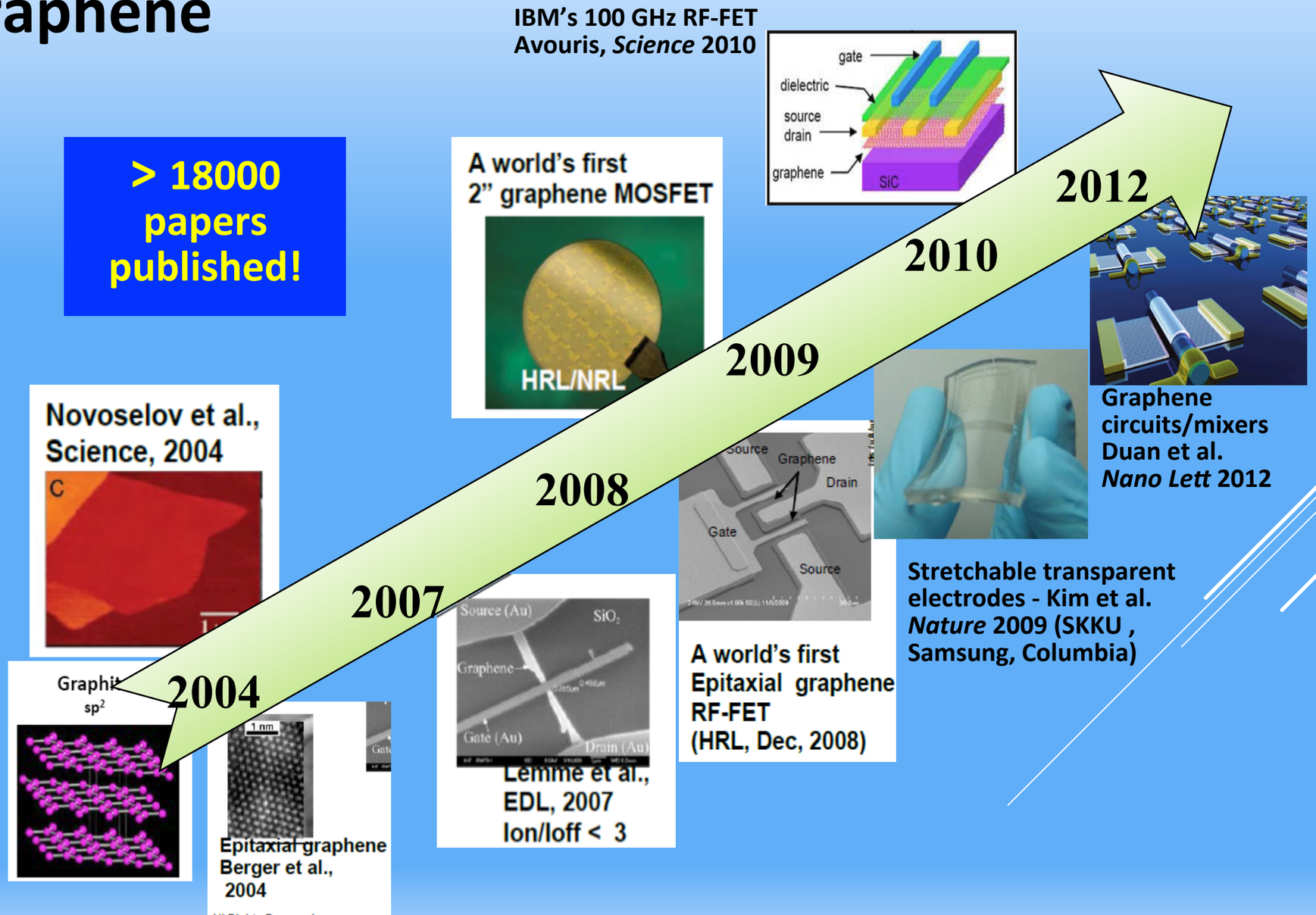
Signs of a Changing Landscape

CHANGING LANDSCAPE

Research: Accelerating Pace of Discovery

Example: Graphene

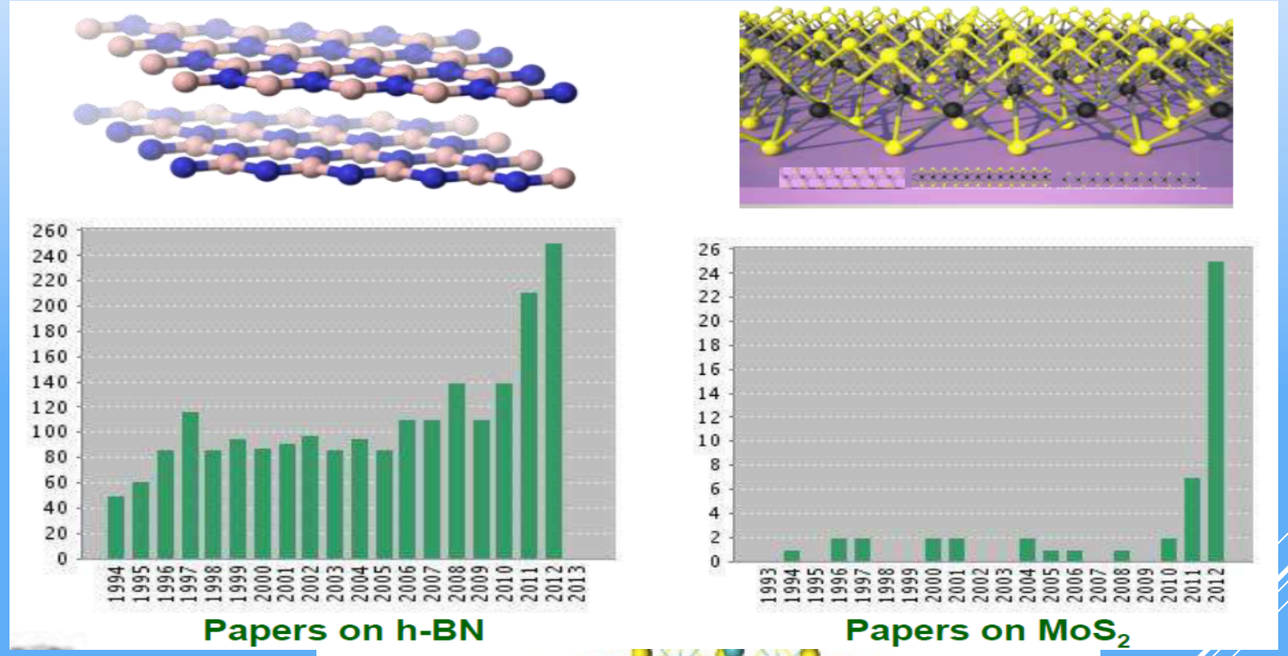
> 18000 papers published!



Emergence of a New Field – 2-D Materials

Graphene is not alone

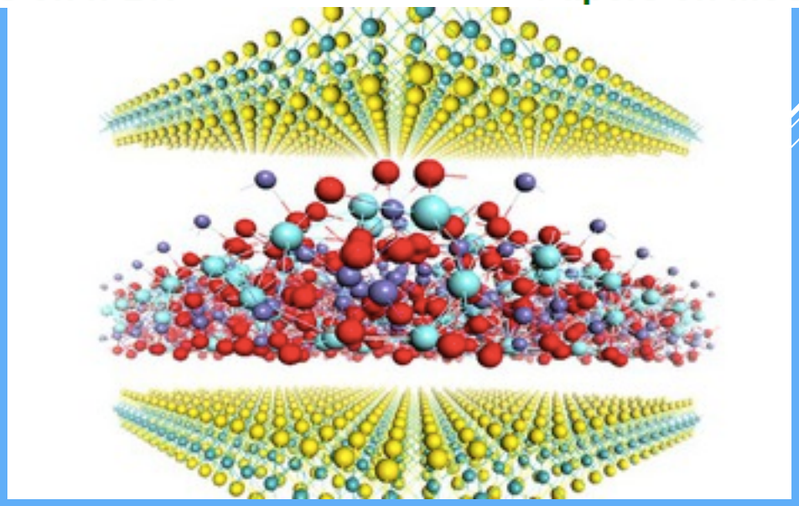
Nature Nanotechnolgy, 2012



The super materials that could trump graphene

A wave of innovative flat materials is following in the wake of graphene — but the most exciting applications could come from stacking them into 3D devices.

Nature News, September 2015



Credit: M. Neupane, R.Lake, and A. Balandin, UC Riverside

CHANGING LANDSCAPE

Research: Emerging Models for Multidisciplinary Collaboration - *Convergence*

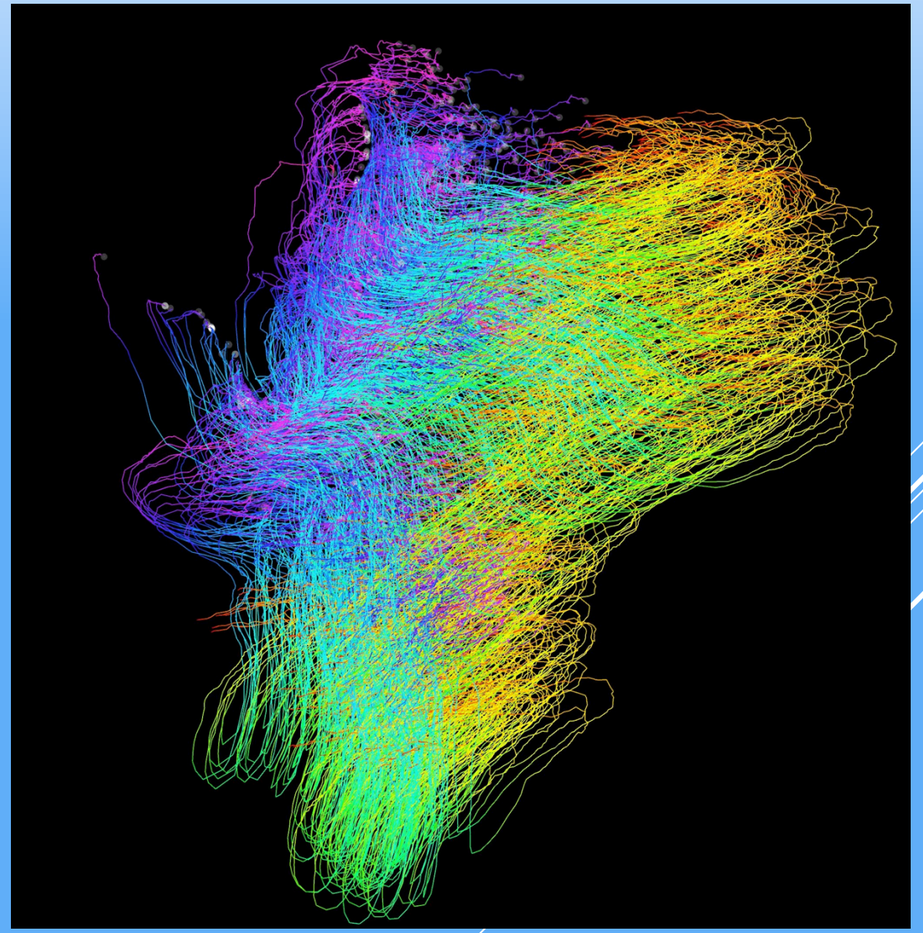
- Examples:
  - Convergence of engineering, physical sciences, and life sciences (MIT)
  - Convergence of engineering, computing, and social-behavioral sciences (NSF CRISP)
  - National Academies Report on Convergence, 2014
- Intellectual merit: deep integration of knowledge, ideas, tools, techniques for greater understanding and major innovations
- Broader impacts: critical for addressing societal needs
- **Importance of working in teams and breaking disciplinary silos**

Do these convergence models offer a new way to construct multidisciplinary center collaborations?

Research: Data and Computing Everywhere

- Computation, simulation, data, visualization, machine learning are becoming ever more powerful
- Internet of Things embedding sensors, computation, and networks into physical and social reality

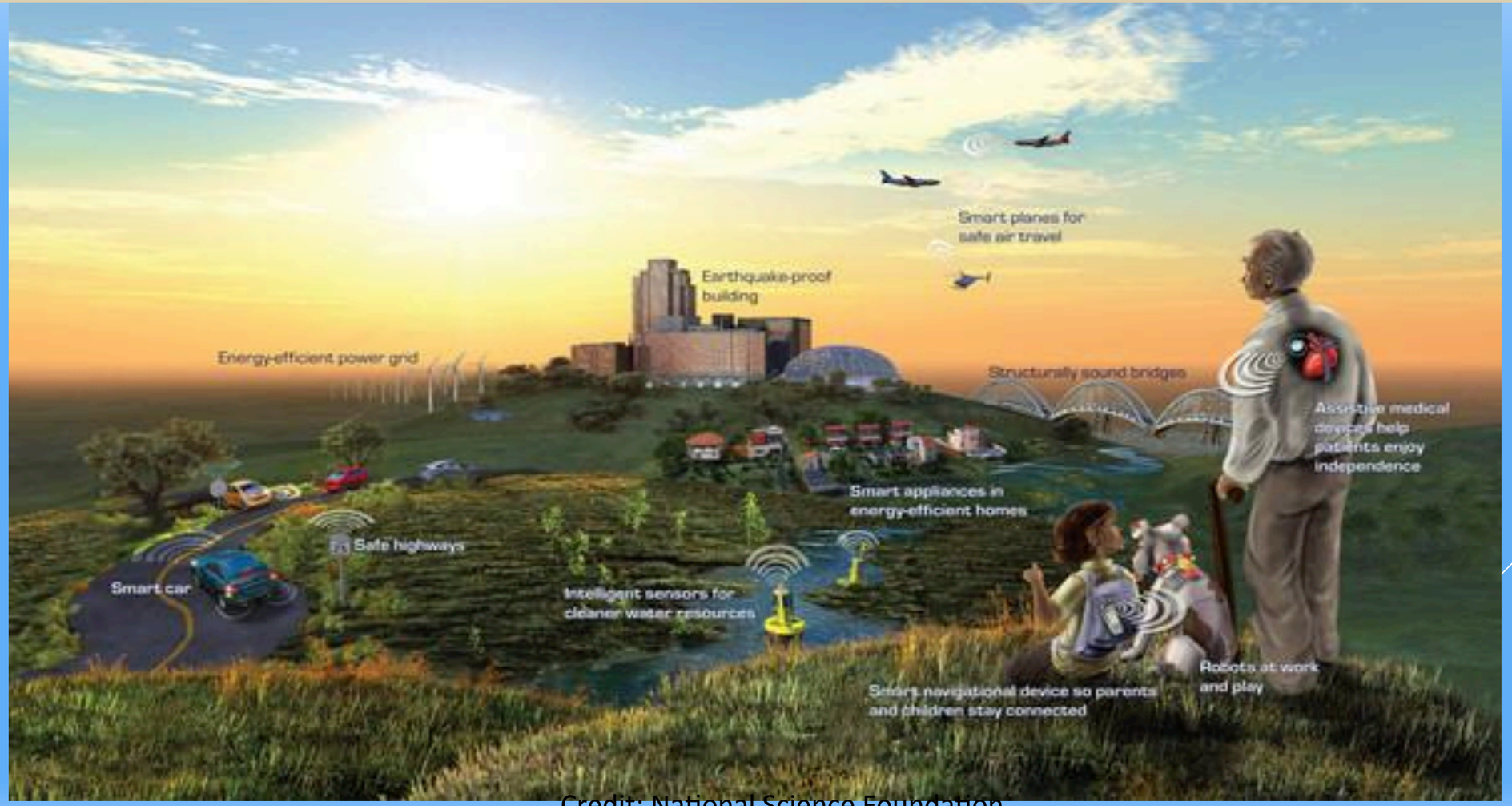
What are the key implications of these growing capabilities for engineering research, education and innovation?



Credit: M. Ritter, J. Tao, H. Zhao, Louisiana State University Center for Computation and Technology

Research: Smart Engineered Systems meet People

Imagine a world that is safe, secure, healthy, vibrant, and resilient…



Credit: National Science Foundation

CHANGING LANDSCAPE

Innovation

"Innovation is the creation and delivery of surprising new knowledge, (*products and services)* that have sustainable value for society."

Curtis Carlson

CHANGING LANDSCAPE

Innovation

- Innovation is regarded as the key to improvements in quality of life, economic growth, increasing wages, solutions to societal challenges

- Fierce debates on:
  - Has the rate of innovation slowed down?
  - Will future innovations create sufficient numbers of jobs?
  - What are appropriate roles for governments and private sectors?

CHANGING LANDSCAPE

Innovation Eco-System

- Rapidly evolving eco-system of startups, accelerators, small, medium, large companies, non-profit organizations, government and public organizations
- Emergence of regional innovation eco-systems
- Growing systematic knowledge about the processes and cultures that foster innovations and their scaling
- Significant success of NSF I-Corps and its implications

CHANGING LANDSCAPE

For Large Technology-Based Companies

Large Corporate Research Labs

Open Innovation

"Collaborative Innovation"

Time

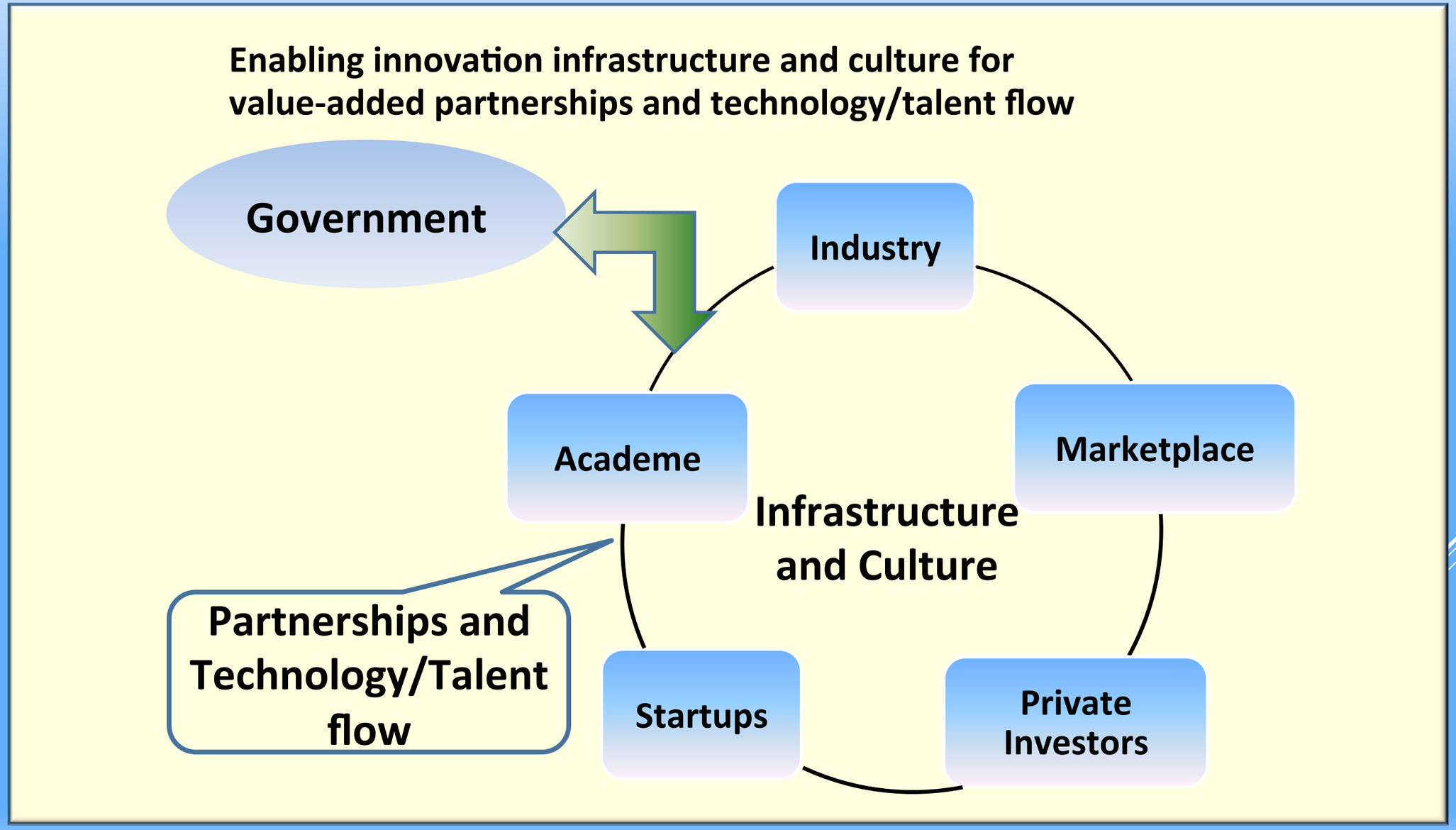
- **In-house R&D**

- **Licensing of technologies**
- **Funding projects and centers**
- **Acquisitions of startups**
- **Mostly tactical partnerships**

- **New platforms to seek ideas**
- **Co-located research parks/ centers**
- **Use of virtual tools**
- **Both tactical and strategic partnerships**

CHANGING LANDSCAPE

A Much More Connected Innovation Ecosystem



CHANGING LANDSCAPE

Education and Workforce: Future Engineers and Innovators

- Engineering education has evolved with widespread adoption of freshman engineering and capstone senior design
- Mentoring and advising programs
- Engineering education research has led to new understandings
- Incorporation of insights from engineering education research
  - Active learning
  - Flipped classrooms
  - Hybrid virtual + in-class instruction models
  - Engineering into K-12
- Core skills for engineers of the future
  - Technical excellence + 21st century skills

CHANGING LANDSCAPE

Graduate Education

- Large growth in MS and PhD programs and graduates
- Value of deep technical expertise
- Importance of working in multi-disciplinary teams
- Recognition of long, unpredictable career paths
- Need for and interest in broader communications, innovation and entrepreneurship educational experiences
- Universities working to adapt to these changes

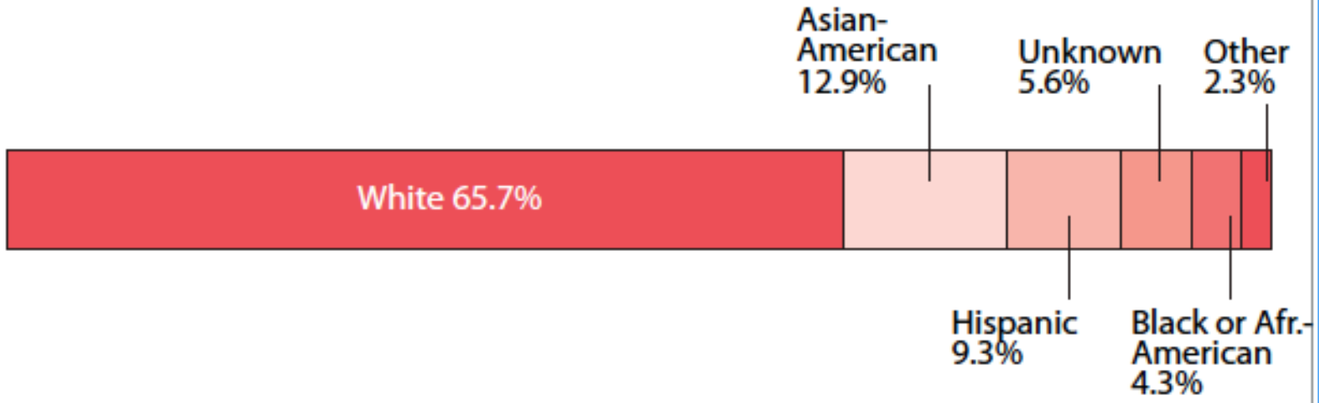
Inclusion Remains a Major Challenge in the face of Major Demographic Changes

Engineering Degrees

Bachelor's Degrees by Gender, 2013

	2004	2005	2006	2007	2008	2009	2010	2011	2012
Female	20.3%	19.5%	19.3%	18.1%	18.0%	17.8%	18.1%	18.4%	18.9%
Male	79.7%	80.5%	80.7%	81.9%	82.0%	82.2%	81.9%	81.6%	81.1%

Bachelor's Degrees by Ethnicity, 2013*



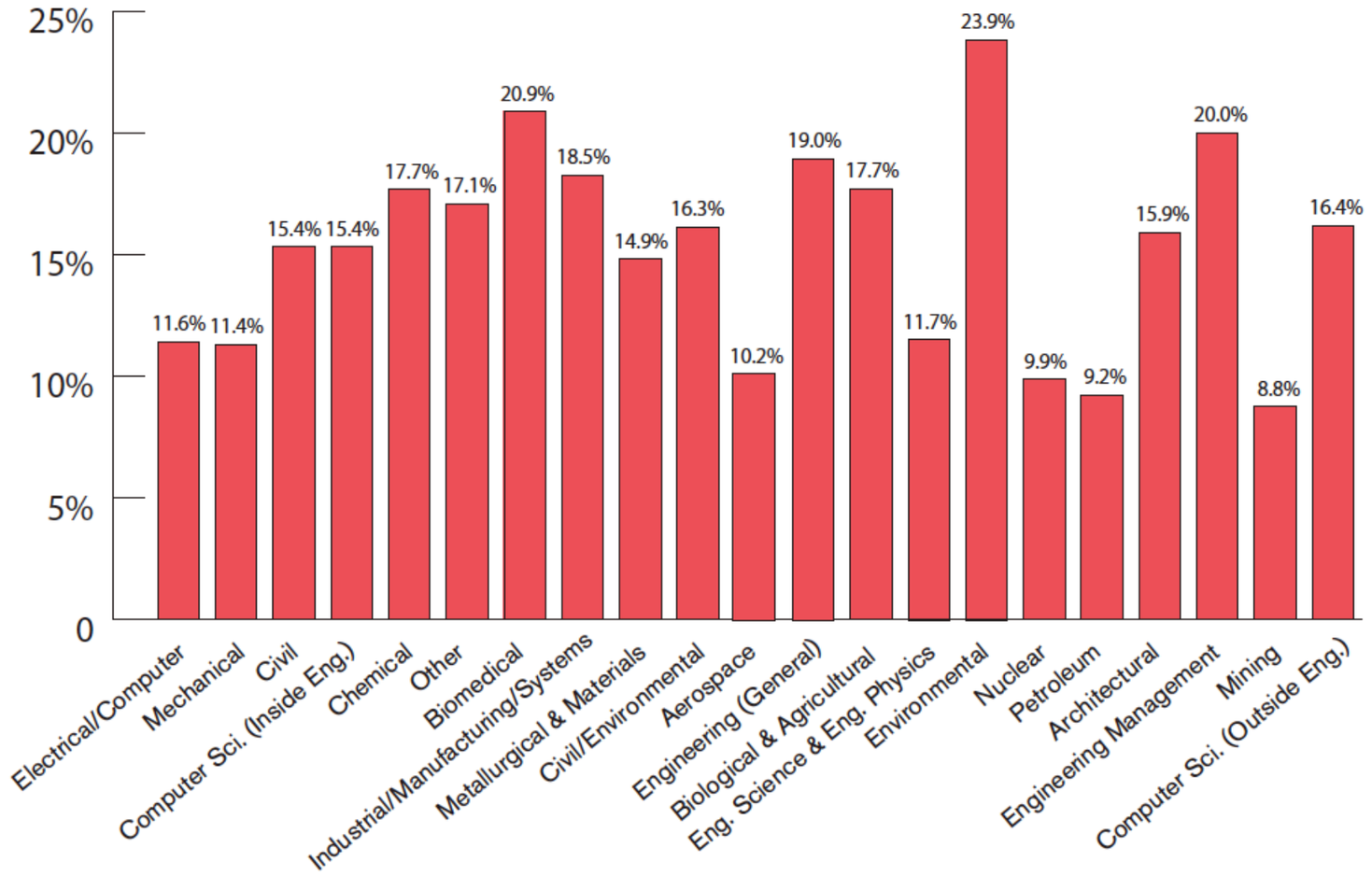
	2004	2005	2006	2007	2008	2009	2010	2011	2012
Black or African American	5.1%	5.3%	5.0%	4.9%	4.7%	4.6%	4.5%	4.2%	4.2%
Hispanic	5.6%	5.8%	6.0%	6.2%	6.5%	6.6%	7.0%	8.5%	9.0%
Other	8.0%	8.6%	8.5%	8.3%	8.9%	11.0%	1.2%	1.6%	2.0%
Asian American	14.2%	14.1%	13.8%	13.3%	13.0%	12.4%	12.2%	12.2%	12.2%
White	67.1%	66.2%	66.7%	67.3%	66.9%	65.4%	69.8%	66.6%	66.2%
Unknown							5.3%	6.9%	6.5%

Source: ASEE, By the Numbers,11-47

Source: ASEE, By the Numbers,11-47

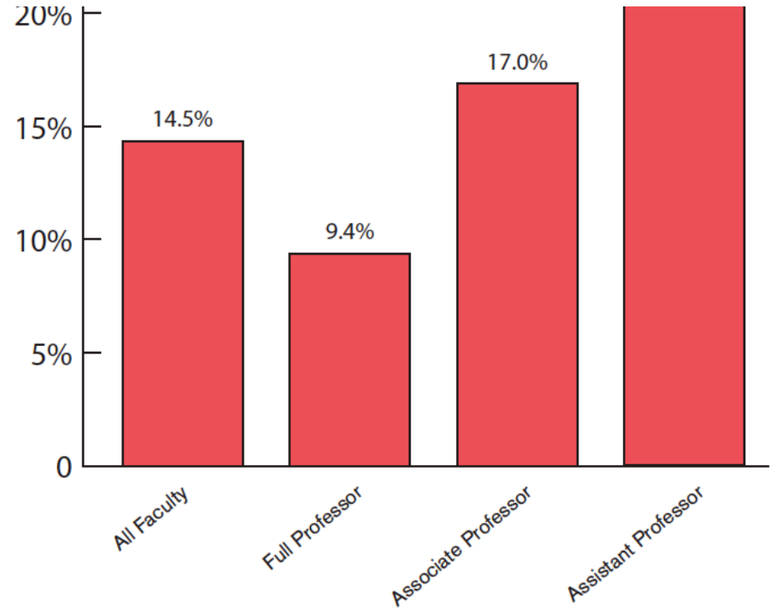
Faculty Diversity

Percentage of Women Tenured/Tenure-Track Faculty by Discipline: 14.5%



	Women	African-American	Asian	Hispanic
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%	24.1%	3.7%
2012	14.0%	2.7%	24.6%	3.9%
2013	14.5%	2.6%	25.2%	3.6%

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



Source: ASEE, By the Numbers,11-47

CHANGING LANDSCAPE

People: Faculty and Students

- Junior faculty strongly interested in innovation, entrepreneurship and impacts beyond traditional aspirations of scholarship and research

- Generational shifts in students – millenials, generation Z, post-millenials

We always overestimate the change that will happen in two years and underestimate the change that will happen in ten years.

Bill Gates

Key Question 1

What models might most effectively enable breakthrough engineering research and discoveries that require center-scale investment considering the convergence of physical sciences, engineering and life sciences and social sciences?

Key Question 2

What educational models of center-based engineering research programs are best suited to creating a more diverse, internationally aware, and flexible engineering talent pool that is capable of addressing complex, real-world problems?

Key Question 3

What academic-industry/practitioner partnership models might most effectively promote advances in use-inspired basic and translational research, accelerate technology commercialization, and strengthen the broader innovation ecosystem?

Key Question 4

What metrics can be used to define successes and risks of such center programs?

Additional Considerations

- There are many very important stakeholders and organizations in engineering research, education, and innovation
  - Universities, industry, state/local governments, K-14, non-profits, philanthropists
- NSF center-scale investments should be focused, synergistic with and leverage other investments and efforts
- NSF centers should utilize latest knowledge from social/behavioral aspects of multidisciplinary team research
- NSF programs must attract the most talented and diverse faculty and students

Final Thoughts

- Be visionary – your work has tremendous potential to have a huge impact on engineering research and benefit the nation in the coming years
- Committee recommendations should be big picture and forward looking
- NSF is keenly interested and looks forward to receiving your recommendations

Thank you!