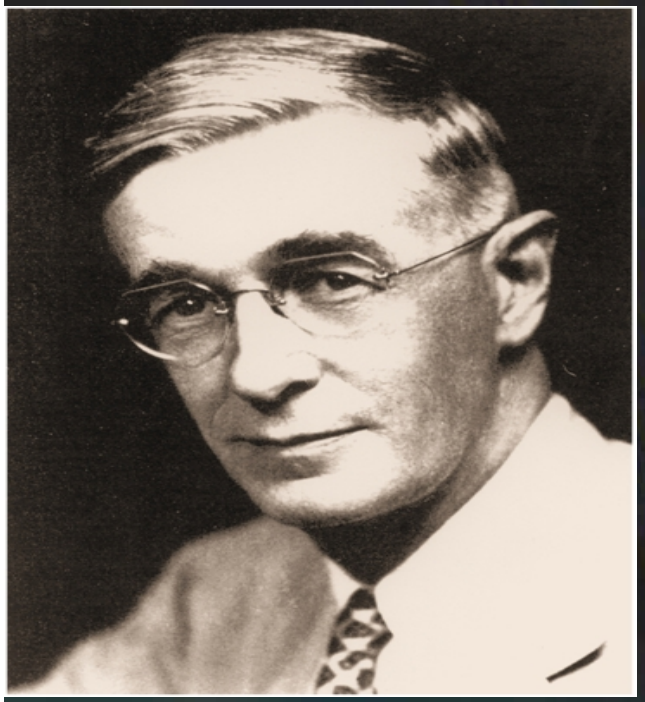
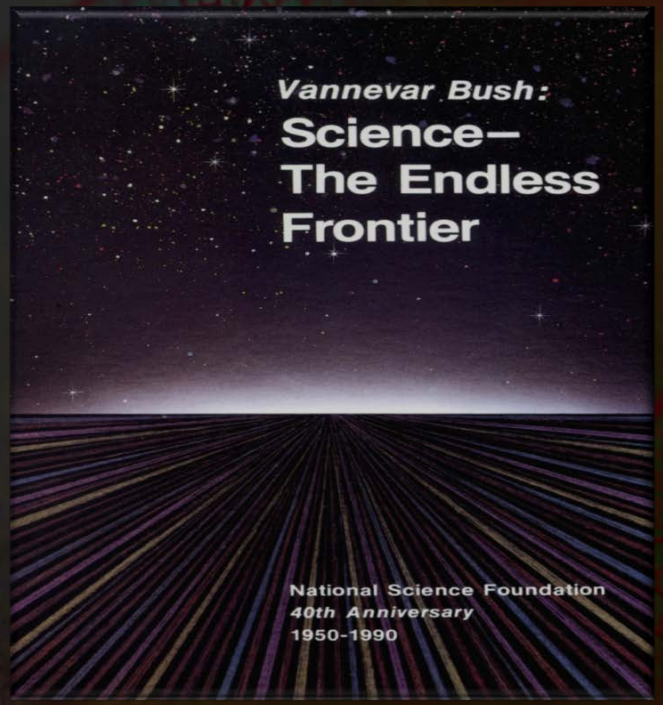
EFRI: A Process to Identify Emerging Frontiers in Research and Innovation for Engineering Leadership

Sohi Rastegar,
Senior Advisor
Office of Emerging Frontiers and Multidisciplinary Activities

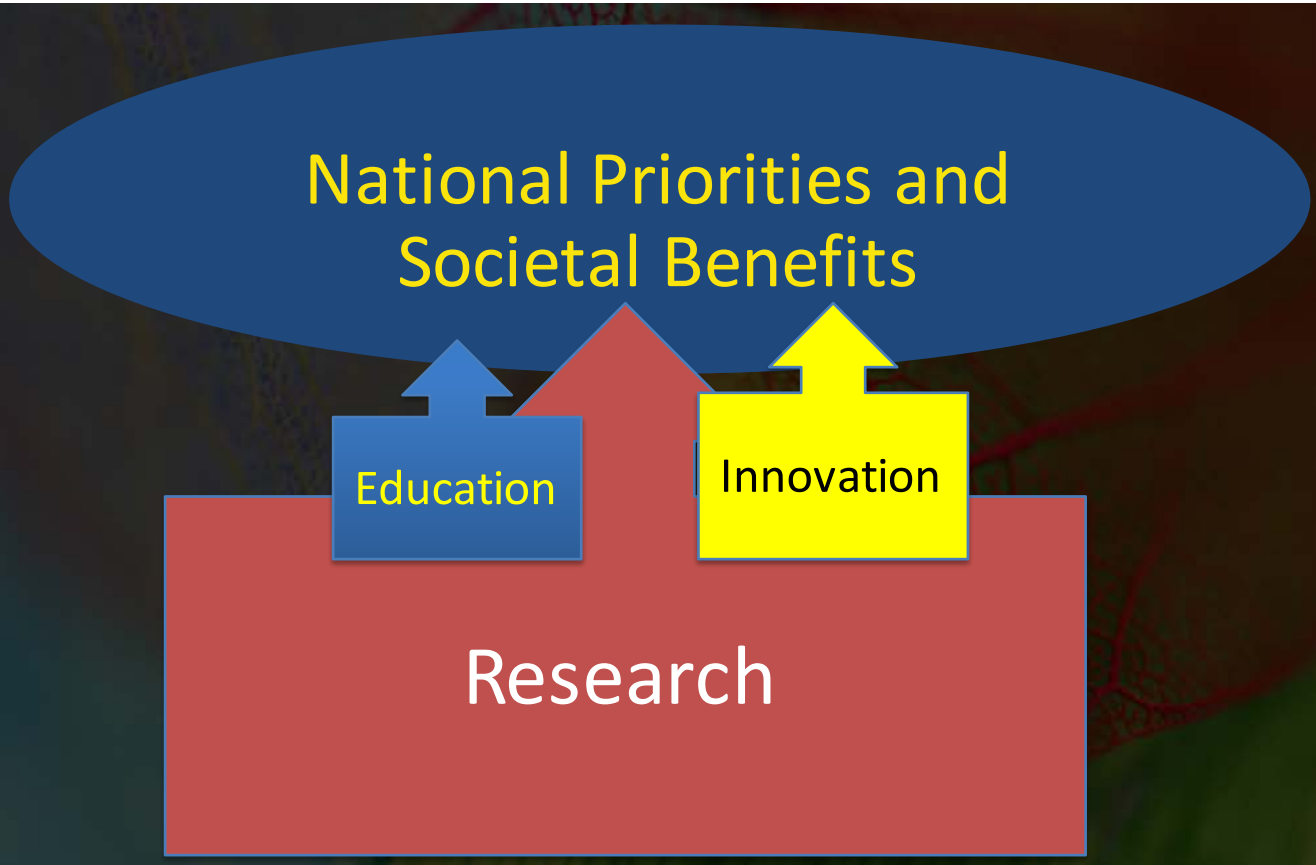




Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard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

Image courtesy MIT Museum



Addressing national priorities by building on core engineering programs

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

Top Engineering Achievements of the 21st Century

- What will this list look like?

Larger Context

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

Some Major Trends and Forces

- Ubiquitous computing and communications
  - Computational modeling, data, simulation, optimization pervasive in all fields of engineering
  - Networks and computation deeply integrated into engineered systems
  - Machine intelligence
- Systems science and engineering
  - Multi-scale analysis, design, and optimization
  - Integration of physical and cyber components
  - Range: nano- to micro- to macro-scale
  - Scale and complexity: large numbers of components
  - Safety, robustness, resilience, …

A Trend of Convergence

Deep integration of knowledge, tools, techniques, and modes of thinking to address pressing societal problems and profound research questions

Convergence of engineering, physical science, computer science, life science, and social and behavioral science

Looking Ahead: Ten Big Ideas

Navigating the New Arctic

Harnessing Data for 21st Century Science and Engineering

Work at the Human-Technology Frontier: Shaping the Future

RESEARCH IDEAS

Understanding the Rules of Life: Predicting Phenotype

The Quantum Leap: Leading the Next Quantum Revolution

Windows on the Universe: The Era of Multi-messenger Astrophysics

PROCESS IDEAS

Growing Convergent Research at NSF

NSF-Includes: Enhancing Science and Engineering through Diversity

Mid-scale Research Infrastructure

NSF 2050: Seeding Innovation

Emerging Frontiers in Research and Innovation Program

- **MANDATE** - Focus on important emerging areas in a timely manner.

  STRATEGY:
  - **COMMUNITY DRIVEN** - Engages the research community (through DCL) and ENG/NSF PDs to identify and fund a portfolio of projects in strategic emerging interdisciplinary areas that may not be supported with current NSF programs and in which ENG researchers play the leading role.
  - **PTR AND IDR** - Uses PTR (Potentially Transformative / High risk, High reward) and IDR (interdisciplinary) as criteria for project selection
  - **MID-SIZE GROUP AWARDS** - It is the main Midscale funding mechanism in ENG **($2M / 4-year projects**)

- **TOPIC LEADERS** - Program Directors from ENG Divisions in collaboration with PDs from other NSF Directorates and other Federal agencies, as appropriate

- http://nsf.gov/eng/efma

$34M
FY 17 Request

KEY EFRI CRITERIA

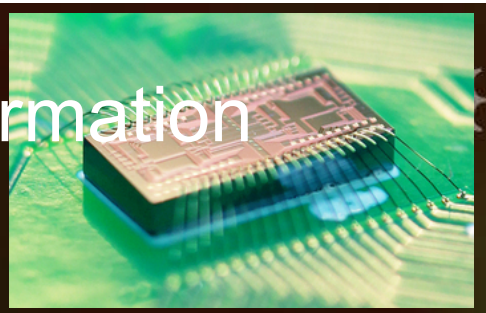
- **TRANSFORMATIVE-** Topics and projects that lead to significant leap or paradigm shift in fundamental engineering knowledge
- **NATIONAL NEEDS/GRAND CHALLENGE-** Strong potential for significant progress on a national need or grand challenge
- **ENGINEERING LEADERSHIP** – Topics and project in which Engineering researchers can play a leadership role

Ten Years of EFRI Topics

FY 2007	Auto-Reconfigurable Engineered Systems (**ARES**) Cellular and Biomolecular Engineering (**CBE**)
FY 2008	Cognitive Optimization (**COPN**) Resilient and Sustainable Infrastructures (**RESIN**)
FY 2009	Biosensing and Bioactuation (**BSBA**) Hydrocarbon from Biomass (**HyBi**)
FY 2010	Science in Energy and Environmental Design (**SEED**) Renewable Energy Storage (**RESTOR**)
FY 2011	Engineering Multicellular and Interkingdom Signaling (**MIKS**); Mind, Machines, and Motor Control (**M3C**)
FY '12,'13	Flexible Bioelectronics Systems (**BioFlex**), Origami Design for the Integration Of Self-assembling Systems For Engineering Innovation (**ODISSEI**); Photosynthesis Biorefineries (**PSBR**)
FY'14,15	2-Dimensional Atomic-Layer Research and Engineering (**2-DARE**)
FY 16, 17	Advancing Communication Quantum Information Research in Engineering (**ACQUIRE**) New Light and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry (**NewLAW**)

NAE GRAND CHALLENGES

Advancing Communication Quantum Information Research in Engineering (ACQUIRE)



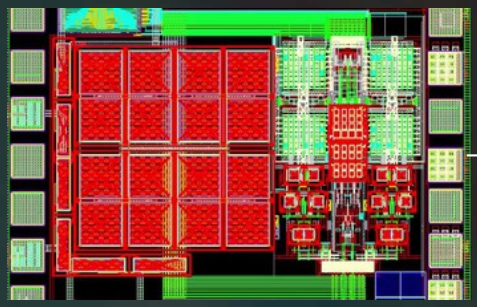
- ***Key Idea:*** **Address key engineering research challenges to enable room temperature, chip-level transducers, repeaters, systems and architectures for a secure, scalable quantum communication network.**

(1) Reproducible room temperature single photon sources and detectors on a chip,
(2) Low-energy quantum devices such as repeaters and memories,
(3) Generation of quantum entangled Qbits scalable to multi-Qbits, and demonstration of a secure, loss-less, fiber-based quantum communication link.

- The goal is to demonstrate a reliable quantum communication link that optimizes the different aspects of the network, with the potential to provide a transformative and highly secure future network.

New Light and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry (NewLAW)

- ***Key Idea*: Breaking symmetries and challenging fundamental laws governing wave motion and field transport**



  - Investigate, design, characterize and test material systems and devices that exploit the possibilities afforded by the ability to **control one-way, edge-bound, defect-immune, non-reciprocal transport of energy and information**.
  - Non-reciprocity and topologically protected wave propagation will have profound implications on how stimuli and information are transmitted within materials, or how energy can be guided and steered so that its effects may be controlled or mitigated. Breaking fundamental symmetries and reciprocity in acoustic, mechanics, photonics, and radio waves will enable one-way propagation, giant isolation, and unique devices for wave manipulation and routing.
  - Will enable full duplex for radio-frequencies, light, sound, mechanical waves, and will lead to new concepts for wave- based imaging (ultrasound, sonar, and radar), thermal management, communications, and acoustic/optical processing.

- **Will address priority areas such as secure communication and crowding of frequency spectra in telecommunications, reduction of noise pollution, new materials for impact and blasts protection, and novel sensing strategies for ubiquitous sensing of smart infrastructure.**

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?

What We Expected in 2006

- **New centers**
- **New or revised programs at NSF or other agencies**
- **New technologies**

Some Examples/Outcomes

- **NEW CENTER (High-risk High pay-off):**

  EBICS STC (2007 EFRI-CBE PI Roger Kamm)

- **NEW PROGRAM**

  Critical Resilient Inter-dependent Infrastructure Systems and Processes (CRISP) (ENG, CISE, SBE) – Based on 2008 EFRI-RESIN Topic)

- **NEW TECHNOLOGIES**

  - Google contact lens led by Babak Parviz (2009 EFRI-BSBA PI)

  - Origami-based Autonomous Robots led by Daniela Rus (2011 EFRI-ODISSEI PI)

EFRI Origami Project Example

Multi-functional origami systems

- The project “Programmable Origami for Integration of Self-assembling Systems in Engineered Structures” (1240383) led by Daniela Rus of the Massachusetts Institute of Technology in collaboration with Erik Demaine of MIT, Sang bae Kim of MIT, and Robert Wood of Harvard University.
- flat structures capable of autonomously changing their geometric and mechanical.
- **Will transform the way we build machines**

Origami robot folds itself up, crawls away

EFRI TOPIC SELECTION

(current cycle: For FY 2018)

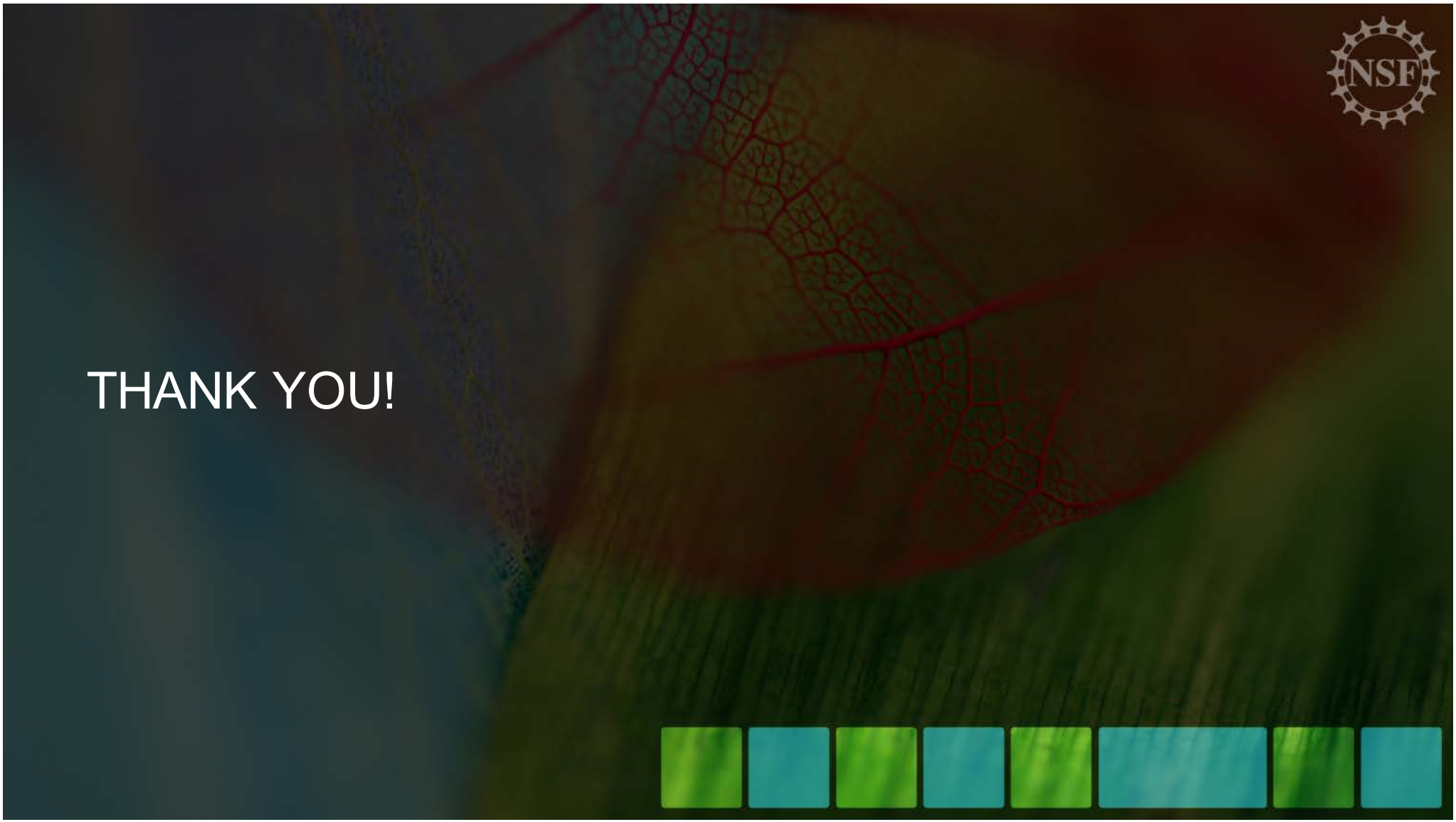
- Continuous Community Input (Publications, Conferences, Advisory Committee, Committees of Visitors, Panels, Workshops, …)
- **Explicit Research Community Input through Website (Dear Colleague Letter)**
  - **https://www.nsf.gov/pubs/2016/nsf16138/nsf16138.jsp**
  - **(Deadline: October 31, 2016)**
- Frontier Ideas Panel (Feb 2017)
  - **A panel of external experts review Program Director and Research Community Ideas**
- ENG Leadership Review (March 2017)
  - **TOPICS ARE FINALIZED**
- Spring Advisory Committee (April 2017)
  - **TOPICS ARE ANNOUNCED AND MADE PUBLIC**

Program Directors are the Leaders for EFRI Topics

PUBLIC ACCESS AND OPEN DATA

- Public Access
- We have a public access repository at https://par.nsf.gov/
- A new FAQ on public access came out yesterday https://www.nsf.gov/pubs/2017/nsf17060/nsf17060.jsp
- Special report on NSF public access https://www.nsf.gov/news/special_reports/public_access/
- This year NSF will start reporting on submissions to the repository, per the plan at https://www.nsf.gov/pubs/2015/nsf15052/nsf15052.pdf

- Open Data info: https://www.nsf.gov/data/


THANK YOU!