21st Century Engineering

The Challenge of Change

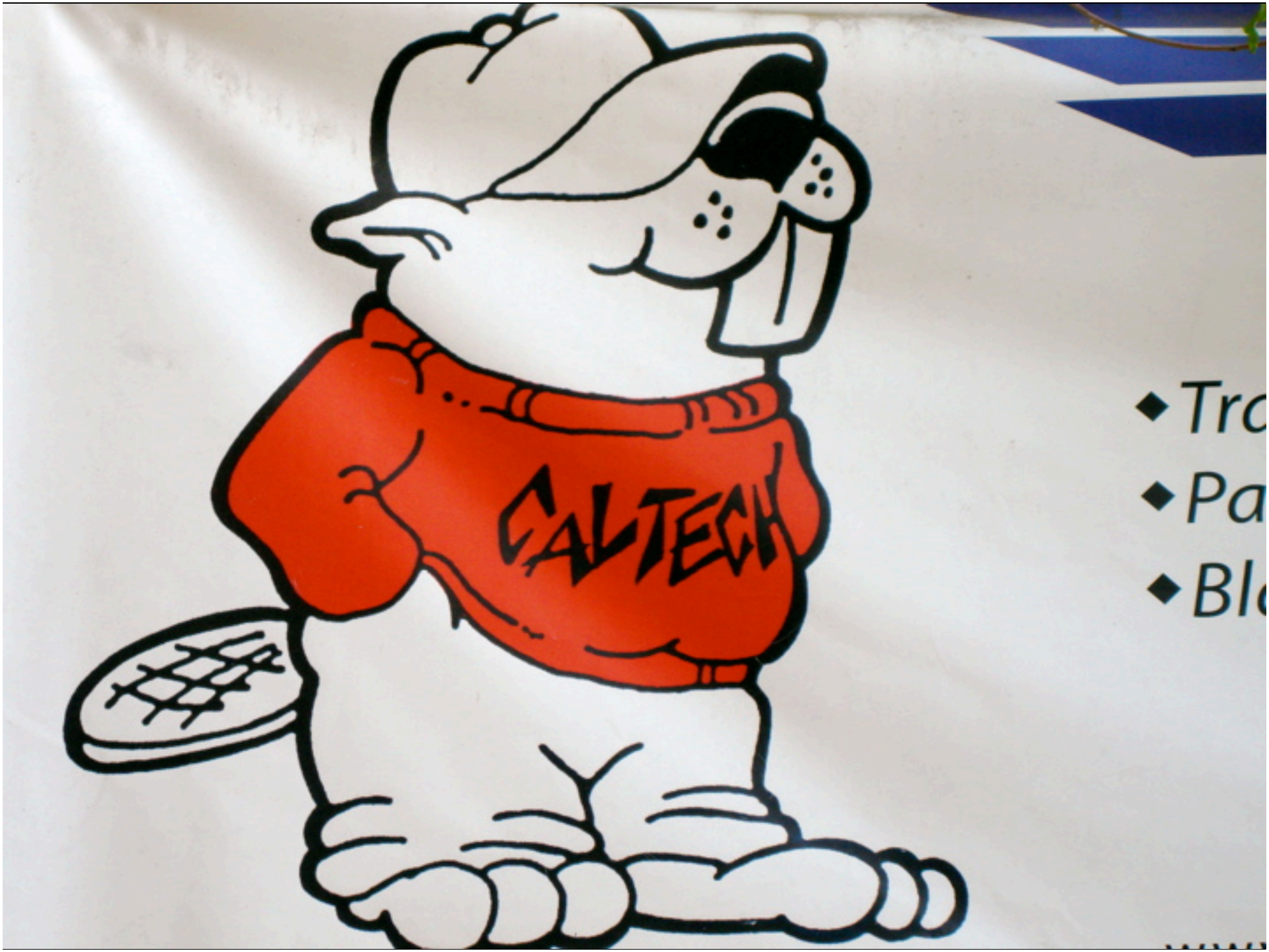
- The changing workforce and technology needs of a global knowledge economy are changing engineering practice demanding far broader skills.
- Importance of technological innovation to economic competitiveness and national security is driving a new priority for application-driven basic engineering research.
- Challenges such as out sourcing and off shoring, decline of student interest in STEM careers, inadequate social diversity, and immigration constraints are raising serious questions about the adequacy of current national approach to engineering.

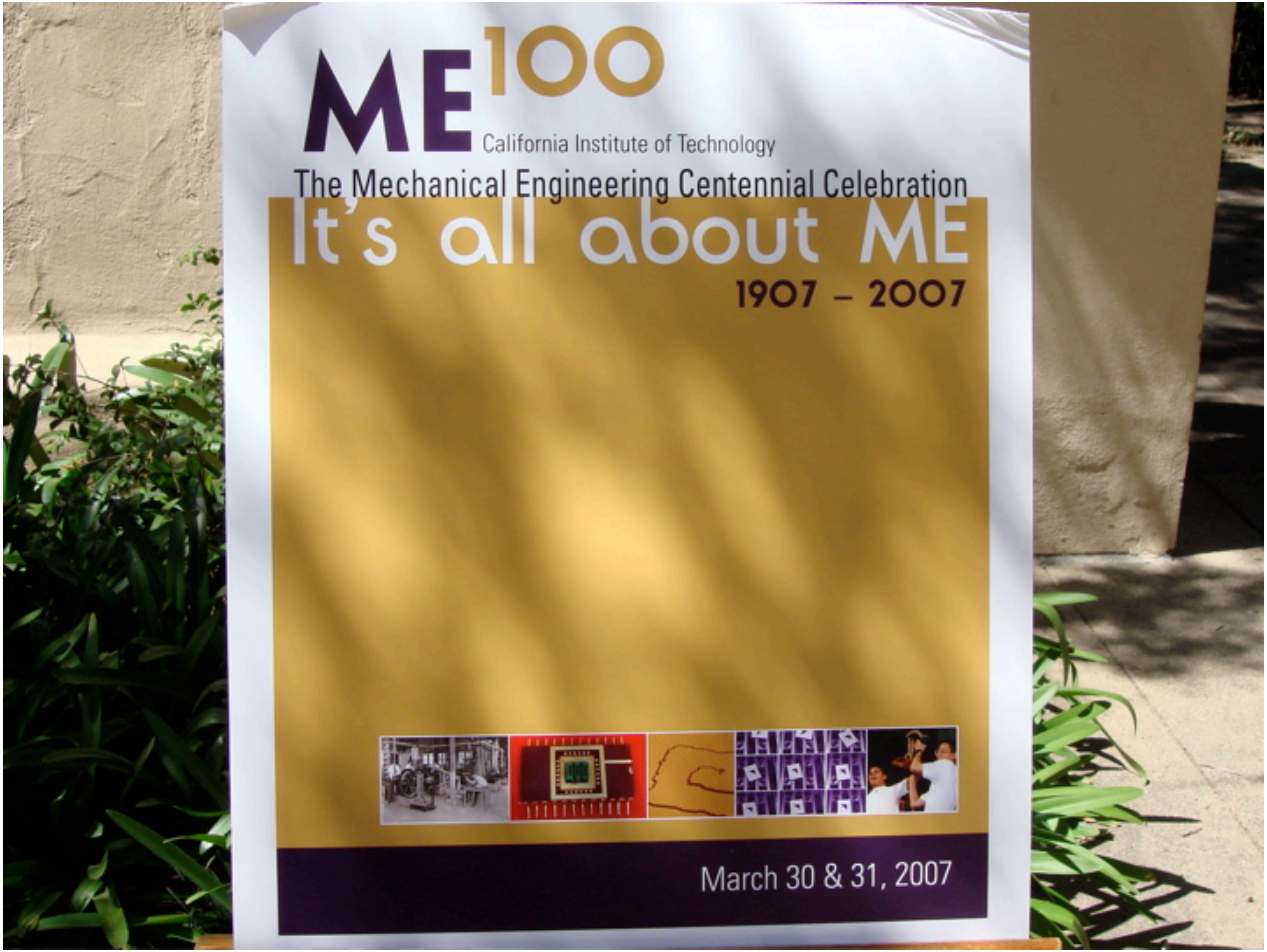
Engineering Practice

Engineering Research

Engineering Education


California Institute of Technology

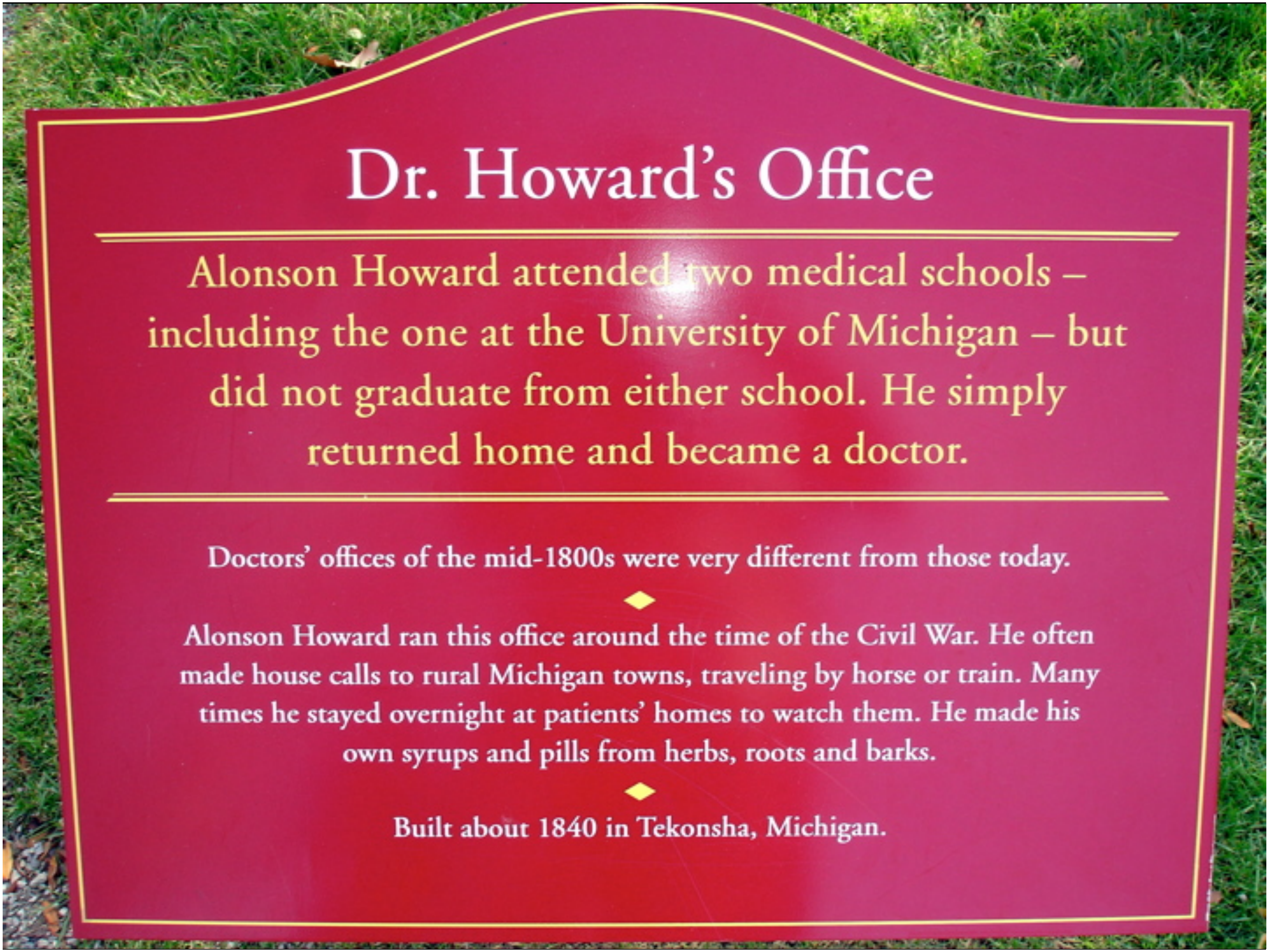

CALTECH


ME100
California Institute of Technology
The Mechanical Engineering Centennial Celebration
It's all about ME
1907 – 2007
March 30 & 31, 2007


CALTECH

An Interesting Comparison: Medicine

…at the turn of the last century


Dr. Howard's Office
Alonson Howard attended two medical schools – including the one at the University of Michigan – but did not graduate from either school. He simply returned home and became a doctor.
Doctors' offices of the mid-1800s were very different from those today.
Alonson Howard ran this office around the time of the Civil War. He often made house calls to rural Michigan towns, traveling by horse or train. Many times he stayed overnight at patients' homes to watch them. He made his own syrups and pills from herbs, roots and barks.
Built about 1840 in Tekonsha, Michigan.


Ext.
Lyons
Heart.
Ext.
Butternu
Bark.
Ext.
Bonesen
W.G.S


Ext.
W. Snake
Root.
Ext.
Skunk
Cabbage.
Ext.
Skunk
Cabbage.


Ext.
Buckeye
EXTRACT
OF
BUCK-EYE
useful for treatment
of
fever

The Medical Profession

- During the 19th century medical education had evolved from a practice-based apprenticeship to an entirely didactic (lecture-based) education.
- To become a doctor, one needed only a high school diploma, a year of lectures, and a few dollars for a license to begin practice as a physician.
- The changing health care needs of society, coupled with the changing knowledge base of medical practice, would drive a very rapid transformation of the medical profession, along with medical education, licensure, and practice.

The Flexner Report

- The Carnegie Foundation commissioned noted educator Abraham Flexner to survey 155 medical schools and draft a report on the changing nature of the profession and the implications for medical education.
- The key to his study was to promote educational reform as a public health obligation: “If the sick are to reap the full benefit of recent progress in medicine, a more uniformly and expensive medical education is demanded."

MEDICAL EDUCATION IN THE UNITED STATES AND CANADA

A REPORT TO
THE CARNEGIE FOUNDATION
FOR THE ADVANCEMENT OF TEACHING

BY

ABRAHAM FLEXNER

WITH AN INTRODUCTION BY

HENRY S. PRITCHETT
PRESIDENT OF THE FOUNDATION

BULLETIN NUMBER FOUR (1910)
(Reproduced in 1960)
(Reproduced in 1972)

437 MADISON AVENUE
NEW YORK CITY 10022

Flexner’s Impact

- The Flexner Report of 1910 transformed medical education and practice into the 20th century paradigm of scientific (laboratory-based) medicine and clinical training in teaching hospitals.
- Flexner held up Johns Hopkins University medical school as the model (the existence proof) of the new approach, requiring a baccalaureate degree for entry, a teaching hospital for training, and a strong scientific foundation.
- Over the next two decades, two-thirds of all medical schools were closed, and those that remained were associated with major universities!

Oh, and by the way…

- Although he was primarily focused on medicine, Flexner raised very similar concerns about engineering education even at this early period.
- “The minimum basis upon which a good school of engineering accepts students is, once more, an actual high school education, and the movement toward elongating the technical course to five years confesses the urgent need of something more.”

A Flexner Report for Engineering?

- Mann Report (1918)
- Wilkenden Report (1923)
- ASEE Grinter Report (1955)
- ASEE Green Report (1994)
- NRC BEED Report and ABET EC2000
- NAE Engineering of 2020 (2004)
- Carnegie Foundation Study (2006)
- Bill Schowalter: “Appearance every decade of a definite report on the future of engineering education is as predictable as the sighting of the first crocuses in spring.” (2003)

Yet, despite these efforts

- Although engineering is one of the professions most responsible for profound changes in our society, its characteristics of practice, research, and education have been remarkably constant–some might suggest even stagnant–relative to other professions.
- Engineers are still used as commodities by industry, and engineering services are increasingly off shored.
- Engineering research is still misunderstood and inadequately supported by industry and government.
- “Most of our universities are attempting to produce 21st century engineers with a 20th century curriculum in 19th century institutions.” (JJD)

The stakes are very high!!!

- An extrapolation of current trends such as the off shoring of engineering jobs and services, inadequate investment in long-term engineering research, inadequate innovation in engineering education, declining interest on the part of students in STEM careers, and immigration constraints raises very serious concerns.
- Without concerted action, America faces the very real prospect of losing its engineering competence in an era in which technological innovation is the key to economic competitiveness, national security, and social well-being.
- Bold and concerted actions are necessary to sustain and enhance the profession of engineering in America–its practice, research, and education!

The Approach: Roadmapping

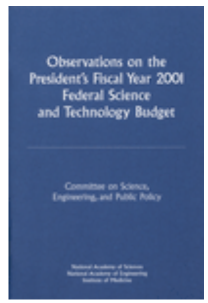
- Engineering Today (“Where we are…”)
- Engineering Tomorrow (“Where we need to be …”)
- Gap Analysis (“How far we have to go…)
- The Roadmap (“How to get there…)

NAE-RAGS-NII-ACI… Reports

FS&T Reports to date

1999

2000



2001

2002

2003

CRITICAL CHOICES: SCIENCE, ENERGY, AND SECURITY

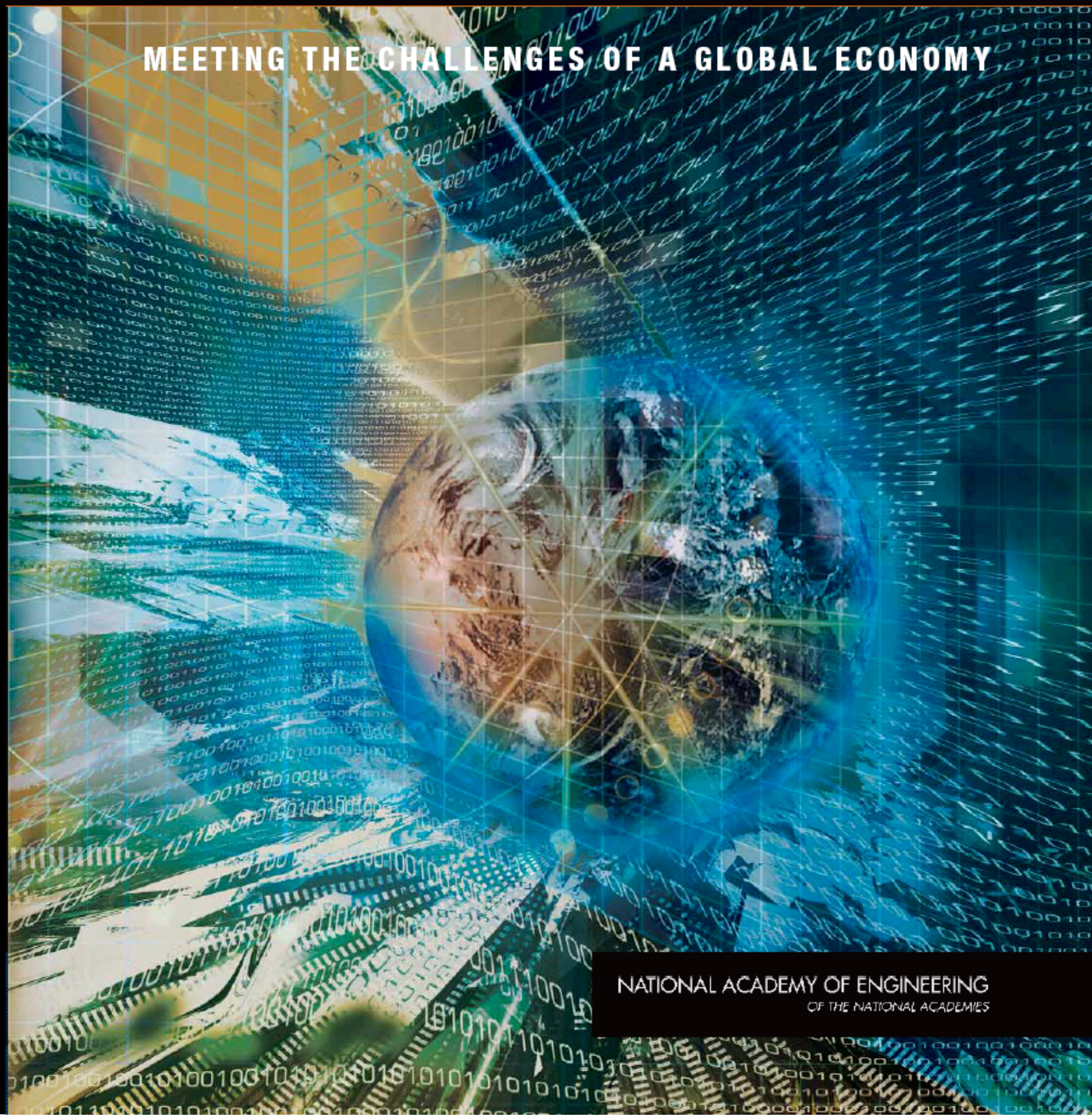
Final Report of the Secretary of Energy Advisory Board's Task Force on the Future of Science Programs at the Department of Energy

October 13, 2003

Secretary of Energy Advisory Board
U.S. Department of Energy

ENGINEERING RESEARCH AND AMERICA'S FUTURE

MEETING THE CHALLENGES OF A GLOBAL ECONOMY



NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

educate next-generation innovators
deepen science and engineering skills
explore knowledge intersections
equip workers for change
support collaborative creativity
energize entrepreneurship
reward long-term strategy
build world-class infrastructure
invest in frontier research
attract global talent
create high-wage jobs

INNOVATE AMERICA

NATIONAL INNOVATION INITIATIVE SUMMIT AND REPORT

thriving in a world of challenge and change

Council on Competitiveness

EXECUTIVE SUMMARY

Prepublication Copy

RISING ABOVE THE GATHERING STORM

Energizing and Employing America for a Brighter Economic Future

NATIONAL ACADEMY OF SCIENCES, NATIONAL ACADEMY OF ENGINEERING, AND INSTITUTE OF MEDICINE OF THE NATIONAL ACADEMIES

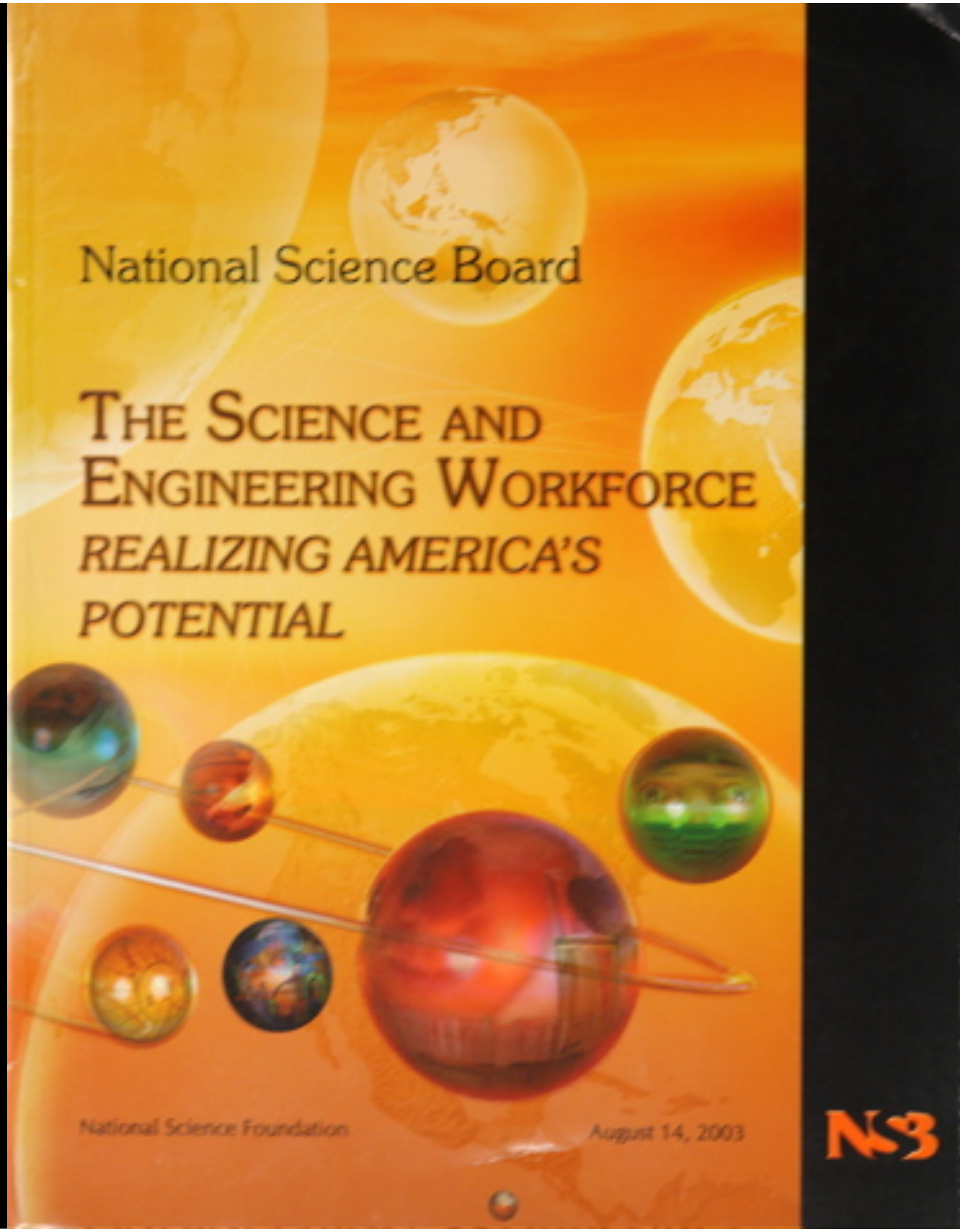
American Competitiveness Initiative

Leading the World in Innovation

Domestic Policy Council
Office of Science and Technology Policy

February 2006

STEM Education Reports


National Science Board
THE SCIENCE AND ENGINEERING WORKFORCE
REALIZING AMERICA'S POTENTIAL
National Science Foundation
August 14, 2003
NSB

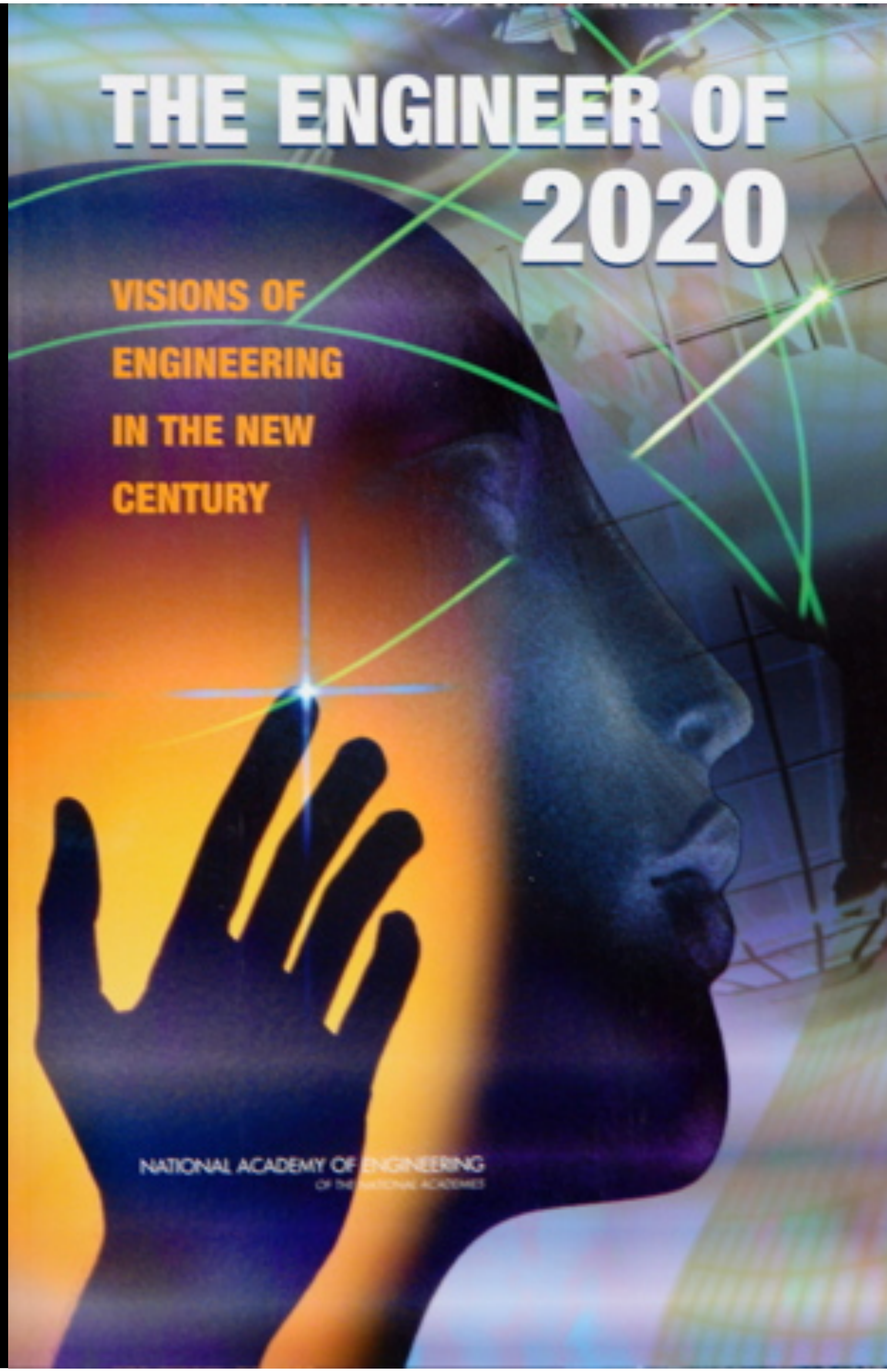
CONFERENCE PROCEEDINGS

The U.S. Scientific and Technical Workforce

Improving Data for Decisionmaking

Terrence K. Kelly, William P. Butz, Stephen Carroll,
David M. Adamson, Gabrielle Bloom, editors

RAND SCIENCE AND TECHNOLOGY


THE ENGINEER OF 2020
VISIONS OF ENGINEERING IN THE NEW CENTURY
NATIONAL ACADEMY OF ENGINEERING


EDUCATING THE ENGINEER OF 2020
ADAPTING ENGINEERING EDUCATION TO THE NEW CENTURY
NATIONAL ACADEMY OF ENGINEERING

Summer 2006

The BRIDGE

LINKING ENGINEERING AND SOCIETY

The Changing Face of Engineering Education
Lisa R. Lattuca, Patrick T. Terenzini, J. Fredericks Volkwein, and George D. Peterson

The "Value-Added" Approach to Engineering Education: An Industry Perspective
Theodore C. Kennedy

A Call for K–16 Engineering Education
Jacquelyn F. Sullivan

Preparing Engineering Faculty as Educators
Susan A. Ambrose and Marie Norman

Redefining Engineering Disciplines for the Twenty-First Century
Zehev Tadmor

Educating Engineers for 2020 and Beyond
Charles M. Vest

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

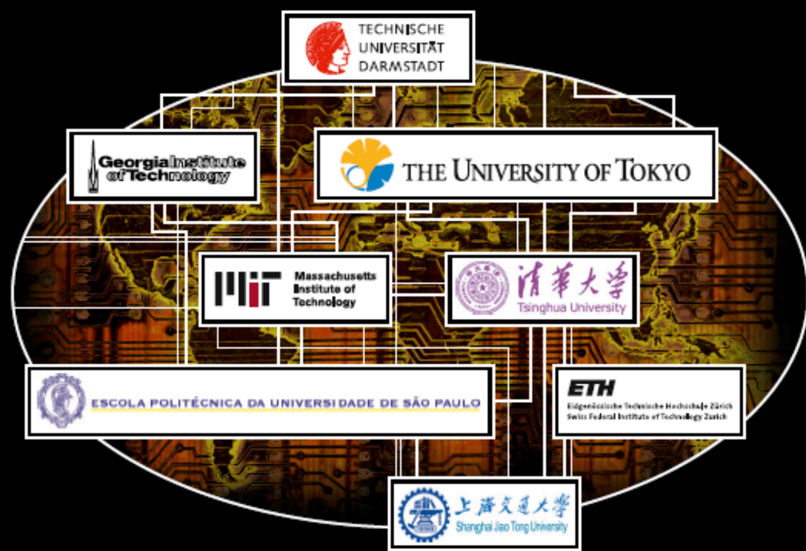
Promoting the technological welfare of the nation by marshalling the knowledge and insights of eminent members of the engineering profession.

Journal of Engineering Education

THE RESEARCH JOURNAL FOR ENGINEERING EDUCATION

SPECIAL ISSUE: THE ART AND SCIENCE OF ENGINEERING EDUCATION RESEARCH

January 2005 | Vol. 94 No. 1



In Search of Global Engineering Excellence

Educating the Next Generation of Engineers for the Global Workplace

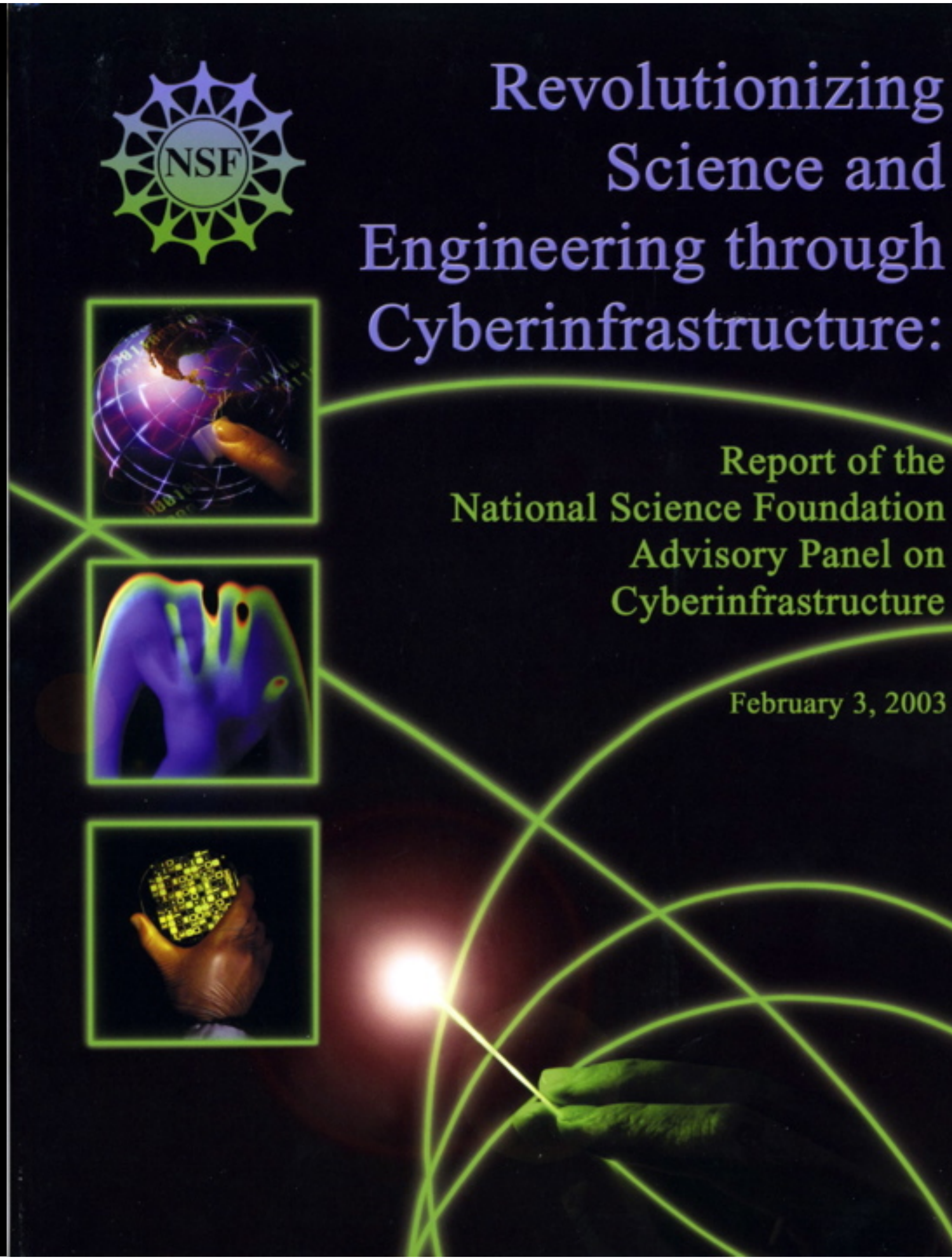
Other Related Reports

A TEST OF LEADERSHIP

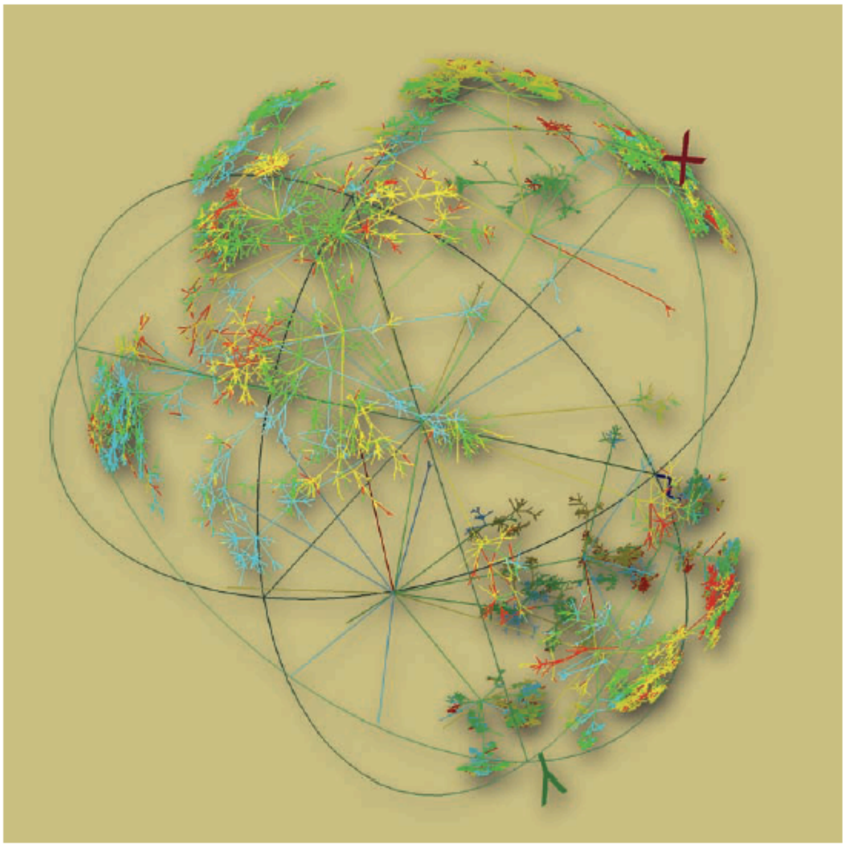
Charting the Future of U.S. Higher Education

Pre-Publication Copy September 2006

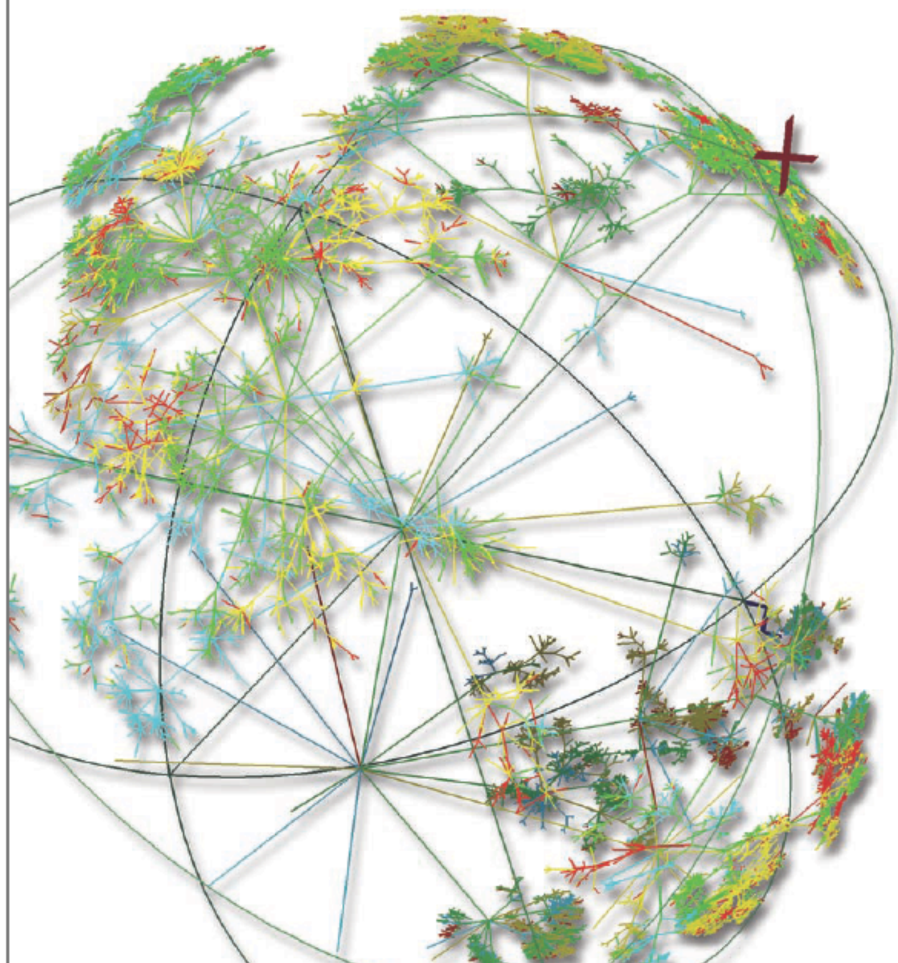
A Report of the Commission Appointed by
Secretary of Education Margaret Spellings

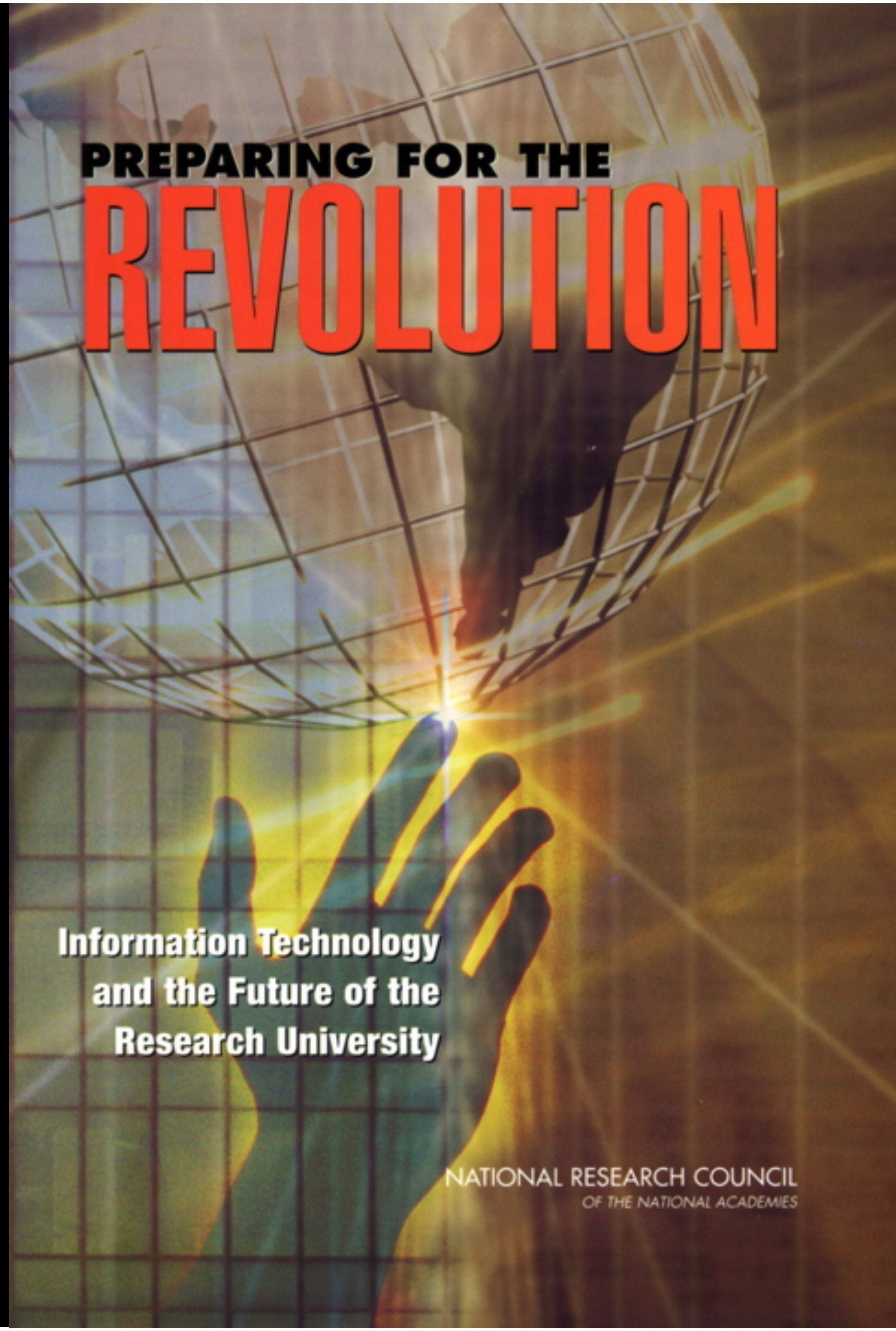

Revolutionizing
Science and
Engineering through
Cyberinfrastructure:
Report of the
National Science Foundation
Advisory Panel on
Cyberinfrastructure
February 3, 2003

NSF's Cyberinfrastructure Vision for 21st Century Discovery



NSF Cyberinfrastructure Council
National Science Foundation



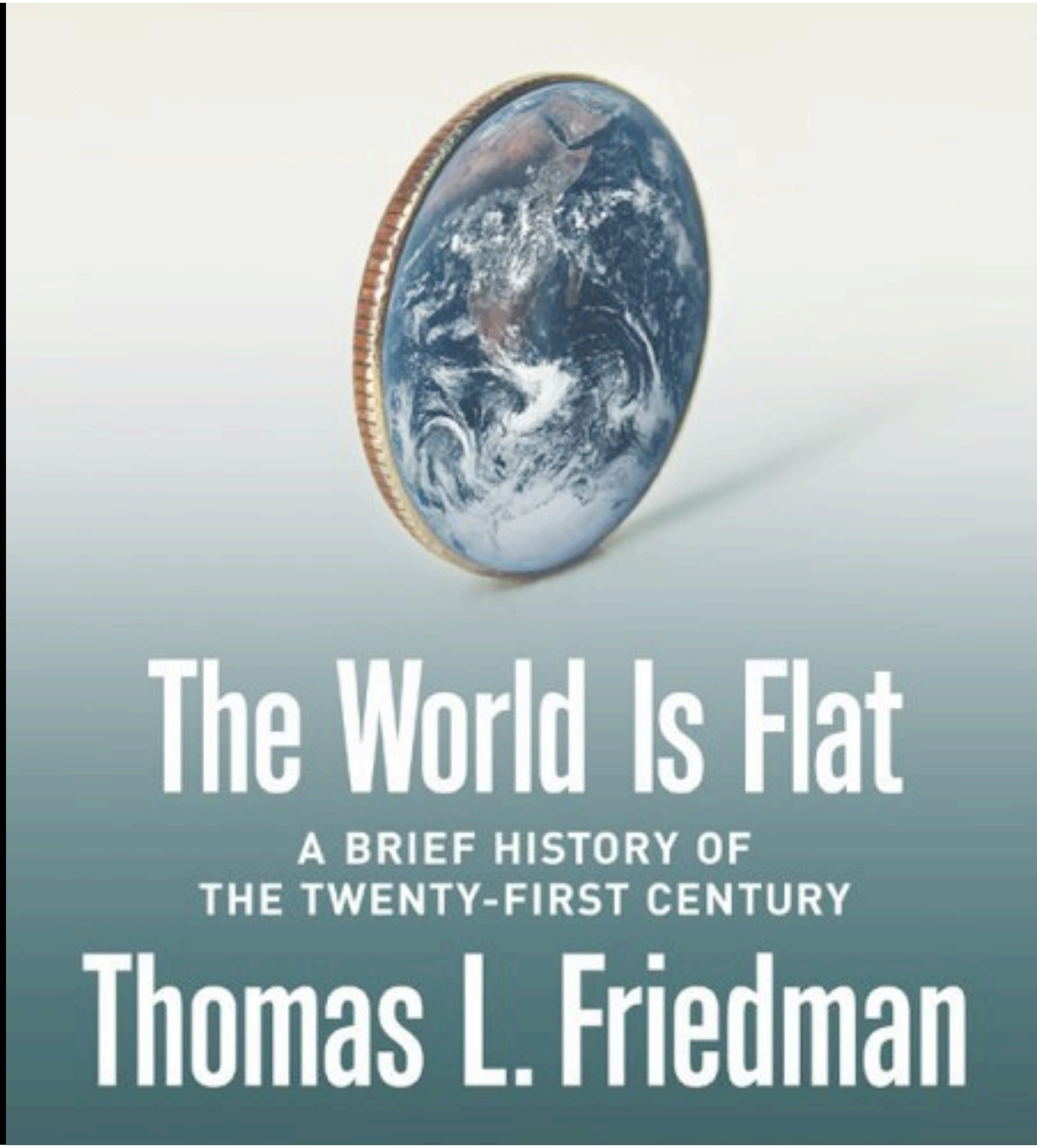

PREPARING FOR THE
REVOLUTION
Information Technology
and the Future of the
Research University
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES


ISSUES
IN SCIENCE AND TECHNOLOGY
THE NATIONAL ACADEMIES
THE UNIVERSITY OF TEXAS AT DALLAS
FALL 2005
Information Technology and the Research University
Envisioning a Transformed University
Cyberinfrastructure and the Future of Collaborative Work
The Economic Imperative for Teaching with Technology
Managing a Rapidly Changing Environment
Lessons from Corporations
Also:
The Case for Carbon Capture and Storage
Preparing for Catastrophes
U.S. $11.50 / CAN. $17.50

Engineering Today…
and Tomorrow

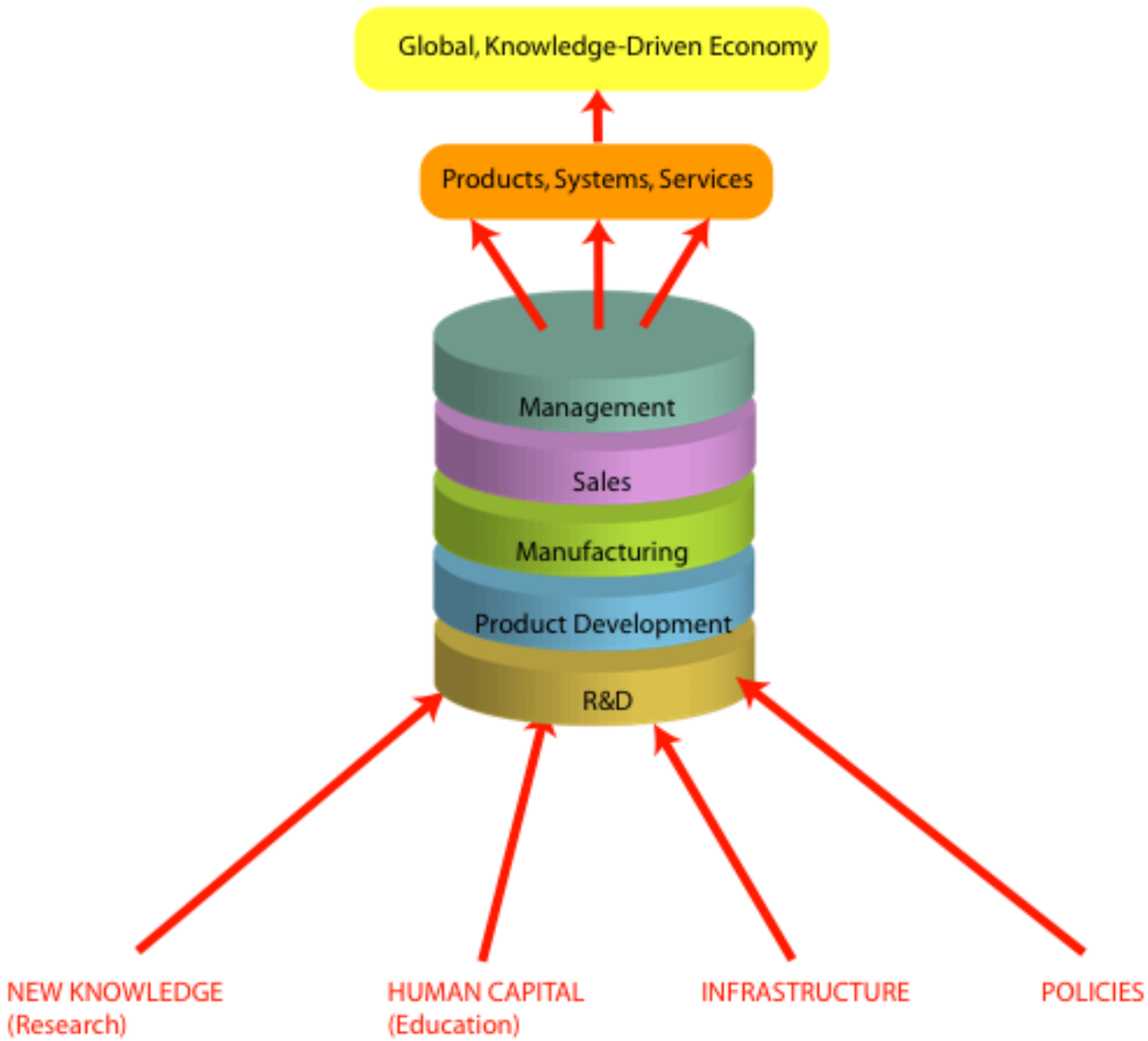
Engineering Practice

The Way the World Works Today

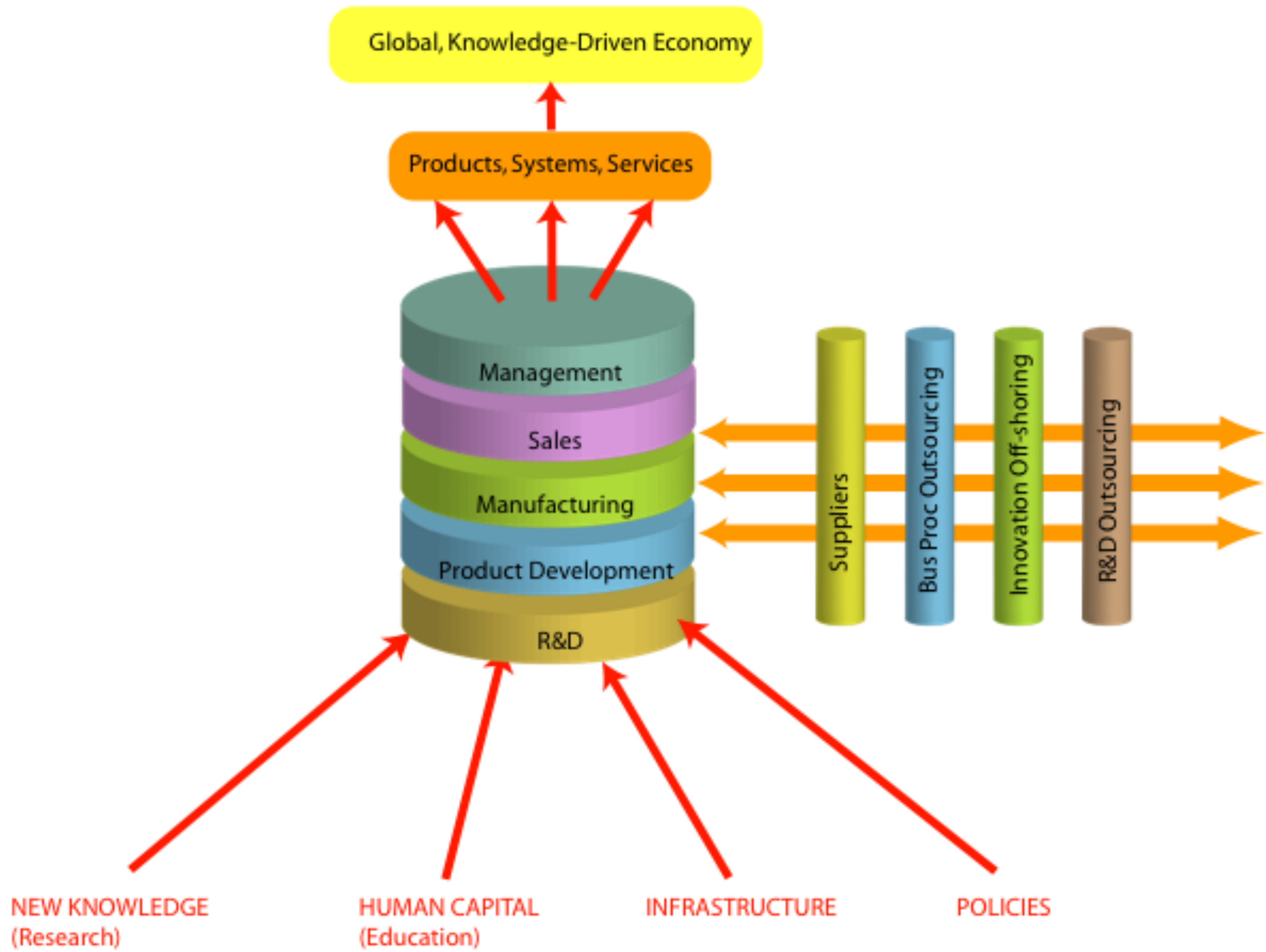

The World Is Flat
A BRIEF HISTORY OF
THE TWENTY-FIRST CENTURY
Thomas L. Friedman

Innovation and Globalization

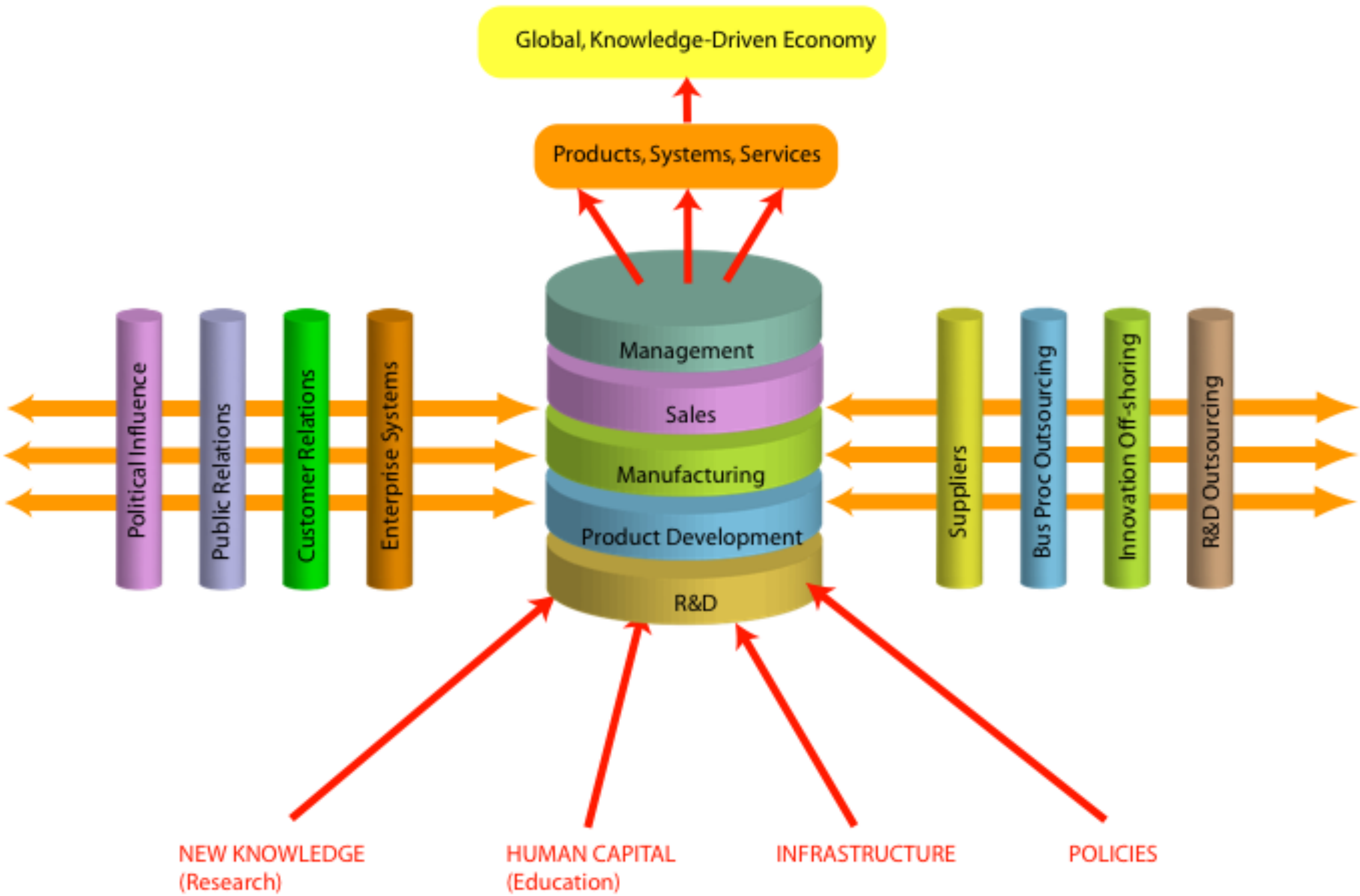
- A radically new system for creating wealth has emerged that depends upon the creation and application of new knowledge and hence upon educated people and their ideas.
- "Intellectual work and capital can be delivered from anywhere–disaggregated, delivered, distributed, produced, and put back together again…" (Friedman)
- "Some three billion people who were excluded by the pre-Internet economy have now walked out onto a level playing field, from China, India, Russia, and Eastern Europe, regions with rich educational heritages."

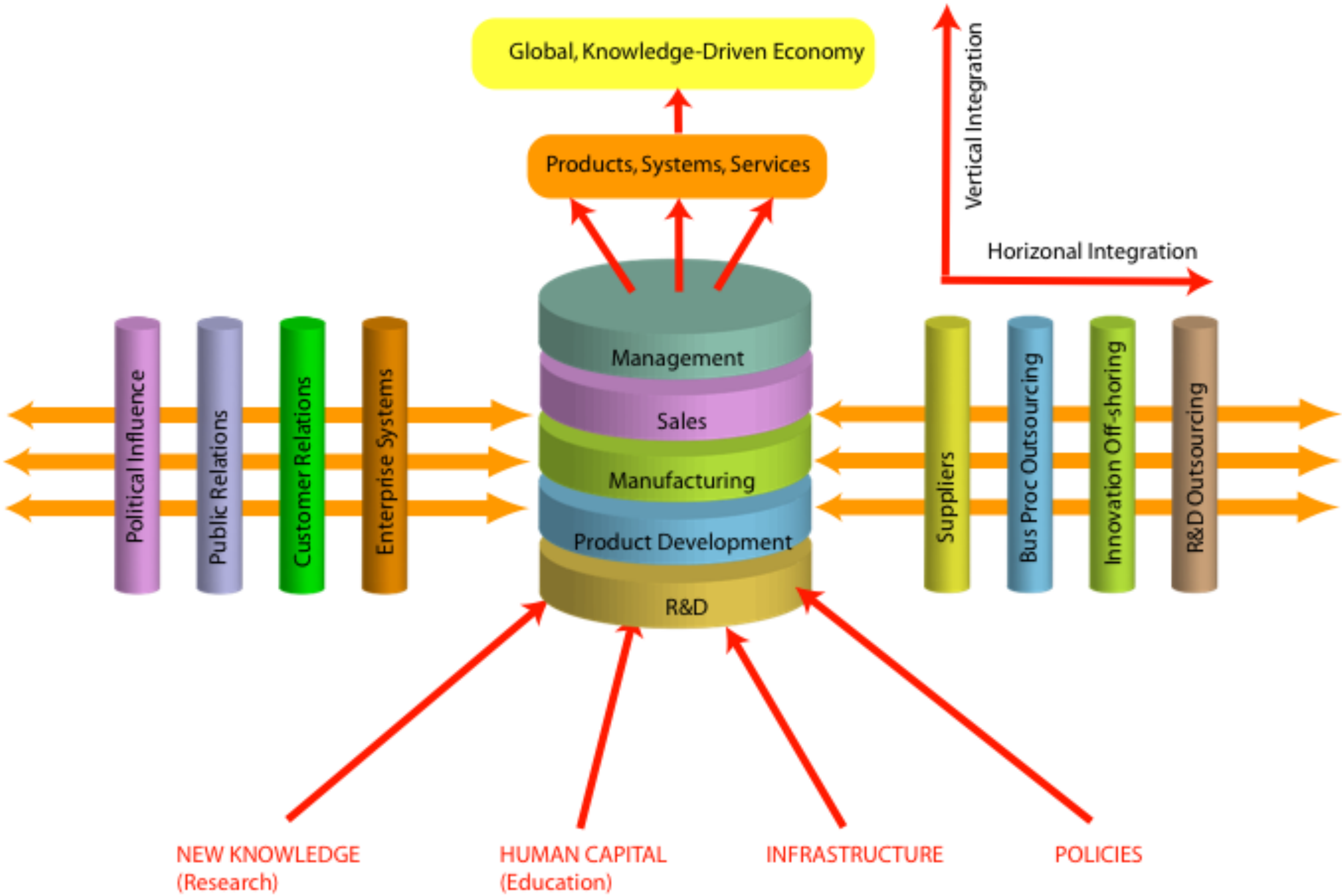


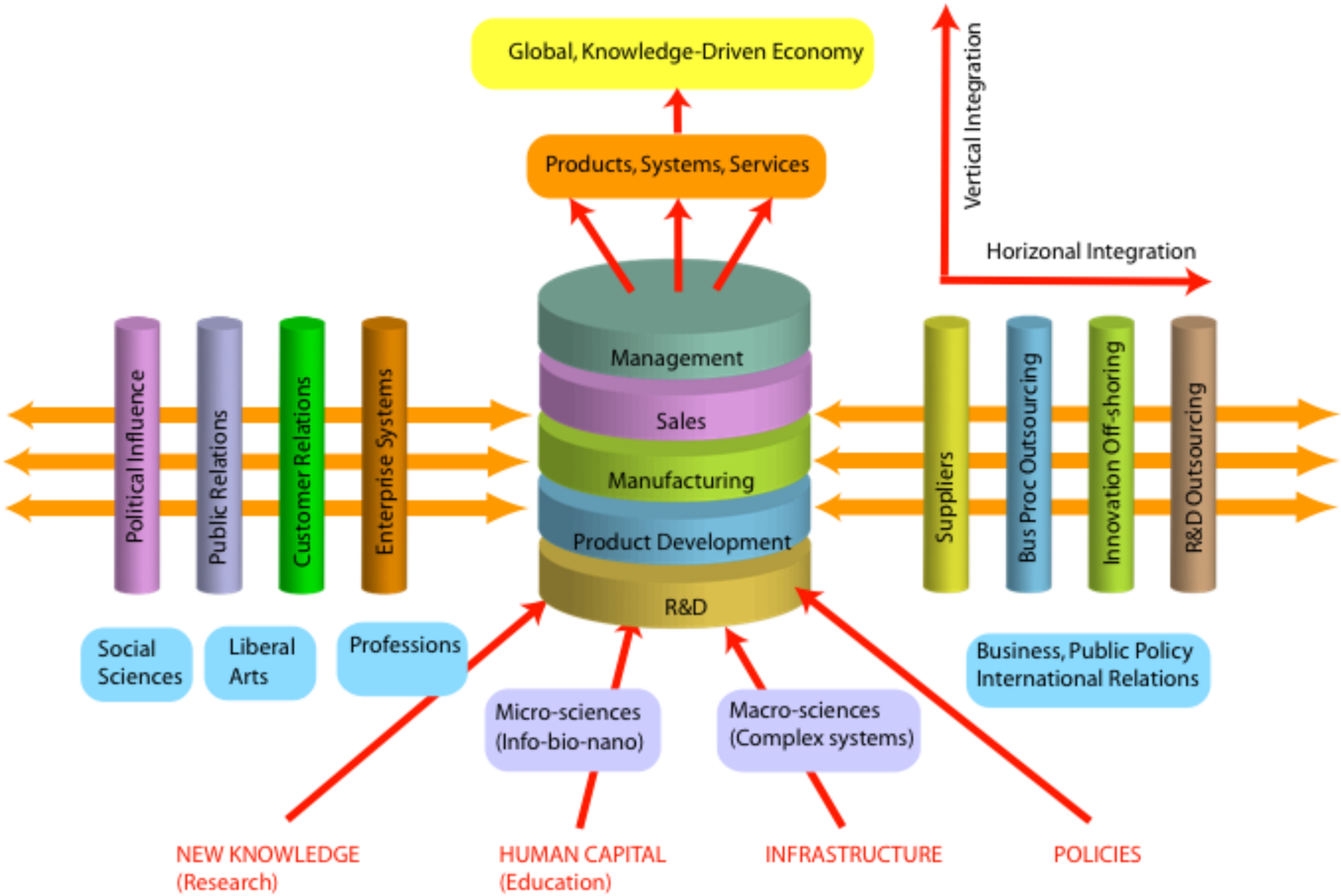
Global, Knowledge-Driven Economy
Products, Systems, Services
Management
Sales
Manufacturing
Product Development
R&D
NEW KNOWLEDGE
(Research)
HUMAN CAPITAL
(Education)
INFRASTRUCTURE
POLICIES



Global, Knowledge-Driven Economy
Products, Systems, Services
Management
Sales
Manufacturing
Product Development
R&D
Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
NEW KNOWLEDGE
(Research)
HUMAN CAPITAL
(Education)
INFRASTRUCTURE
POLICIES


Global, Knowledge-Driven Economy
Products, Systems, Services
Management
Sales
Manufacturing
Product Development
R&D
Political Influence
Public Relations
Customer Relations
Enterprise Systems
Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
NEW KNOWLEDGE
(Research)
HUMAN CAPITAL
(Education)
INFRASTRUCTURE
POLICIES


Global, Knowledge-Driven Economy
Products, Systems, Services
Vertical Integration
Horizonal Integration
Political Influence
Public Relations
Customer Relations
Enterprise Systems
Management
Sales
Manufacturing
Product Development
R&D
Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
NEW KNOWLEDGE
(Research)
HUMAN CAPITAL
(Education)
INFRASTRUCTURE
POLICIES



Global, Knowledge-Driven Economy
Products, Systems, Services
Vertical Integration
Horizonal Integration
Management
Sales
Manufacturing
Product Development
R&D
Political Influence
Public Relations
Customer Relations
Enterprise Systems
Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
Social Sciences
Liberal Arts
Professions
Business, Public Policy International Relations
Micro-sciences (Info-bio-nano)
Macro-sciences (Complex systems)
NEW KNOWLEDGE (Research)
HUMAN CAPITAL (Education)
INFRASTRUCTURE
POLICIES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The Global Economy

- Today's global corporations manage their technology activities to take advantage of the most capable, creative, and cost-effective engineering talent, wherever they find it.
- The rapid evolution of high quality engineering services in developing economies with low labor costs raises a serious question about the viability of the U.S. engineer.
- This is a moving target as global sourcing moves up the value chain to product design, development, and innovation.

The Challenge to US Engineers

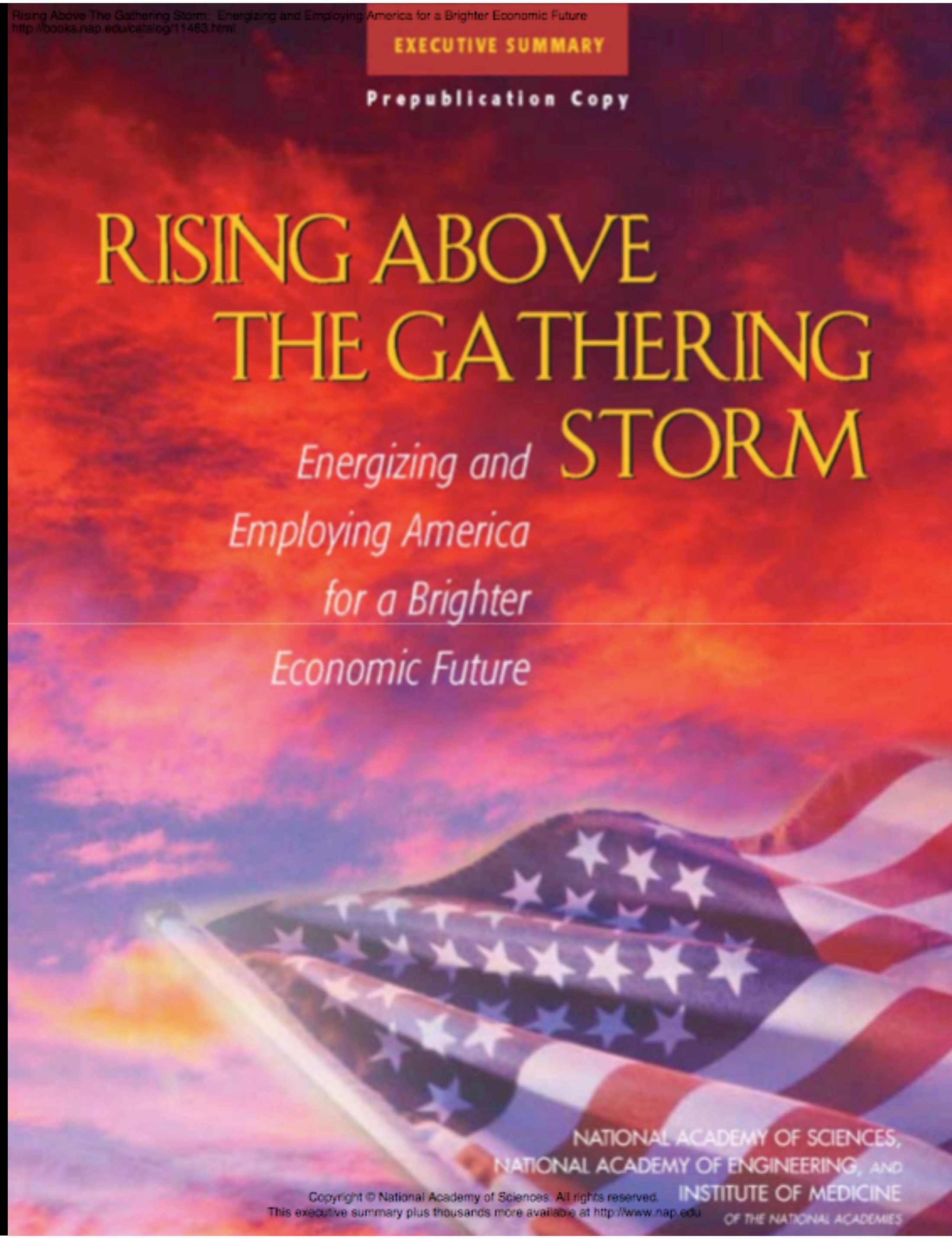
- Engineers must develop the capacity of working in global markets characterized by great cultural diversity.
- This requires a much faster pace of innovation, shorter product cycles, lower prices, and higher quality than ever before.
- Global innovation requires a shift from traditional problem solving and design skills to more innovative solutions imbedded in an array of social, environmental, cultural, and ethical issues.
- And they must achieve several times the value-added of engineers in other parts of the world to sustain their competitiveness relative to global sourcing.

Prestige and Influence?

- In the U.S. the engineering profession still tends to be held in relatively low public esteem compared to other learned professions such as law and medicine.
- American industry utilizes engineers as consumable commodities, subject to layoffs or off shoring when their skills become obsolete or replaceable by cheaper engineering services from abroad.
- Industry managers are limited in increasing head count of U.S. engineers relative to off shoring; many said they would not recommend engineering to their children.
- Students sense this, as evidenced by declining interest in engineering relative to business, law, and medicine.

The Gathering Storm

- "The U.S. is not graduating the volume of engineers and scientists, we do not have a lock on the infrastructure, and we are either flat-lining or cutting back our investments in physical science and engineering. The only crisis the U.S. thinks it is in today is the war on terrorism. It's not!" (Craig Barrett)
- "The U.S. has started to lose its worldwide dominance in critical areas of science and innovation. Europe and Asia are making large investments in physical science and engineering, while the U.S. has been obsessed with biomedical research to the neglect of other areas." (William Broad)


Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future
http://books.nap.edu/catalog/11463.html
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Prepublication Copy
RISING ABOVE THE GATHERING STORM
Energizing and Employing America for a Brighter Economic Future
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OF THE NATIONAL ACADEMIES
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deepen science and engineering skills
explore knowledge intersections
equip workers for change
support collaborative creativity
energize entrepreneurship
reward long-term strategy
build world-class infrastructure
invest in frontier research
attract global talent
create high-wage jobs

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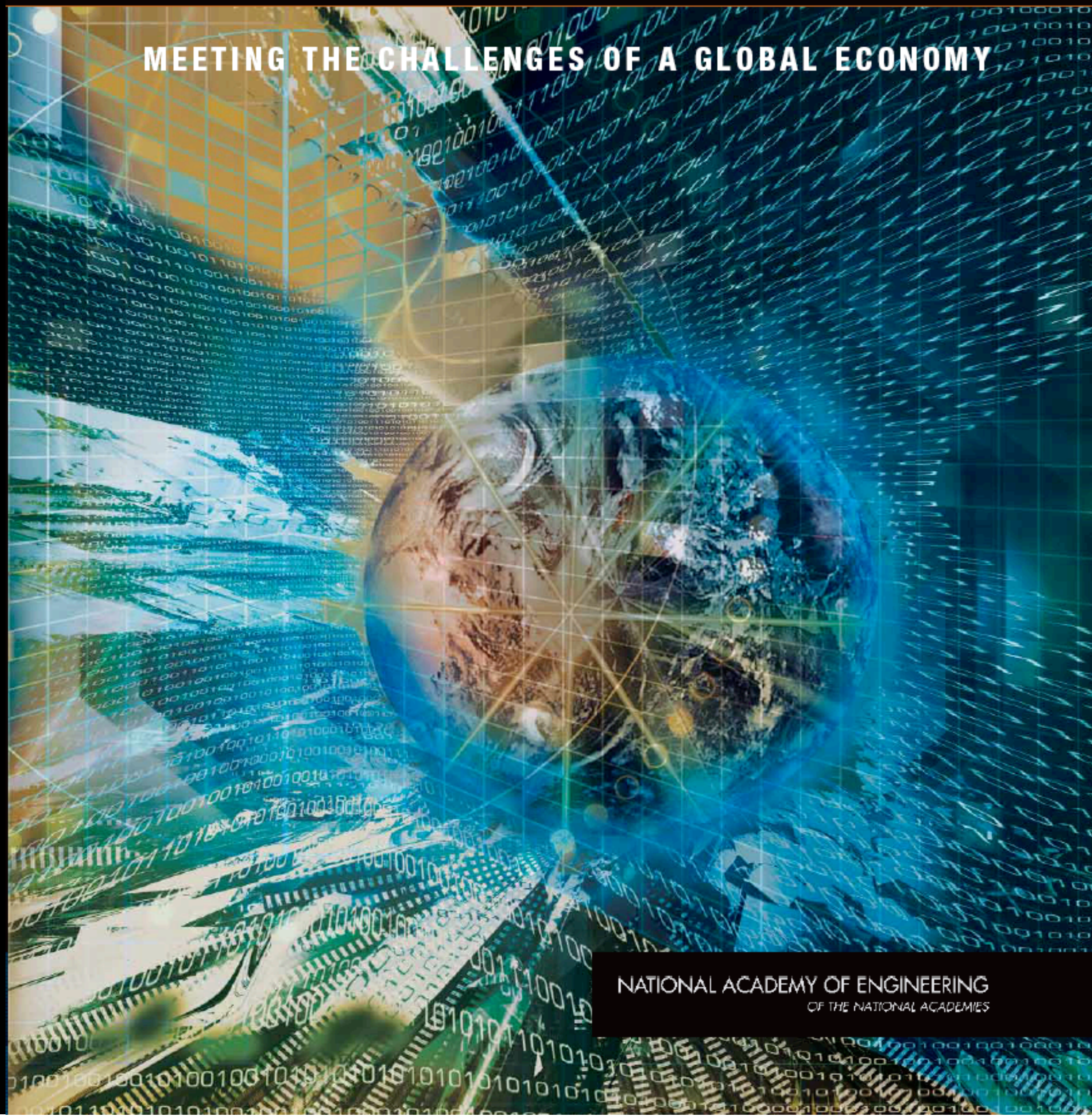
Council on Competitiveness


AMERICAN COMPETITIVENESS INITIATIVE
LEADING THE WORLD IN INNOVATION
DOMESTIC POLICY COUNCIL
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
FEBRUARY 2006

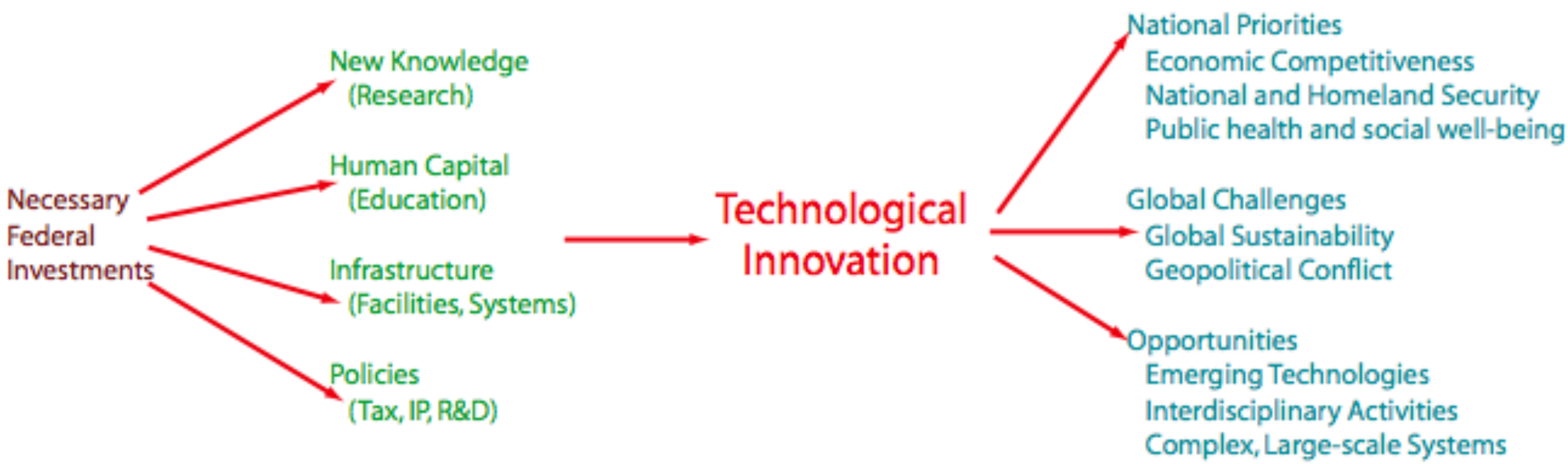
Engineering Research

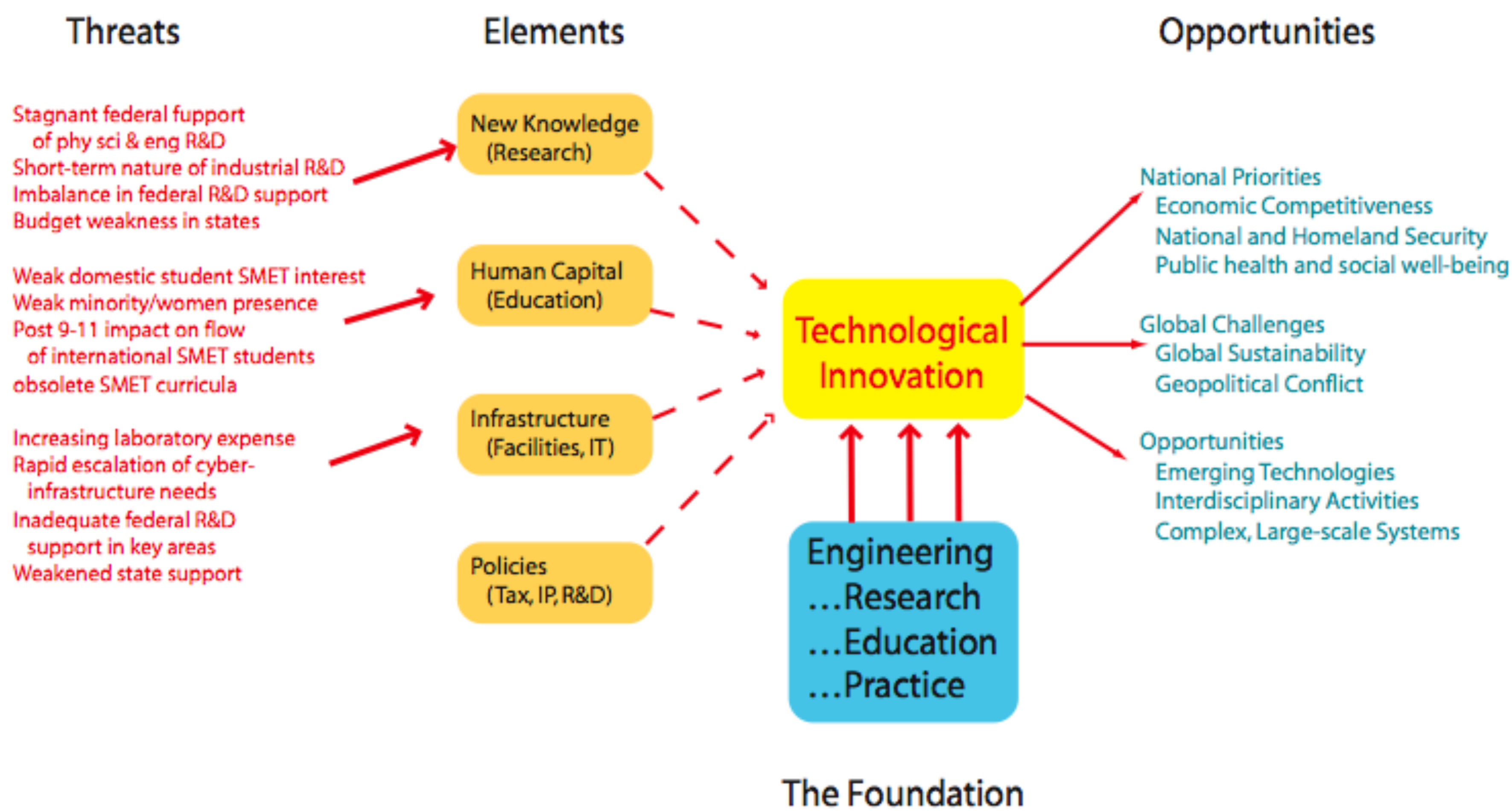
ENGINEERING RESEARCH AND AMERICA'S FUTURE



MEETING THE CHALLENGES OF A GLOBAL ECONOMY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

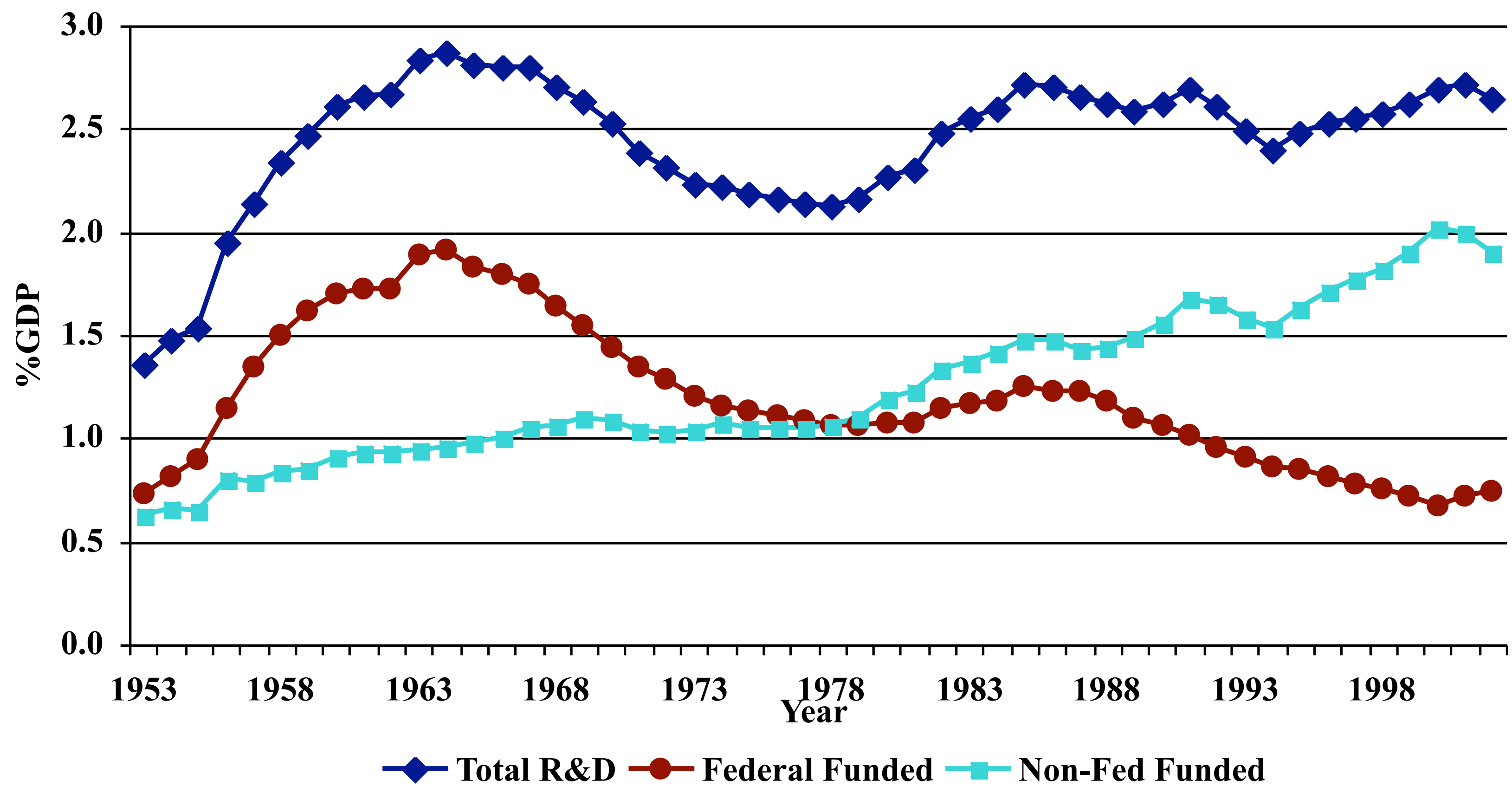

Necessary
Federal
Investments
New Knowledge
(Research)
Human Capital
(Education)
Infrastructure
(Facilities, Systems)
Policies
(Tax, IP, R&D)
Technological
Innovation
National Priorities
Economic Competitiveness
National and Homeland Security
Public health and social well-being
Global Challenges
Global Sustainability
Geopolitical Conflict
Opportunities
Emerging Technologies
Interdisciplinary Activities
Complex, Large-scale Systems


Threats
Elements
Opportunities
Stagnant federal fupport
of phy sci & eng R&D
Short-term nature of industrial R&D
Imbalance in federal R&D support
Budget weakness in states
Weak domestic student SMET interest
Weak minority/women presence
Post 9-11 impact on flow
of international SMET students
obsolete SMET curricula
Increasing laboratory expense
Rapid escalation of cyber-
infrastructure needs
Inadequate federal R&D
support in key areas
Weakened state support
New Knowledge
(Research)
Human Capital
(Education)
Infrastructure
(Facilities, IT)
Policies
(Tax, IP, R&D)
Technological
Innovation
Engineering
…Research
…Education
…Practice
The Foundation
National Priorities
Economic Competitiveness
National and Homeland Security
Public health and social well-being
Global Challenges
Global Sustainability
Geopolitical Conflict
Opportunities
Emerging Technologies
Interdisciplinary Activities
Complex, Large-scale Systems

Disturbing Trends

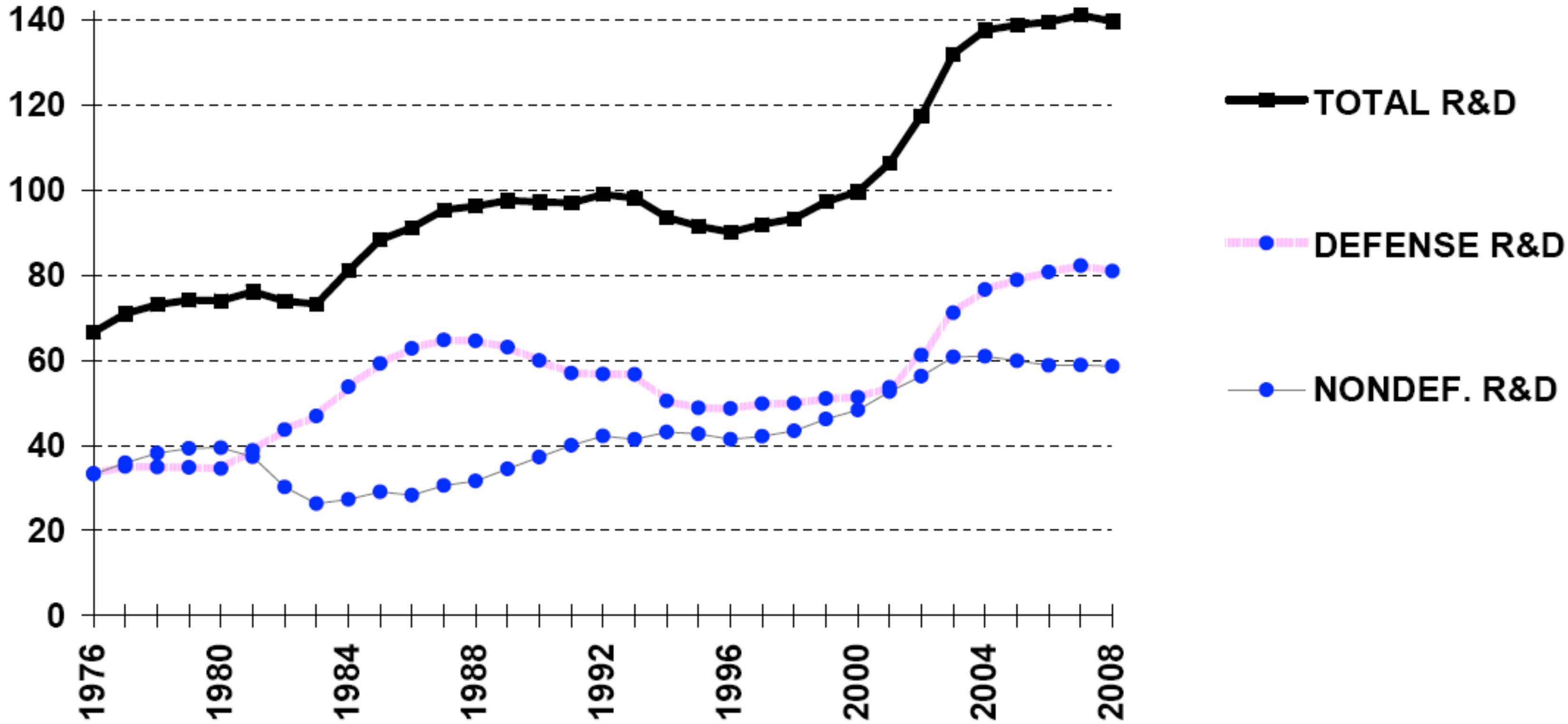
- Large and growing imbalance in federal R&D funding (e.g., NIH = $30 B, NSF = $6 B)
- Federal R&D has declined from 70% of national R&D in 1970s to less than 30% today.
- Increased emphasis on short-term R&D in industry and government-funded R&D
- Deterioration of engineering research infrastructure
- Declining interest of U.S. students in STEM careers
- Eroding ability of U.S. to attract STEM students, scientists, and engineers from abroad.

Federal vs. Nonfederal R&D as Percent of GDP



Trends in Federal R&D, FY 1976-2008

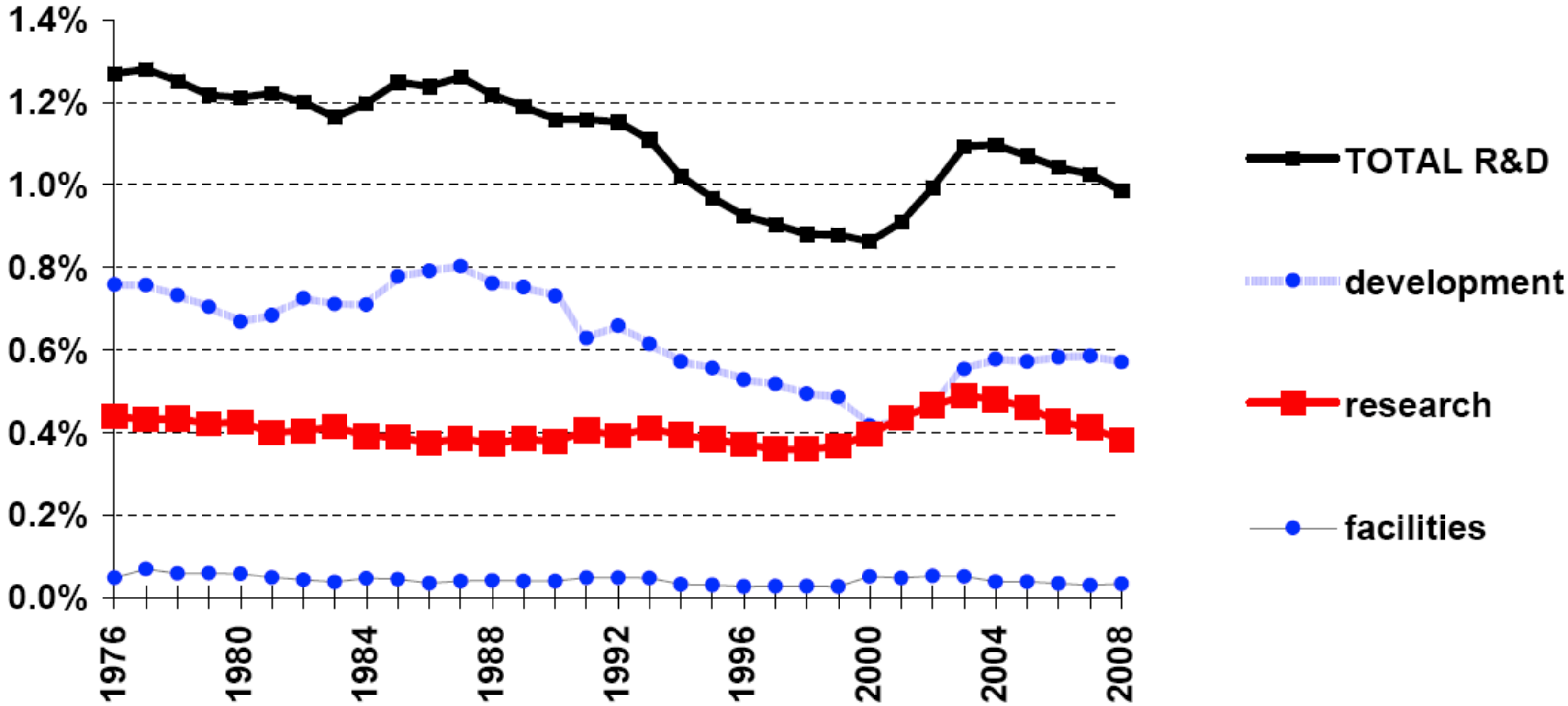
in billions of constant FY 2007 dollars



Source: AAAS analyses of R&D in *AAAS Reports VIII-XXXII.* FY 2008 figures are President's request. FY 2007 figures are latest AAAS estimates of FY 2007 appropriations.
R&D includes conduct of R&D and R&D facilities.
MARCH '07 REVISED © 2007 AAAS

AAAS

Trends in Federal R&D as % of GDP, FY 1976-2008

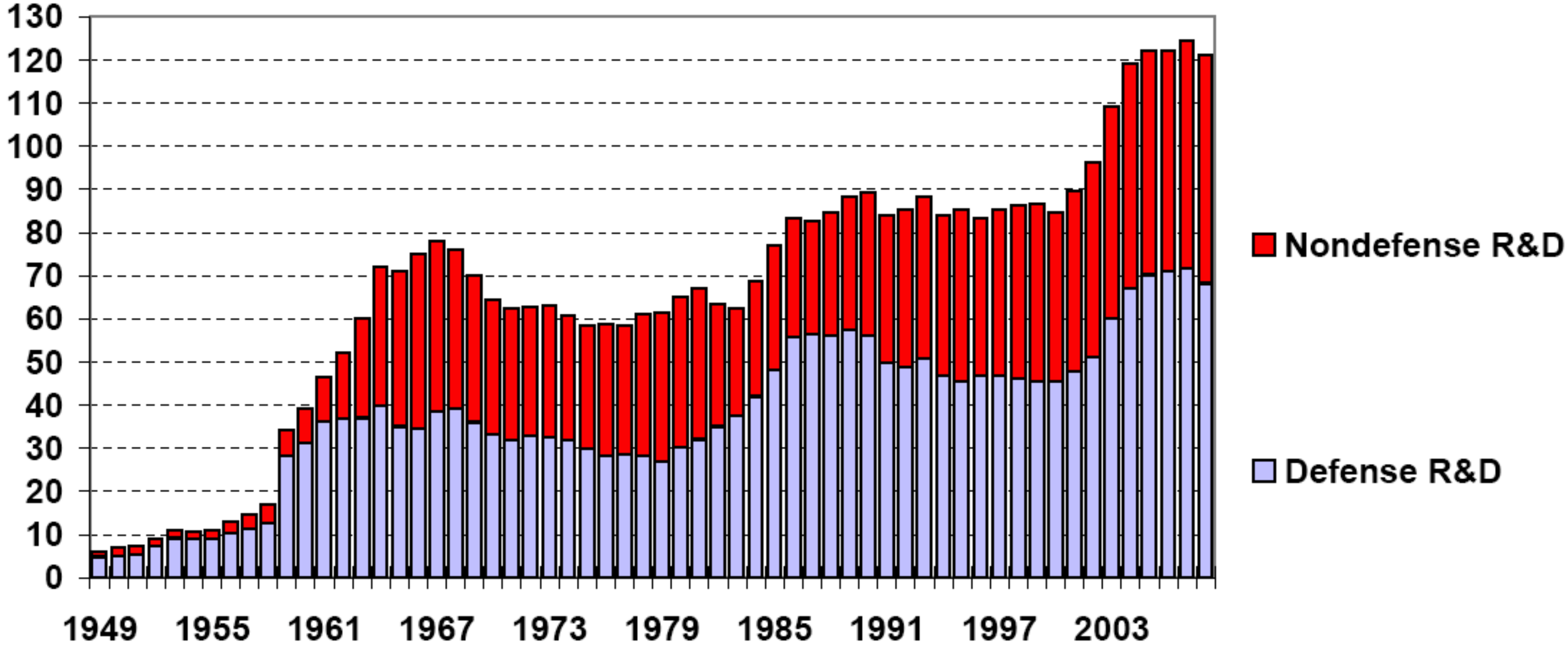


Source: AAAS analyses of R&D in annual AAAS R&D reports. FY 2008 figures are President's request. R&D includes conduct of R&D and R&D facilities. Data to 1984 are obligations from the NSF Federal Funds survey. GDP figures are from OMB, Budget of the U.S. Government FY 2008.

AAAS

Federal Spending on Defense and Nondefense R&D

Outlays for the conduct of R&D, FY 1949-2008, billions of constant FY 2007 dollars

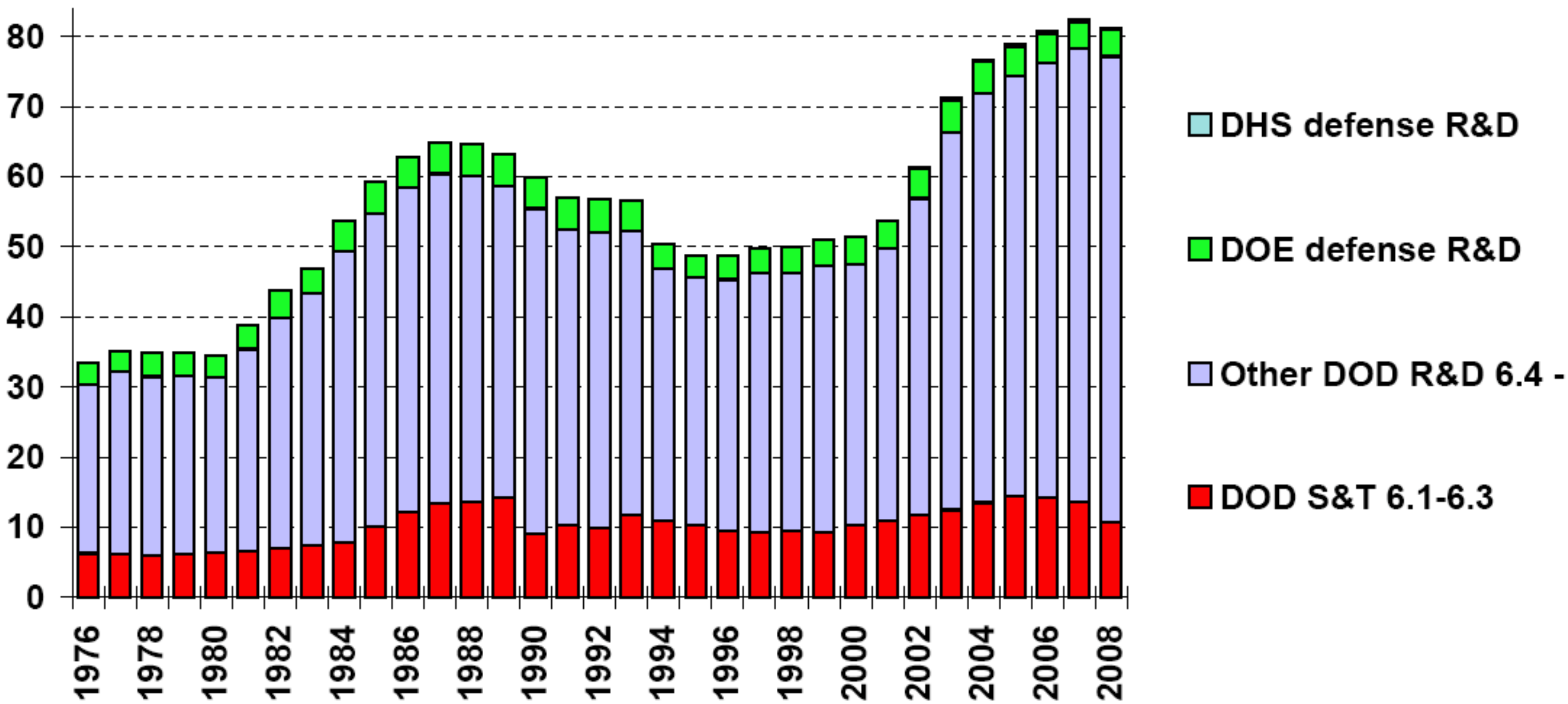


Source: AAAS, based on OMB Historical Tables in *Budget of the United States Government FY 2008.* Constant dollar conversions based on GDP deflators.
FY 2008 is the President's request.
Note: Some Energy programs shifted to General Science beginning in FY 1998.

AAAS

Trends in Defense R&D, FY 1976-2008 *

in billions of constant FY 2007 dollars

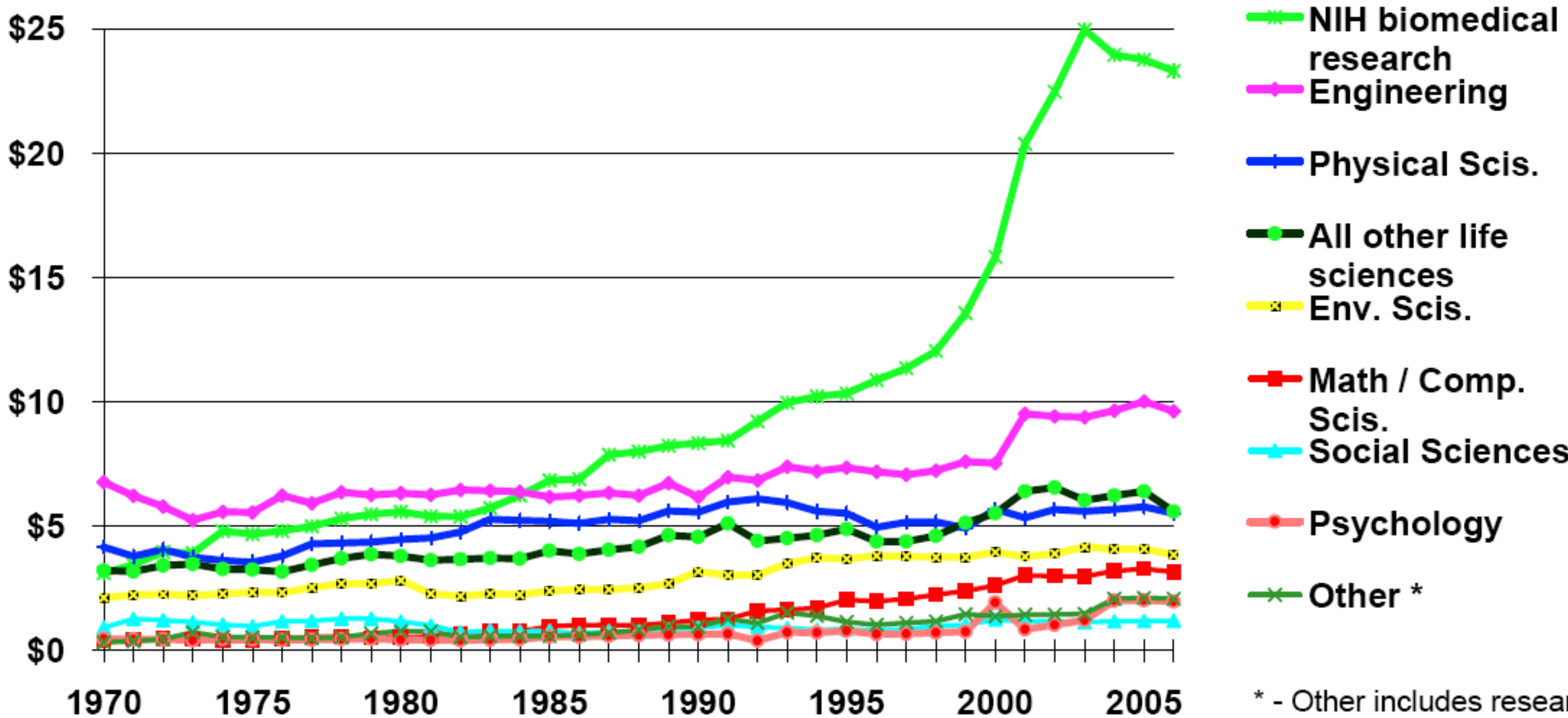


Source: AAAS analyses of R&D in *AAAS Reports VIII- XXXII.* * - FY 2008 figures are President's request. 2007 and 2008 figures include requested supplementals. R&D includes conduct of R&D and R&D facilities. DOD S&T figures are not strictly comparable for all years because of changing definitions.

AAAS

Trends in Federal Research by Discipline, FY 1970-2006

obligations in billions of constant FY 2007 dollars



* - Other includes research not classified (includes basic research and applied research; excludes development and R&D facilities)

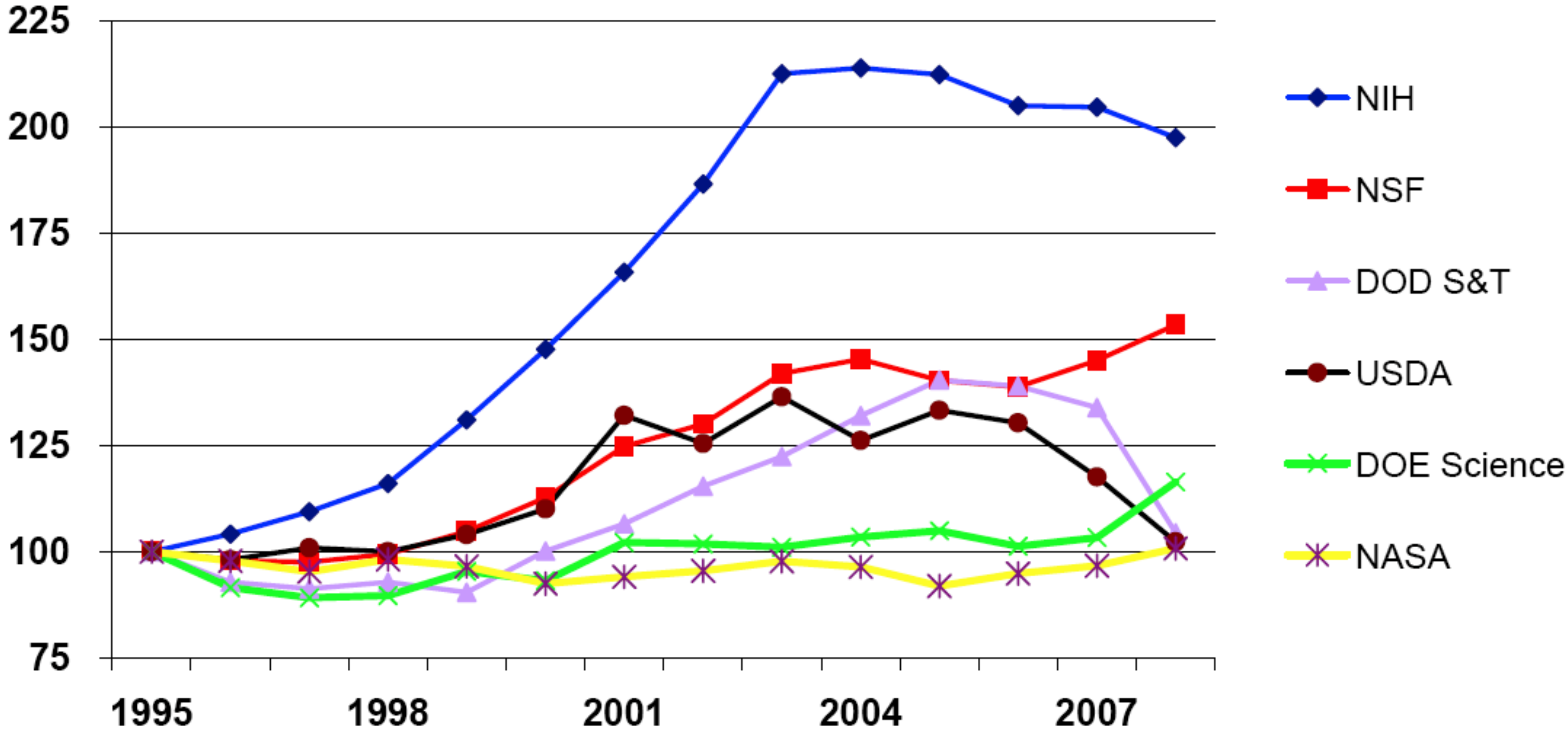
Life sciences - split into NIH support for biomedical research and all other agencies' support for life sciences.

Source: National Science Foundation, *Federal Funds for Research and Development FY 2004, 2005 , 2006,* 2006. FY 2005 and 2006 data are preliminary. Constant-dollar conversions based on OMB's GDP deflators.

AAAS

Trends in Federal R&D, FY 1995-2008*

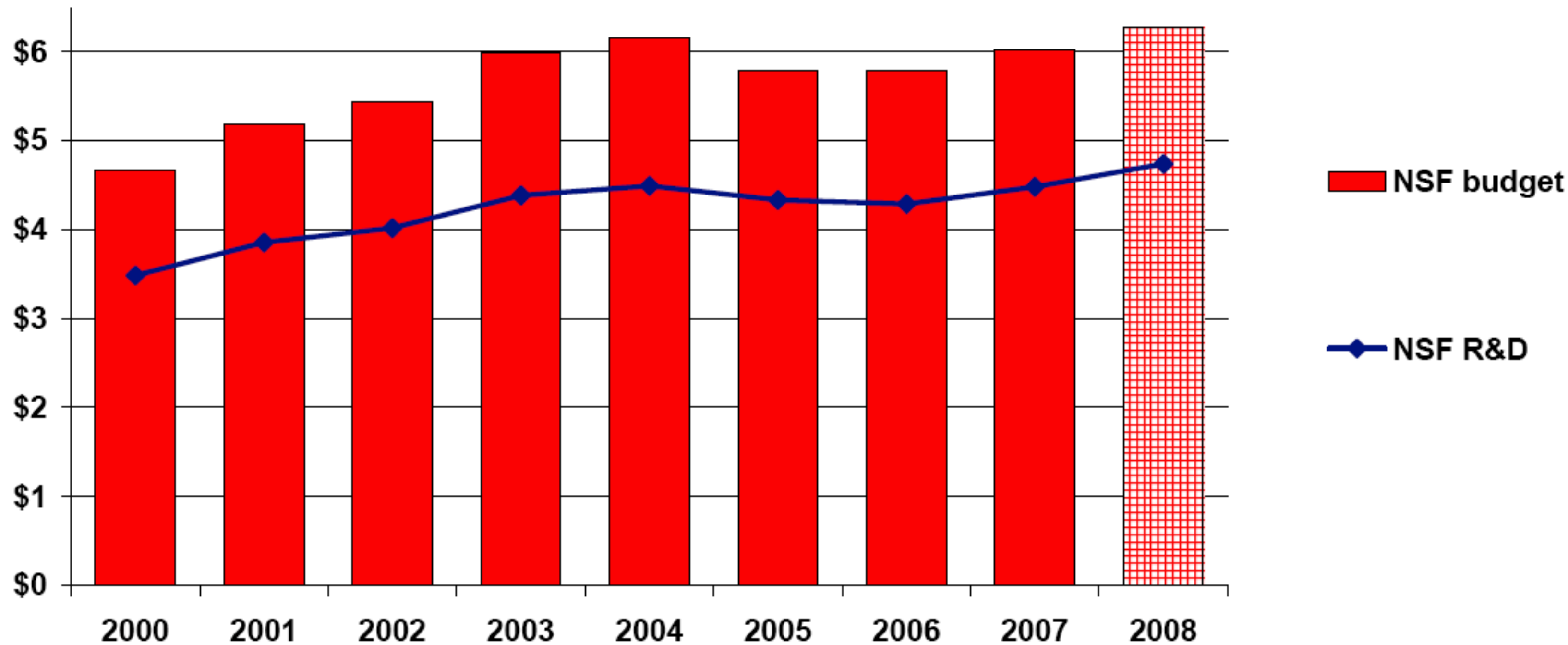
selected agencies in constant dollars, **FY 1995=100**



Source: AAAS analyses of R&D in *AAAS Reports VIII- XXXII.*
* FY 2008 figures are President's request. FY 2007 figures are latest AAAS estimates of FY 2007 appropriations.
R&D includes conduct of R&D and R&D facilities.

National Science Foundation Budget, FY 2000-2008

(budget authority in billions of constant FY 2007 dollars)



Source: National Science Foundation, and latest AAAS estimates of FY 2008 budget. FY 2008 is budget request; FY 2007 is estimate of final appropriation.

FEB. '07 REVISED

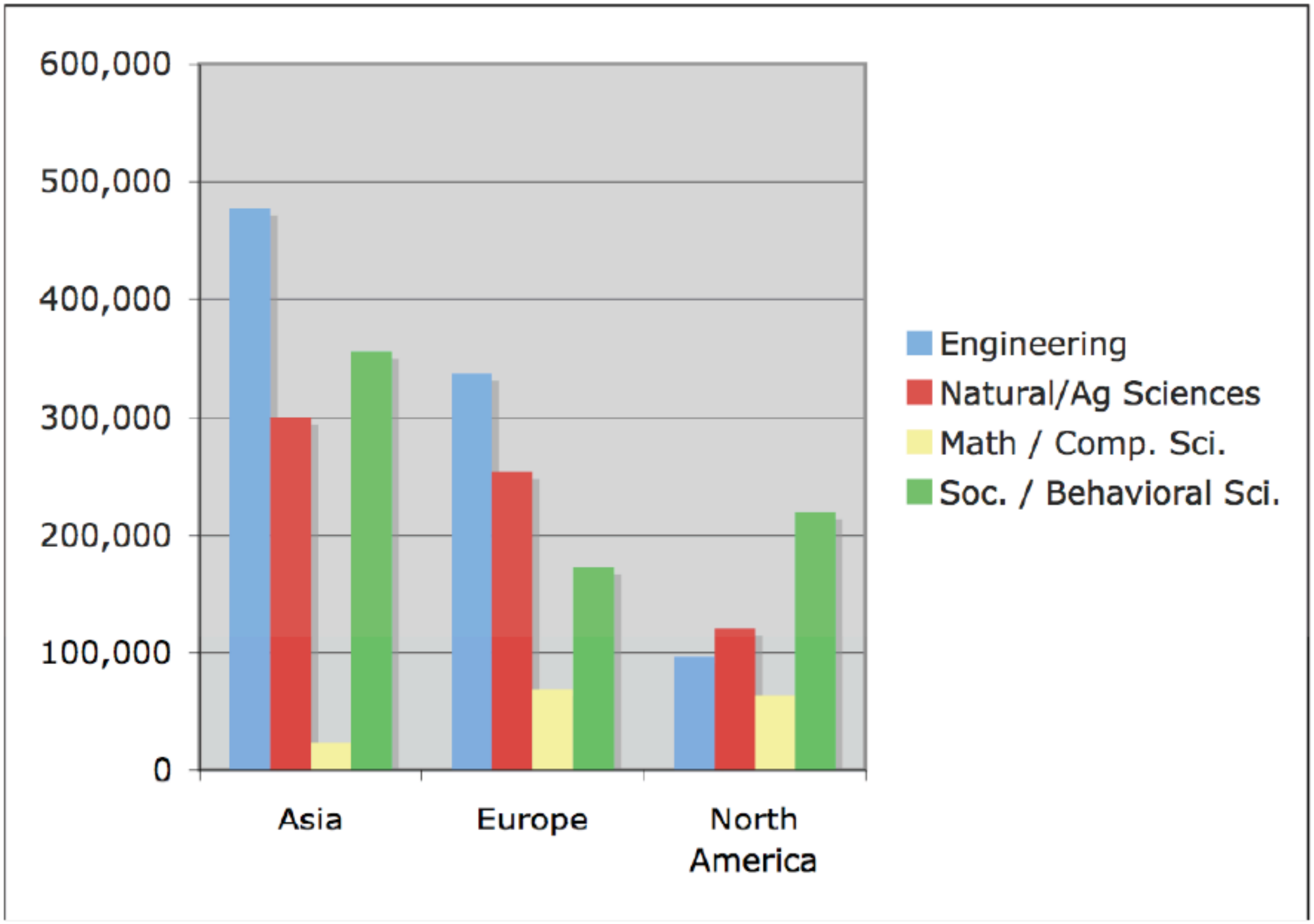
Engineering Education

Engineering Workforce Concerns

- Student interest in science and engineering careers is at a low ebb–and likely to go much lower as the implications of global sourcing become more apparent!
- Cumbersome immigration policies in the wake of 9-11 along with negative international reaction to U.S. foreign policy is threatening the pipeline of talented foreign science and engineering students.
- It is increasingly clear that a far bolder and more effective strategy is necessary if we are to tap the talents of all segments of our increasingly diverse society (particularly women and underrepresented minorities).

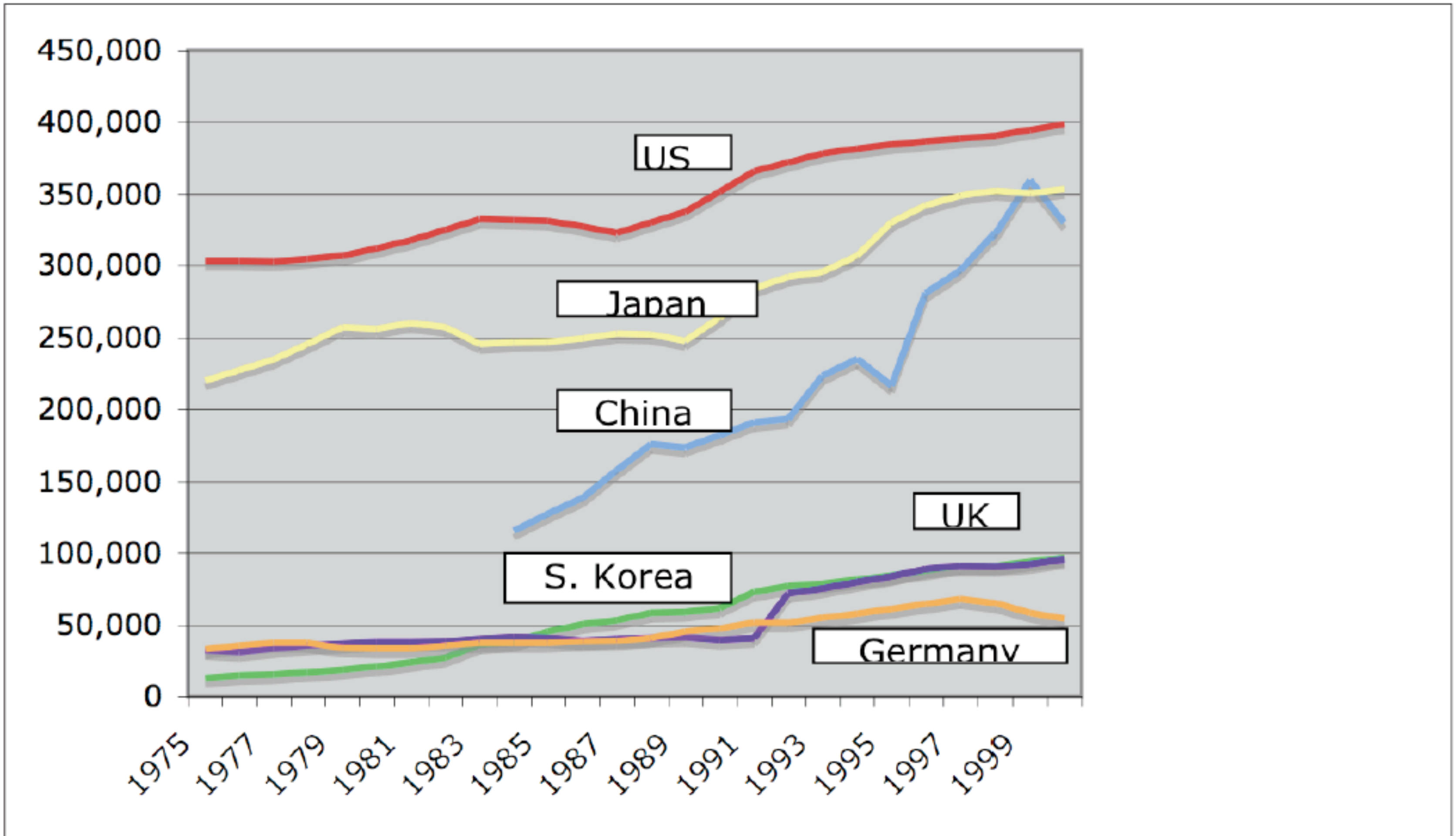
First University S&E Degrees

(Asia dominates.)



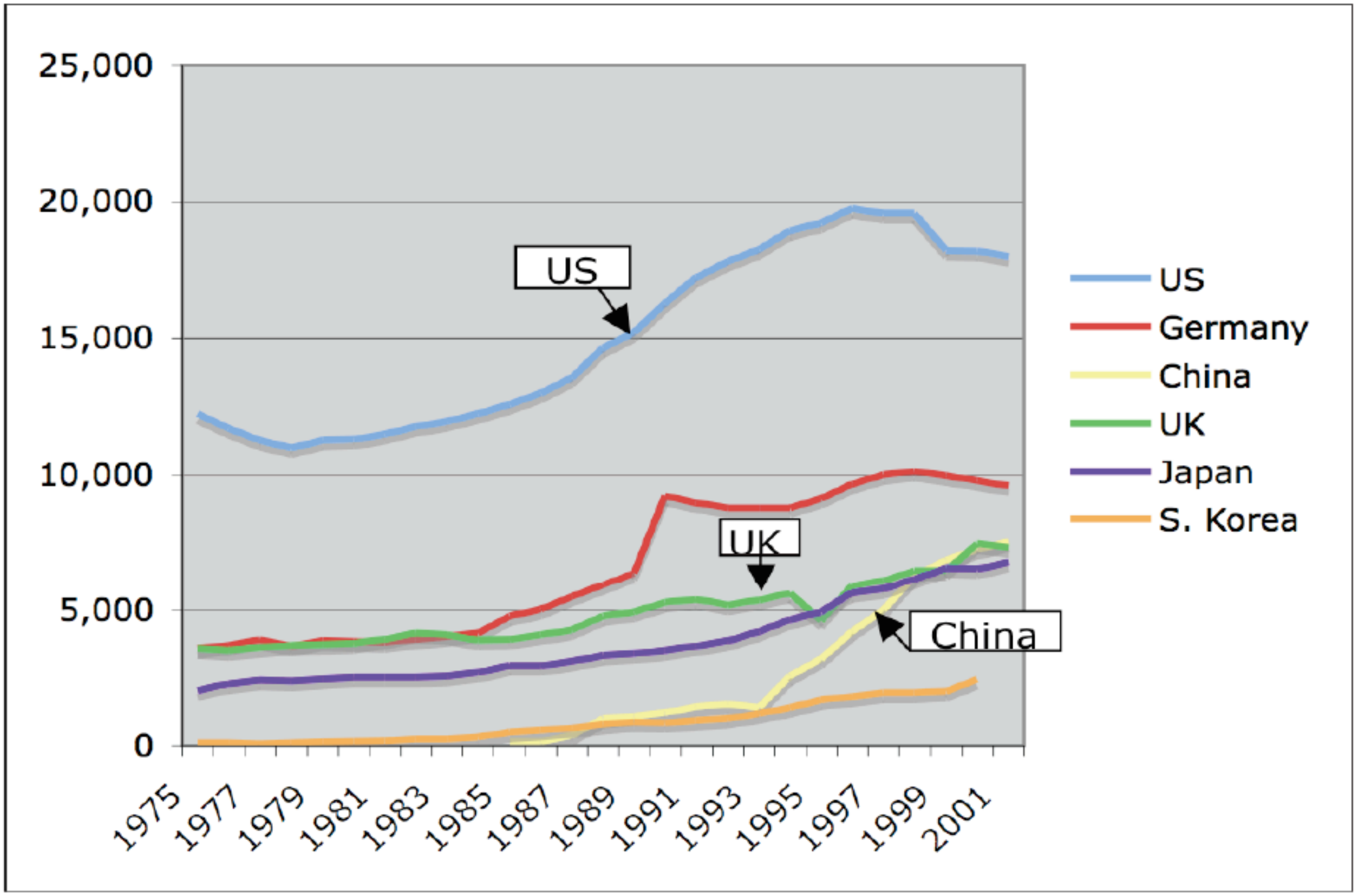
Source: Science and Engineering Indicators 2004, National Science Foundation, Washington, DC

S&E First University Degrees
(China's remarkable growth)



Source: Science and Engineering Indicators 2004, National Science Foundation, Washington, DC

S&E Doctoral Degrees
(Similar trends with a 10 year lag; US slows.)



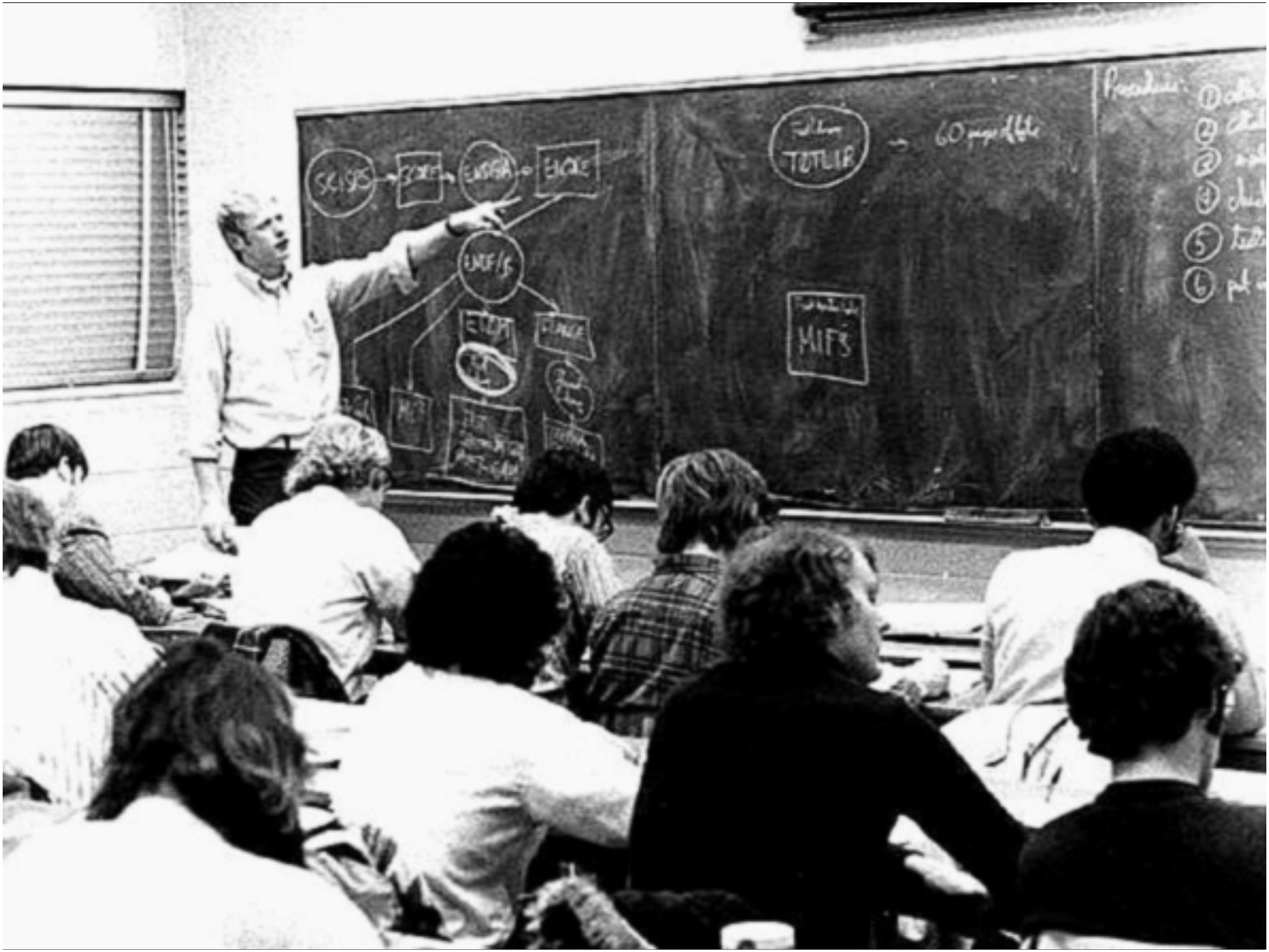
Source: Science and Engineering Indicators 2004, National Science Foundation, Washington, DC

International Comparisons

- While absolute comparison production of U.S. engineers (85,000/y) with China (350,000/y) and India (170,000/y), of far more importance is the trend.
- Similarly, PhD comparisons of U.S. (17,000/y) and China (8,000/y) is misleading; China is doubling every 5 years.
- Today the U.S. currently produces less than 8% of world's engineers and this is dropping fast.
- Clearly the U.S. cannot achieve engineering leadership through the number of engineering graduates. It must focus instead on quality and value-added through new educational paradigms for a rapidly changing, global, knowledge-driven economy.

Yet, same old…same old…

- Curriculum still stresses analytical skills to solve well-defined problems rather than engineering design, innovation, and systems integration.
- Continue to pretend that an undergraduate education is sufficient, despite fact that curriculum has become bloated and overloaded, pushing aside liberal education.
- Failed to take a more formal approach to lifelong learning like other professions (medicine, law).
- Need to broaden education to include topics such as innovation, entrepreneurial skills, globalization, knowledge integration.
- And make it all exciting and attractive to young people!


TOTLIB
MIFS

Transforming Engineering Education

"For too long traditional engineering education has been characterize by narrow, discipline-specific approaches and methods, an inflexible curriculum focused exclusively on educating engineers (as opposed to all students), an emphasis on individual effort rather than team projects, and little appreciation for technology's societal context. Engineering education has not generally emphasized communication and leadership skills, often hampering engineers' effectiveness in applying solutions. Engineering is perceived by the larger community to be specialized and inaccessible, and engineers are often seen as a largely homogenous group, set apart from their classmates in the humanities, social sciences, and natural sciences. Given these perceptions, few women and minorities participate in engineering, and non-engineering students are rarely drawn to engineering courses." Princeton, 2005

We need new paradigms…

- To respond to incredible pace of intellectual change (e.g., from reductionism to complexity, analysis to synthesis, disciplinary to multidisciplinary)
- To accommodate a far more holistic approach to addressing social needs and priorities, linking economic, environmental, legal, and political considerations with technological design and innovation.
- To reflect in diversity, quality, and rigor the characteristics necessary to serve a 21st C world.
- To infuse in our students a new spirit of adventure, in which risk-taking and innovation are seen as an integral part of engineering practice.


THE OLIN "EDUCATIONAL SYSTEM"
Applicants who are:
Extensive Admission Screening
Educational Program and Personal Development
Engineering Project Experience
start