Exploring Innovation Frontiers Initiative

Transform.

A New Agenda to Boost U.S. Innovation-Driven Competitiveness in the 21st Century

Compete.

Council on Competitiveness

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Letter from the President

In June 2015, the Council on Competitiveness (Council) launched the Exploring Innovation Frontiers Initiative (EIFI)—a national, public-private effort to accelerate the over-the-horizon, transformative innovation models that will drive U.S. competitiveness in the coming decades—sponsored by the National Science Foundation (NSF) Directorate of Engineering, Office of Emerging Frontiers of Research and Innovation (EFRI). EIFI was conceived and jump-started in response to continually evolving models of innovation, driven by the dramatically accelerating pace of technological innovation that is creating new challenges and opportunities for America's innovation capacity and capability.

The range of stakeholders in the innovation ecosystem—along with the opportunities for value creation—continues to grow in size and complexity. Furthermore, the innovation ecosystem, much like the technologies emerging from it, is evolving at a rate outpacing stakeholders' current ability to adapt. With this in mind, the Council set out to distill elements of the innovation ecosystem into distinct categories to understand where leaders of industry, universities, national laboratories, and labor see opportunities to enact public policies that create a more accessible, supportive environment for sustained innovation and economic growth.

During the course of EIFI, the Council and its members convened a series of distinctive, expert dialogues to uncover new recommendations to strengthen the spectrum of innovation—from discovery to deployment in the marketplace. Drawing on lessons learned from each of these dialogues, the council issues the following series of reports:

- ***Launch***—based on the National Launch Dialogue at the Georgia Tech Global Learning Center on June 9, 2015, co-hosted by G. P. "Bud" Peterson, President, Georgia Institute of Technology; C. Michael Cassidy, President & CEO, Georgia Research Alliance; and Hala Moddelmog, President & CEO, Metro Atlanta Chamber. The Council and dialogue participants laid out the initiative's framework and identified major elements of the innovation ecosystem, reviewing innovation trends driving the creation of the EIFI.
- ***Diversify***—based on the Southwestern Regional Dialogue at the UCR ARTSblock on November 23, 2015, hosted by Kim A. Wilcox, Chancellor of the University of California Riverside. The Council found diversity to be a key driver accelerating innovation. Education must be accessible to broad constituencies of America's talent base; creating more opportunities for those with different backgrounds to interact enhances our problem-solving abilities.

- ***Stimulate***—based on the Southern Regional Dialogue at the Mays City Center on November 15, 2016, hosted by M. Katherine Banks, Vice Chancellor for Engineering in the Texas A&M University System and Dean of the College of Engineering at Texas A&M University. The Council looked at key technologies expected to underpin America's future competitiveness. America must be first movers on these technologies, set global standards for their use and enact appropriate frameworks so new innovations can be rapidly applied deployed to the marketplace.
- ***Venture***—based on the Midwestern Regional Dialogue at the Washington University in St. Louis on June 6, 2017, hosted by Mark Wrighton, Chancellor of the Washington University in St. Louis. The Council explored key characteristics of successful innovation-enhancing entrepreneurial environments. Entrepreneurs are the conduits through which innovations appear in the market and can begin to create value, underscoring the need to enable innovators to create successful startups, driving job creation, and economic and productivity growth.

This report represents a distillation and concentration of the critical outcomes from each report, connecting threads across the national and regional dialogues to drive powerful recommendations and construct a roadmap to a more open, robust, transformative and productive innovation ecosystem in the United States.

I would like to thank the NSF for their support of this critical work, as well as the many experts, innovation practitioners, and future innovators who shared their perspective as an innovation ecosystem stakeholder to shape the recommendations contained within this report. I would like to extend a special appreciation to our partners and hosts of the EIFI dialogues, for allowing us access their extensive networks and institutions, without which this effort would not have been possible. The Council looks forward to continuing to engage leaders at the local, regional, and national level to enact a transformational innovation action agenda to enhance economic growth and U.S. productivity and prosperity.

Sincerely,

Deborah L. Wince-Smith

The Honorable Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

Summary of Exploring Innovation Frontiers Initiative Dialogues

Advances in knowledge and its application in technology and innovation are the main sources of productivity and economic growth, wealth creation and a rising standard of living. Today, the ways in which knowledge is converted into these economic outcomes are changing and expanding.

In 2015, the Council on Competitiveness (Council) and the National Science Foundation (NSF) forged a groundbreaking public-private partnership, launching the Exploring Innovation Frontiers Initiative (EIFI) to examine these changes across the global innovation landscape, and the opportunities and challenges they present for the United States.

The Council on Competitiveness and the NSF bring important and complementary knowledge and perspectives to the table in exploring the new contours of innovation, with the Council further contributing broad-based expertise and global experiences from its diverse membership spanning business, industry, academia, government and the non-profit sector. EIFI builds on more than a decade of the Council's and its members' examination of U.S. innovation, started in 2004 with the National Innovation Initiative (NII) and its report, *Innovate America*, which helped set the path for U.S. science and technology policy during the following decade.

As a major source of federal research and development funding in the science of innovation and active participant in the U.S. innovation ecosystem, the NSF brings an invaluable perspective on the current state-of-the-art in models of innovation. Moreover, the NSF is the only federal agency unconstrained by a subject-specific mission and, thus, is the natural partner for a topic as broad as innovation.

The Honorable France A Córdova, Director, National Science Foundation.

Call To Action

Why EIFI Now? EIFI comes at a critical moment in time in national innovation systems research and action. New, transformational models driven by the democratization and self-organization of innovation are emerging and beginning to take root across the nation. These developments are occurring against the backdrop of increasing global innovation-based competition, growing capacity for innovation in countries around the world, and rising internal challenges in the U.S. innovation system such as changing demographics, lack of diversity and inequality of opportunity in the U.S. education system. In response, innovation practitioners and stakeholders are facing difficult questions about how individuals, teams, communities and national institutions of knowledge creation and innovation will transform to support current and future U.S. innovation.

> "Our societal and innovation landscape are changing rapidly, and we need to thoroughly understand these changes."
>
> **Dr. France A Córdova, Director**
> National Science Foundation
> National Launch Dialogue, Atlanta, GA, June 9, 2015

As changes in the process of innovation unfold, increasing attention is being paid to the science of the innovation process itself, and how to reduce its risk and uncertainty. Researchers and academics have contributed for decades to the field of corporate management, and are now beginning to focus their attention on new types of organizational structures, and methods to accelerate and optimize technology commercialization.

Analyzing Changes to Innovation and Their Implications. EIFI was launched as a qualitative analysis to collect, synthesize and disseminate broadly the experiential knowledge of active innovation practitioners. **This information will be used to provide academicians with direction for future research in innovation, business leaders and strategists with insights to inform future business models, and policymakers with knowledge to enact public policies that create a supportive environment for sustained innovation-driven growth.**

To carry out the analysis for EIFI, the Council and the NSF hosted four expert dialogues across the United States, informed by best-in-class intelligence from reports and initiatives making the competitiveness case for strengthening innovation ecosystems. The dialogues included:

- The **National "Launch" Dialogue** in Atlanta, Georgia on June 9, 2015, co-hosted by G.P. "Bud" Peterson, President of the Georgia Institute of Technology; C. Michael Cassidy, President & CEO of the Georgia Research Alliance; and Hala Moddelmog, President & CEO of the Metro Atlanta Chamber.
- The **Southwestern Regional Dialogue** in Riverside, California on November 23, 2015, hosted by Kim A. Wilcox, Chancellor of the University of California Riverside, with a special focus on talent and diversity.
- The **Southern Regional Dialogue** in Houston, Texas on November 9, 2016, hosted by M. Katherine Banks, Vice Chancellor for Engineering in the Texas A&M University System and Dean of the College of Engineering at Texas A&M University, focused on three technology vectors the Council identified as foundational to the nation's future competitiveness: energy and manufacturing, autonomy and transportation, and engineered healthcare.
- The **Midwestern Regional Dialogue** in St. Louis, Missouri on June 6, 2017, hosted by Mark Wrighton, Chancellor of the Washington University in St. Louis, with a special focus on the linkages between innovation and entrepreneurship.

The EIFI systematically explored major elements of the U.S. innovation ecosystem through each of its dialogues. The National Launch Dialogue was foundational and wide reaching, while regional dialogues dove deeper into components of the U.S. innovation ecosystem such as talent, technology, entrepreneurship, and the models, networks and systems that connect these components into an engine of economic growth. To explore this landscape, the dialogues convened a diverse and representative mix of innovation leaders from industry (small, medium, large and entrepreneurial companies), academia (university presidents, faculty, researchers and students), national laboratories and research institutions, labor leaders and key influencers (foundation and media leaders).

The Council designed the dialogue series to provide the body of knowledge and experience needed to meet the EIFI goals:

- Craft with national and regional stakeholders a transformational innovation action agenda that draws on the strengths of NSF research and positions the United States as a global innovation leader for decades to come,
- Catalyze a larger movement to enhance U.S. competitiveness and economic growth by accelerating knowledge creation and the transfer of science and engineering research into market reality, and
- Expand and improve public and private sector engagement in the innovation process.

Top: *Dr. Pramod Khargonekar, Vice Chancellor for Research and Distinguished Professor of Electrical Engineering and Computer Science, University of California, Irvine; and former Assistant Director, Directorate for Engineering, National Science Foundation.*

Bottom: *Dr. Richard Buckius, Former Chief Operating Officer, National Science Foundation.*

Four EIFI Dialogues
An Overview

EIFI National Launch Dialogue

Atlanta, Georgia
June 9, 2015

SPEAKERS

Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

G.P. "Bud" Peterson
President
Georgia Institute of Technology

France Córdova
Director
National Science Foundation

Kim Wilcox
Chancellor
University of California, Riverside

Chad Evans
Executive Vice President
Council on Competitiveness

PANELS AND BREAKOUT SESSIONS

Setting the Stage: Exploring New Models of Innovation

Pramod Khargonekar
Vice Chancellor for Research and Distinguished Professor of Electrical Engineering and Computer Science, University of California, Irvine; and former Assistant Director, Directorate for Engineering, National Science Foundation

Ileana Arias
Principal Deputy Director of CDC/ATSDR
Center for Disease Control and Prevention

Paul Hommert
Former Director, Sandia National Laboratory; and former President, Sandia Corporation

Mark Little
Former Senior Vice President, Director of GE Global Research, Chief Technology Officer
GE—Global Research Center

Rod Makoske
Senior Vice President of Corporate Engineering, Technology, and Operations
Lockheed Martin

Next Generation Innovator
Jasmine Burton
Founder and President, Wish for WASH, LLC; and Recent Graduate, Georgia Institute of Technology

Untapped Innovation Capacity

Judy Genshaft
President and CEO/Corporate Secretary
University of South Florida

Al Bunshaft
Senior Vice President, Global Affairs
Dassault Systèmes

Stephen Cross
Executive Vice President for Research
Georgia Institute of Technology

Greg Hyslop
Vice President and General Manager of Boeing Research and Technology
The Boeing Company

Mark Lytle
Vice Chancellor for Economic Development, Board of Regents, University System of Georgia

Next Generation Innovator
Rachel Ford
Instructor, Georgia Tech Venture Lab; and Undergraduate, Georgia Institute of Technology

Creating and Nurturing New Talent Breakout Session

Andrew Garman
Founder and Managing Partner
New Venture Partners

Alan Taetle
General Partner
Noro-Moseley Partners

Paul Sanberg
President, National Academy of Inventors; and Senior Vice President for Research, Innovation, and Economic Development
University of South Florida

Innovation for Prosperity Panel

James Garrett
Dean, College of Engineering
Carnegie Mellon University

The Honorable Kwanza Hall
Council Member—District 2
Atlanta City Council

Keoki Jackson
Vice President and Chief Technology Officer
Lockheed Martin

G. Wayne Clough
President Emeritus
Georgia Institute of Technology

Hala Moddelmog
President and CEO
Metro Atlanta Chamber

Next Generation Innovator
Partha Unnava
CEO, Better Walk Inc.; and Former Undergraduate, Georgia Institute of Technology

Creating New Markets, New Jobs and Growing the Economy Breakout Session

David Norton
Vice President for Research
University of Florida

Dona Crawford
Associate Director for Computation
Lawrence Livermore National Laboratory

Mohammad Zaidi
Chief Technology Officer, Retired
Alcoa, Inc.

The Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness; Mr. C. Michael Cassidy, President, Georgia Research Alliance; The Honorable France A. Córdova, Director, National Science Foundation; Dr. G. P. "Bud" Peterson, President, Georgia Institute of Technology; and Ms. Hala Moddelmog, President & CEO, Metro Atlanta Chamber.

The National Launch Dialogue in Atlanta brought together more than 100 business, academic and national laboratory leaders, innovators and stakeholders, all thought leaders with significant experience in the world of innovation. This foundational dialogue, national in scope and broad in vision, set the stage for the EIFI dialogue series anchored in regions of the country that embody the transformational changes to the process of innovation occurring in the United States. As part of a region successfully cultivating a rich innovation ecosystem, Atlanta was an ideal setting for the national EIFI dialogue.

The Atlanta dialogue focused on three major themes: new transformative models of innovation and how people pursue innovation today; the demographic, socioeconomic and geographic landscape of the national innovation system; and the process by which innovation diffuses into the economy.

New Transformative Models of Innovation

Panelists and participants discussed drivers of change in the U.S. innovation system, including technology convergence, the multi-faceted nature of important problems facing the Nation and the world, and shifts in the focus of business R&D toward support for near-term needs of business units. As a result, companies increasingly look externally—for example, to universities, other industries or start-up companies—for new technologies. Also, the development of new and complex innovations often requires a multidisciplinary skill set. These changes are increasing strategic partnerships and expanding the scope of participants in the innovation system.

Panelists also explored the growing emphasis on regional models of innovation that leverage local and regional innovation assets and competitive strengths, the value of anchoring these ecosystems with research universities, and integrating them into regional strategic planning.

Questions Raised for Future Dialogues

- What are the trends on the horizon that have the potential to transform the way we think about and pursue innovation?
- How can leaders leverage EIFI to support and/or accelerate efforts to develop local and regional systems of innovation, particularly in areas where these ecosystems do not yet exist?
- How can leaders use the EIFI to address low levels of federal investment in basic research?
- What are the origins of science, technology and innovation communities of support and how do they function?
- How do we replicate and scale these support systems in communities where they are not available?

Untapped Innovation Capacity

A foundational theme and major discussion revolved around the lack of demographic and socioeconomic diversity in the science, technology and innovation ecosystem. As innovation becomes ever more the engine of economic growth, wider access to innovation ecosystems becomes more critical to national and personal prosperity. However, the diverse communities that will continue to increase their share of the U.S. population in the decades ahead are the same communities that are largely disconnected from innovation ecosystems.

Discussion focused on how to address the lack of foundational skills such as numeracy and literacy found in some communities, how to get young people into the science and engineering pipeline at an early age, and barriers to access to the innovation ecosystem faced by people of color, women and low-income students. There was also discussion about a lack of geographic diversity in the distribution of financial capital for innovation.

Questions Raised for Future Dialogues

- Is the process of building regional innovation ecosystems fundamentally local?
- What are the reasons to transcend localism and knit together these regions with national strategy?
- How do regions without research institutions build innovation ecosystems?
- Why are women, minorities and low-income students underrepresented in STEM fields?
- What are the threats to the innovation ecosystem created by the rising cost of education and the concomitant increase in student debt?

Dr. G. P. "Bud" Peterson, President, Georgia Institute of Technology.

Innovation for Prosperity

Panelists discussed the perception that innovation, in recent years, has become more destructive than disruptive and, at least partially, responsible for the hollowing out of the middle class, driving an anti-technology sentiment in the country. These perceptions could undermine support for investment in science, technology and innovation. Participants identified the need to have an innovation ecosystem that translates into broad-based national prosperity.

Questions Raised for Future Dialogues

- Is the falling social standing of technology and innovation among the American public the result of misperceptions? Or, do these claims have merit?
- What are, if any, the negative or harmful effects of innovation?
- If there are negative or harmful effects, how can we mitigate them? Or, are they a natural element of a healthy and dynamic innovation-driven economy?
- Is public support for investments in science and technology flagging?
- Does the public view science in a different light than technology and innovation?

EIFI Southwestern Regional Dialogue

Talent, Diversity, Accessibility, and Inclusion in the U.S. Innovation System

Riverside, California
November 23, 2015

SPEAKERS

Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

Kim A. Wilcox
Chancellor
University of California, Riverside

Pramod Khargonekar
Vice Chancellor for Research and Distinguished Professor of Electrical Engineering and Computer Science, University of California, Irvine; and former Assistant Director, Directorate for Engineering, National Science Foundation

Chad Evans
Executive Vice President
Council on Competitiveness

Susan Wessler
Home Secretary, National Academy of Sciences; and Neil A. and Rochelle A. Campbell Presidential Chair for Innovations in Science Education
University of California, Riverside

PANELS

Diversity in the U.S. Innovation Ecosystem

Pramod Khargonekar
Vice Chancellor for Research and Distinguished Professor of Electrical Engineering and Computer Science, University of California, Irvine; and former Assistant Director, Directorate for Engineering, National Science Foundation

M. Katherine Banks
Vice Chancellor for Engineering, The Texas A&M University System; and Dean of Engineering
Texas A&M University

Leslie A. Hickle
Vice President of New Business Opportunities and Project Management
BioAtla

John E. Leonard
Senior Vice President, Development
Vaccinex, Inc.

Next Generation Innovator
Katherine Espinoza

Accessing the Crown Jewels of the U.S. Innovation Systems: Socioeconomic Diversity in Higher Education

Kim A. Wilcox
Chancellor
University of California, Riverside

Lynne Brickner
President
ARCS Foundation, Inc.

Judy White
Superintendent
Moreno Valley Unified School District

Next Generation Innovator
Monica Natividad
Graduate Student Researcher
University of California, Riverside

Planting the Seeds of Innovation: Geographic Diversity in the U.S. Innovation Ecosystem

Michael Pazzani
Vice Chancellor for Research
University of California, Riverside

Sheldon Schuster
President and Professor
Keck Graduate School

Jay Goth
Executive Director
InSoCal Connect

Sean Gallagher
Director, Research and Development, Analytik Jena US; and former Chief Technology Officer
UVP

Diversity of Outcomes: Exploring the Distribution of Innovation's Benefits

J. Adalberto Quijada
District Director, Santa Ana District Office
U.S. Small Business Administration

C. Michael Cassidy
President and CEO
Georgia Research Alliance

Agenor Mafra-Neto
CEO
ISCA Technologies, Inc.

Paul D'Anieri
Provost and Executive Vice Chancellor
University of California, Riverside

Next Generation Innovator
Jeffrey McDaniel
Ph.D. Candidate, University of California, Riverside, Department of Computer Science and Engineering

The Southwestern Regional Dialogue held at the University of California-Riverside brought together more than 30 business, academic, non-profit and national laboratory leaders, innovators and stakeholders who examined the ways different types of diversity—geographic, socioeconomic, gender and race—affected the potential for innovation in America. As one of the most economically diverse universities in the country, Riverside was an ideal location to explore the inclusiveness of the U.S. innovation ecosystem.

Discussions focused on three major themes: how public and private innovation institutions are addressing the challenge of increasing the participation of groups underrepresented in science, technology, engineering and mathematics (STEM); expanding access to U.S. research universities; and the development of local and regional innovation ecosystems, with a focus on the human element of innovation.

Diversity in the U.S. Innovation Ecosystem

Panelists and participants identified and discussed reasons women and some minority groups are underrepresented in undergraduate and graduate level science and engineering education, and how to address these challenges. This includes changes needed in the nature of undergraduate STEM courses, the benefits of bringing more practical experience into the classroom, the need for communities of support, and the need for students to see employment prospects to motivate their persistence in the studies needed to attain a STEM degree. Speakers discussed several interventions in STEM education that improved student outcomes.

Questions raised for future dialogues:

- How can we more effectively generate interest in STEM during primary education?
- How do we inspire the next generation of innovators to pursue STEM disciplines?
- Are unique incentives required to attract students of different genders, race or socioeconomic background?
- What can EIFI do to support career mentoring or provide resources to those concerned about employment prospects in their field?

Accessing the Crown Jewels of the U.S. Innovation System, Socioeconomic Diversity in Higher Education

Panelists explored alignment of the current model of higher education with society's changing needs and the need to accommodate changing enrollment demands. The rising cost of higher education was identified as a serious challenge to socioeconomic diversity in the U.S. innovation system, as demand for student resources increases and financial support from government decreases. As schools pass increased costs onto students in the form of higher tuition, financial concerns may impact a student's willingness and ability to pursue an education for fear of the amount of debt accumulated by the end of their academic career. Providing additional student support costs money, and the school districts, communities and universities in greatest need of such support are the ones that struggle the most for money.

Questions raised for future dialogues:

- Is leveling the playing field for higher education solely a matter of increasing funding?
- How will the United States maintain its lead in higher education?
- What can be done to lower the cost of education for students?
- Has the value of a degree changed?

Group photo of all attendees of the EIFI Southwestern Dialogue, taken outside of the ARTSblock at the University of California, Riverside.

Geographic Diversity in the U.S. Innovation Ecosystem

Panelists explored emerging trends transforming the way people engage in the innovation ecosystem, and why some communities develop creative, productive and robust innovation clusters, while other communities around the country do not have the same access to innovation ecosystems. Many communities do have innovation assets. However, they may not have integrated them with economic development strategies, or connected these assets in a way that innovators can leverage, draws innovators to their location or captures the attention of the community to invest in STEM. Panelists further discussed how to build innovation ecosystems in regions disconnected from communities of science, technology and innovation, and those without research institutions.

Questions raised for future dialogues:

- Should regions claim unique innovation disciplines, or spread all innovation capacities throughout the United States?
- Are regions appropriately incented to develop innovation ecosystems?
- What methods do regions have to broadcast progress in developing innovative communities?

Exploring the Distribution of Innovation's Benefits

Panelists explored the degree to which Americans have what it takes to compete in a global, innovation-driven economy, disparities in the distribution of gains from innovation, and how innovation's opportunities and benefits impact individuals at different income levels and levels of educational attainment. For example, the prosperity unleashed by recent digital innovations is disproportionately benefitting the highest skilled workers and owners of capital rather than being widely distributed. Panelists agreed that the path to more equitable distribution of innovation's benefits is through education that enables individuals to engage with and adapt to new innovations.

Questions raised for future dialogues:

- Is there incompatibility between the foci of liberal arts teaching and vocational training?
- What are more examples of successful methods to increase the accessibility of innovation's benefits?
- Will resolving the challenges of innovation distribution require modification of existing structures or building anew?
- Are these issues felt more strongly in certain regions than in others?
- How would resolutions differ based on the region, if at all?

EIFI Southern Regional Dialogue

New Innovation Models and Technology Disruptors: Catalyzing Exponential Change within Regions

Houston, Texas
November 15, 2016

SPEAKERS

M. Katherine Banks
Vice Chancellor for Engineering
Texas A&M University System; and Dean of the College of Engineering
Texas A&M University

Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

Richard Buckius
Former Chief Operating Officer
National Science Foundation

Chad Evans
Executive Vice President
Council on Competitiveness

Greg Powers
Vice President of Technology
Halliburton

PANELS AND BREAKOUT SESSIONS

Emerging Innovation Frontiers: Energy and Manufacturing

The Honorable Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

Lloyd F. Colegrove
Data Services Director
Fundamental Problem Solving Director,
Analytical Technology Center
The Dow Chemical Company

Mark Johnson
Director, Advanced Manufacturing Office,
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Rustom Mody
Vice President/Chief Engineer
Baker Hughes

Alex Reed
CEO
Advanced Polymer Monitoring Technologies

Next Generation Innovator
Austin Rogers
Presenter on Robotic Assessments of Energy

Emerging Innovation Frontiers: Autonomy and Transportation

Reuben Sarkar
Deputy Assistant Secretary for Transportation, Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Dominic "Tony" Antonelli
Acting Director, Advanced Programs, Civil Space, Space Systems Company Lockheed Martin

J. Karl Hedrick
Fellow, Texas A&M Institute for Advanced Study; and James Marshall Wells Professor of Mechanical Engineering University of California, Berkeley

Ahmed Mahmoud
CIO, Global Purchasing and Supply Chain, Customer Care and Aftersales and Quality IT
General Motors

C. Michael Walton
Ernest H. Cockrell Centennial Chair in Engineering
University of Texas at Austin

Next Generation Innovator
Gustavo Tapia
Presenter on Additive Manufacturing: The Path from Tailored Geometry to Tailored Functionality

Fostering Innovations in Energy and Manufacturing Breakout Session

Elizabeth Cantwell
Vice President for Research Development, Office of Knowledge Enterprise Development
Arizona State University

Chad Evans
Executive Vice President
Council on Competitiveness

Fostering Innovations in Autonomy and Transportation Breakout Session

Steven W. Dellenback
Vice President R&D
Southwest Research Institute

Michael Bernstein
Senior Policy Director
Council on Competitiveness

Fireside Chat

Dimitris Lagoudas
Senior Associate Dean for Research, Texas A&M Engineering

Jim Phillips
Chairman and CEO
NanoMech, Inc.

Greg Powers
Vice President of Technology
Halliburton

Gabriel Silva
Manager, Strategic Technologies Group FMC Technologies

The Honorable Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

Emerging Innovation Frontiers: Engineered Healthcare

Sarah Westall
University Instructor, Business Consultant and Radio Host, University of Minnesota

Gang Bao
Foyt Family Professor in Bioengineering; and Director, Nanomedicine Center for Nucleoprotein Machines, CPRIT Scholar in Cancer Research, Rice University

Gerard L. Coté
Director, Center for Remote Health Technologies and Systems; and Holder of the Charles H. and Bettye Barclay Professorship
Texas A&M University

Jon Mogford
Vice Chancellor for Research
The Texas A&M University System

Tong Sun
Director, Central Operations
Institute for Academic Medicine, Houston Methodist

Next Generation Innovators
Garrett Harmon and Kunal Shah
Presenters on Non-Destructive Mechanical Testing for Tissue Engineering Applications

The Southern Regional Dialogue held at Texas A&M University brought together more than 60 business, academic and government leaders, innovators and stakeholders with expertise and experience in innovation at the cutting edge of technology in energy, manufacturing, transportation and healthcare. As a locus for technological innovation in areas such as manufacturing and energy, Houston and Texas A&M were a model backdrop to explore the changing landscape for innovation.

Discussions focused on new innovation models and technology disruptors, and examining these through the lens of energy and manufacturing, rapid advances in autonomous vehicles and systems, healthcare technologies and personalized medicine.

Mr. Jim Phillips, Chairman & CEO, NanoMech Inc.; Mr. Rustom Mody, Vice President–Technical Excellence–Enterprise Technology, Baker Hughes–A GE Company; and Dr. Gregory Powers, Vice President, Technology, Halliburton.

Energy and Manufacturing

Panelists reviewed how the energy industry has benefitted enormously from new technologies, such as game-changing diamond drill bits that led to a dramatic productivity increase in the cultivation of energy resources. However, many technologies for the energy industry have come from outside the industry, which, historically, has been a low investor in R&D. As the industry becomes more complex, it looks more to open innovation, recognizing that solutions can come from anyone, anywhere.

Panelists and participants highlighted the challenges of scaling innovations, such as tolerance of risk in financing, and changes in industry structure that make it difficult for individual firms to capture adequate returns on R&D investments. Scaling innovation is especially challenging in manufacturing, requiring many manufacturers to work with stakeholders, customers, suppliers, academia, and, perhaps, even direct competitors on pre-competitive research.

Automation and Transportation

Panelists explored how the movement of goods and people will be fundamentally transformed in the coming decades. For example, data will be a principal driver in the vehicle revolution in GPS, vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-cloud, offering information on traffic, weather and crowd-sourced conditions, as well as in vehicle-to-itself to self-analyze and diagnose onboard systems.

Societal and ethical factors are likely to arise, for example, as autonomous modes of transport are mixed with human operators. Cyber security is a concern, ensuring data and sensors on-board vehicles are not compromised. In addition, regulatory response has not yet created an environment for automation in transportation to thrive, creating a widening gap between the promise of technology and its applications.

Interdisciplinary Opportunities

Panelists discussed how firms are coping with technology's increased complexity and accelerating rate of advancement, increasingly seeking technological innovations outside of the company and outside of their industry. This has raised the importance of open innovation models and strategic partnerships between companies and small innovative firms, universities and government researchers. Also, the acquisition of intellectual property has become an important driver of merger and acquisitions activity, for example, large companies acquiring small start-ups to gain access to their innovations.

Engineered Healthcare

Panelists explored the coming revolution in healthcare and how ethical and moral challenges, rather than technical challenges, will play a large role in the direction and growth of healthcare technologies in different ways around the world.

Among the most dramatic developments are advances in our understanding of the human genome and dramatic decreases in the cost of genome sequencing, that will allow for intervention in human bodies at the most foundational level. These technologies are likely to raise ethical questions. For example, should these innovations serve to maintain human health or broaden the natural abilities of humans? What are the risks of gene editing being used with malicious intent? Different cultures around the world have very different ethics. Whose cultural norms, value systems and ethics will guide the limits in using these powerful technologies? Development of innovation models are needed to set self-imposed technological limits that satisfy ethical and moral codes.

Other challenges identified include: making effective use of data collected by new healthcare technologies such as wearables and implantables, human-centered design of medical technologies, and regulatory hurdles that could present barriers to healthcare innovation.

Top left: *Dr. Jon Mogford, Vice Chancellor for Research, The Texas A&M University System.*

Top center: *Next Generation Innovator: Mr. Austin Rogers, presenting on Robotic Assessments of Energy.*

Top right: *Next Generation Innovator: Mr. Gustavo Tapia, presenting on Additive Manufacturing: The Path from Tailored Geometry to Tailored Functionality*

Bottom: *Mr. Alex Reed, CEO, Advanced Polymer Monitoring Technologies; Dr. Mark Johnson, former Director, Advanced Manufacturing Office, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy; Mr. Rustom Mody, Vice President–Technical Excellence–Enterprise Technology, Baker Hughes–A GE Company; and Dr. Lloyd F. Colegrove, Data Services Director, Fundamental Problem Solving Director, Analytical Technology Center, The Dow Chemical Company.*

EIFI Midwest Regional Dialogue

Establishing Regional Innovation Ecosystems: Building Startup Magnets

St. Louis, Missouri
June 6, 2017

SPEAKERS

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Cultivating Entrepreneurship

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Barriers to Business Building

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Regions as Magnets for Talent

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Next Generation Innovator
Dana Watt
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The Midwest Regional Dialogue held at the Cortex Innovation District in St. Louis, Missouri brought together more than 40 leaders from academia, industry and government, representing the stakeholders in the St. Louis region's ecosystem for entrepreneurs.

Discussions focused on four major themes: cultivating entrepreneurs; barriers to start-ups and their growth; developing thriving local, state and regional ecosystems that support innovation and entrepreneurship; and attracting talent to a region. St. Louis was an ideal location to explore these themes, as the region and Washington University in St. Louis have established a robust ecosystem in which entrepreneurs and new businesses have flourished.

Cultivating Entrepreneurship

Panelists debated the characteristics of successful entrepreneurs, but concluded that the environment for entrepreneurship was the greatest determining factor for success. They discussed how industry, academia and the public sector could create a regional environment that engenders an entrepreneurial spirit and helps entrepreneurs feel confident enough to take a risk and invest in new projects. Key elements of that environment include accessibility to resources for entrepreneurs, particularly those from underserved communities; supportive institutions that can help guide entrepreneurs toward market opportunities; and the ability of entrepreneurs to understand and dynamically respond to the needs of their customers.

Barriers to Business Building

While panelists pointed out that each new business faces unique challenges within their industry, they identified common barriers to the start-up and growth of new businesses. These include: the risk and challenge of starting a new venture, identifying proper metrics of success for the business, and having the right talent and different skill-sets needed as the business is established, matures and grows.

Enabling Entrepreneurial Ecosystems

Panelists recognized that an entrepreneurial ecosystem has many constituent elements, and a range of stakeholders with different roles to play. However, the relationships developed among these stakeholders is the pivotal factor in the ecosystem overall, and it takes time and patience for these relationships to mature. Having an honest broker can help build these relationships by matching interests, needs and capabilities. Strengthening relationships and building partnerships requires few resources to implement and are efforts easy to replicate elsewhere.

Regions as Magnets for Talent

Panelists focused on a region's ability to entice and encourage individuals to enhance industrial and economic growth. While any region faces unique challenges in attracting and managing talent, communities can work to develop qualities that distinguish themselves and offer compelling reasons for individuals and organizations to relocate. Regions need to clearly communicate the available resources in the region that would benefit talent, such as personal and professional opportunities. Also important is helping identify appropriate employment and education opportunities for family members to help new residents integrate into the region.

Key Findings from the EIFI Dialogue Series

Advances in knowledge, technology and innovation have become the principal drivers of U.S. economic growth, productivity and wealth creation. Given their fundamental role in the U.S. economy, the United States needs to grow and strengthen its capacity for innovation, make more optimal use of its innovation assets, and draw more communities and people into the innovation ecosystem.

There are many points of leverage, as well as challenges in enhancing the U.S. capacity for innovation:

- The United States has the world's greatest collection of innovation assets, residing within every level of the economy—world-leading research universities; a unique system of national laboratories; an agile private sector, globally competitive in commercializing new technology; a thriving start-up culture; regional innovation ecosystems that seek to harness innovation assets to stimulate economic development and job creation; and a world-class cadre of scientists, engineers, technologists and entrepreneurs. In addition, the United States accounts for over one quarter of global R&D investment.[1] However, these assets could be better leveraged and used more optimally to stimulate U.S. economic growth and job creation.
- The emergence and convergence of revolutionary enabling technologies are driving rapid change that is expected to accelerate. New technologies are disrupting the economy and creating turbulence in the workforce. Yet, too many Americans do not have the education and skills needed to thrive in the rapidly changing technological and economic environment, or to assume high-skill jobs in a knowledge-based innovation economy. The world is changing faster than many institutions and models of innovation can accommodate.
- The United States has untapped innovative potential in a population with high interest in invention, entrepreneurship and business start-ups. This is, partially, reflected in the popular use of crowd-sourced innovation platforms, maker spaces and participation in citizen science. But we have not fully leveraged this potential.

These tremendous assets—R&D, laboratory facilities, the talent and skill of scientists, engineers, entrepreneurs and businesses, and others—are knit together in an innovation ecosystem. In the broadest sense, innovation ecosystems are a complex marriage of economic, social, political, organizational and institutional factors that influence the development, diffusion and use of new knowledge (e.g., technologies, business models, social models, products, services, etc.) and are represented by a broad network organizations (firms, universities, venture capital organizations, public agencies, etc.).

1 U.S. National Science Board.

Dr. Ileana Arias, Principal Deputy Director, CDC/ATSDR Center for Disease Control and Prevention; Dr. Paul Hommert, former Director, Sandia National Laboratory; and former President, Sandia Corporation; Dr. Mark Little, Former Senior Vice President, Director of GE Global Research, Chief Technology Officer, GE–Global Research Center; Mr. Rod Makoske, Senior Vice President of Corporate Engineering, Technology, and Operations, Lockheed Martin; and Dr. Pramod Khargonekar, Vice Chancellor for Research and Distinguished Professor of Electrical Engineering and Computer Science, University of California, Irvine; and former Assistant Director, Directorate for Engineering, National Science Foundation.

"While partnerships with universities are a great strength to Sandia and the nation, they are not allowing us to sufficiently tap the depth and focus it in a way that leverages our resources more effectively."

Dr. Paul Hommert
Former Director, Sandia National Laboratory; and former President, Sandia Corporation

The interactions between organizations are regulated by a set of common habits, norms, routines, established practices, rules or laws. Together with organizations, these are the "components" of an innovation system—which must be animated by individuals through, for example, performing R&D, building new competencies, forming new markets, founding new companies, creating and changing organizations, etc.

This dynamic process of conceiving, commercializing and deploying innovations ever more efficiently is the engine and most important source of economic growth. When this engine works, there is endless transformation.

Technology, Innovation and American Society

Perhaps more than any country on Earth or in history, the United States has been the greatest driver and beneficiary of technology and innovation. In the 19th century, entrepreneurs and innovations surrounding agriculture, rail, oil, steel and electricity turned the United States into an industrial and economic powerhouse, laying the foundation for a manufacturing sector that provided middle class jobs and a higher standard of living for millions of Americans. American inventions and advancements in vehicle and aircraft technology revolutionized transportation, and changed society and the geographic face of the country. American-born digital technologies unleashed a revolutionary new age of computing, communications and information mobility, disrupting industries and business models, changing society and culture around the world, and creating enormous new wealth.

Despite this history, technological innovation does not have standing in American society commensurate with its importance to national prosperity.

Americans' Views of Technology

Today, there is growing concern that the gains from innovation are not equitably distributed across Americans. In recent years, the perception that innovation has become more destructive than disruptive is driving an anti-technology sentiment in the country. Many pundits, politicians, prominent science, technology and innovation thought leaders, and a considerable portion of the general public believe that accelerating technological disruption is responsible at least, in part, for the nation's economic malaise and hollowing out of the middle class. Since the dot-com bubble burst, many remain wary of Silicon Valley-style economic development, and innovation such as the "app economy" is not viewed as a jobs engine.

"In a way, we have gone backwards at a time when technology is ever more pervasive in our lives."

Dr. G. Wayne Clough
President Emeritus
Georgia Institute of Technology

Large parts of our population—including many urban youth, rural Americans and communities without research institutions—do not see themselves as part or beneficiaries of the innovation ecosystem. Yet, there are many talented and resourceful problem solvers—young urbanites, rural farmers, makers and tinkerers, etc.—who are not viewed by others, and who do not view themselves, as part of an innovation or entrepreneurial ecosystem.

The lack of scientific literacy contributes to the problem. The complexity and specialization of science and technology are growing, and, as a result, scientists and innovators have a hard time explaining their work and its importance to the general public. The complexity and specialization of science and technology also leads to work that remains out of reach to many Americans. Similarly, while invention, innovation and entrepreneurship are distinct activities, they are parts of the broader process that translates an idea into prosperity. **Yet, the science, technology and innovation community often focuses, instead, on lab-to-market initiatives or technology readiness levels, stopping short of advocating for the positive social and economic impacts of innovation, its power to solve the world's most daunting problems, and broadening the definition of success.**

"I think first and foremost we have to expand our idea of what innovation means and make sure that we are thinking about who does it because often we think it only happens in research institutions."

Kwanza Hall
Council Member-District 2
Atlanta City Council

A negative narrative about technology could undermine national investments in science, technology and innovation. This may foster dangerous perceptions, causing political leaders to feel they have lost the public mandate to invest in science, technology and innovation or, worse, see these as the problem and not the solution to a flagging U.S. economy.

Technology-Driven Turbulence and the Reorganizing Economy

Revving up the U.S. innovation engine does not directly or necessarily translate into American prosperity. Innovation needs to be diffused and scaled. This is a dynamic process undertaken by businesses and people, inherently disruptive, both destroying and creating businesses, markets and jobs. This reorganization of the economy is essential for leveraging new technology to generate the greatest benefits in terms of jobs, economic growth and opportunity, productivity and wealth, and lies at the core of American economic and national security.

A prime example is transportation, which will see significant change in the years ahead. The Wright Brothers made their first powered flight just over 100 years ago in 1903. Less than 60 years later, man first entered space and, within 10 years of that moment, man walked on the moon. Technological innovation in this space has not slowed.

The convergence of autonomy, connected technology, new lighter weight materials, new vehicle powertrains, big data and faster processing speeds, all coming in at lower cost, means the world is on the verge of a revolution in transportation. This revolution will have disruptive effects on infrastructure, and across numerous manufacturing and service industries such as auto manufacturing and repair, parking garages, the taxi industry, goods delivery, the fast food industry, mass transportation systems, road and highway construction, traffic management and urban planning to name a few.

Similarly, we are on the cusp of a wave of engineered heathcare technologies that will likely disrupt heathcare and the heathcare market place. For example, point-of-care technologies have changed dramatically over time. Medicine started as doctors going to the patient. Then hospitals were developed and the patients came to the doctors. Now we are trending back toward returning to the patient, through technology such as wearables and retail genetics. There is a rapidly growing market segment that tracks biometric markers.

Furthermore, the impacts of these technologies will go beyond the individual patient. When testing for illnesses at home before symptoms appear, the moment of exposure is unknown. If exposure is day zero and symptoms appear on day five, by day three these tests can identify illnesses with a predictive value of 90 percent. Similarly, future technological advancements in electroceuticals (using the neurological system as a distributed communication system) may transform the world of physical therapy rehabilitation or for paraplegics who desire to live alone. Technology to identify illnesses before expressing any symptoms is expected to mature in four to five years. From a healthcare perspective, these advances are incredibly valuable. For example, the ability to run such a test from home reduces the "worried well" who now do not need to travel to the doctor's office, freeing healthcare provider resources and limiting exposure to other pathogens.

One of the ways the economy reorganizes around new technology is through the birth and death of firms, and the expansion, contraction, start-up or closing of their establishments (Figure 1). The process of finding creative ways to combine new technologies and processes, and make novel products and services leads to the start-up of businesses, and the decline of less productive businesses or those whose business lines are made obsolete. This churning of firms—driven by technology, and economic, competitive and market factors—helps revitalize the economy, reallocating resources from less profitable businesses to more profitable and competitive ones. The ability to start a business relatively quickly and easily is one of the hallmarks of the U.S. economic system, and a significant underlying factor for new companies to enter a primed market contributing to the success of startups in America.

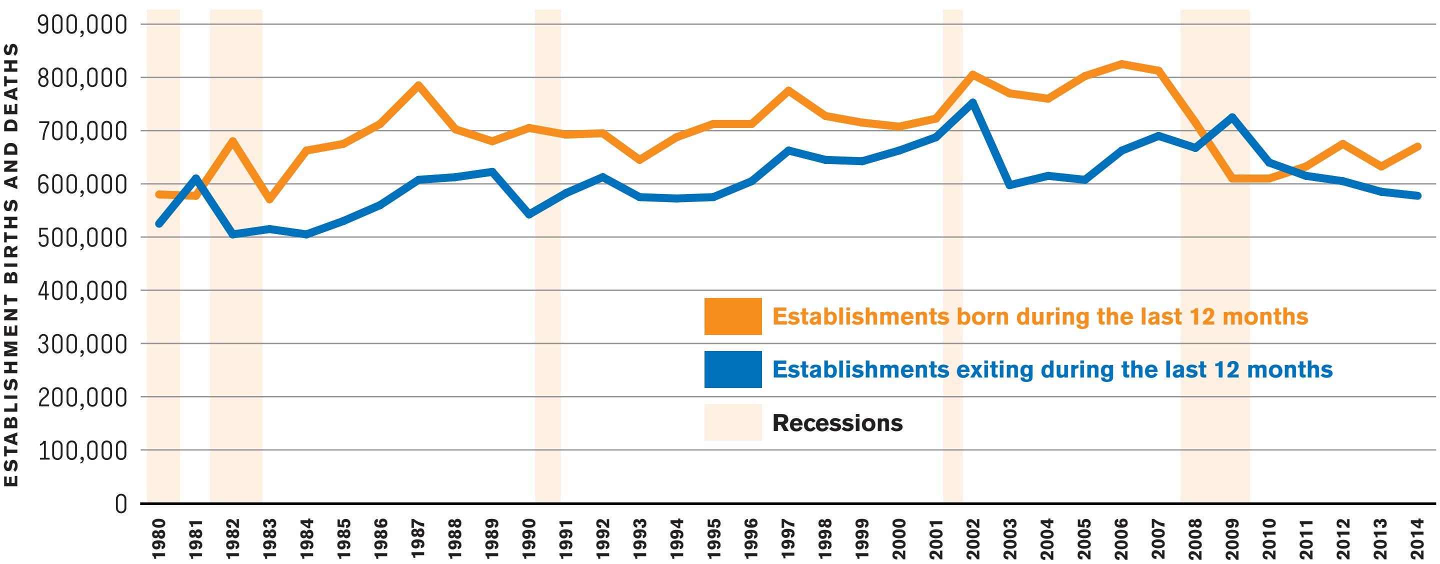
This churn of businesses in the economy can create both opportunities and hardships for workers. Net job gain or net loss numbers mask the much larger gross job flows or churning of jobs in the economy.

> "There is going to be disruptions in terms of jobs and in terms of the economy, but ultimately the broader picture is that they enable prosperity in a grander sense."
>
> **Dr. Keoki Jackson**
> Vice President and Chief Technology Officer
> Lockheed Martin

For example, in the year between March 2015 and March 2016, 10.6 million jobs were lost due to contracting and closing establishments, but 13.1 million jobs were gained from expanding and opening establishments, resulting in a net job gain of nearly 2.5 million jobs,[2] representing a churning of about 20 percent of private sector employment.[3]

Figure 1. Birth and Death Rate of Organizations in the United States

Source: Business Dynamic Statistics, U.S. Bureau of the Census



2 Private sector gross job gains and job losses, annual March to March, Annual Business Employment Dynamics Data, Bureau of Labor Statistics.

3 Private sector gross job gains and gross job losses, as a percent of employment, annual March to March, Annual Business Employment Dynamics Data, Bureau of Labor Statistics.

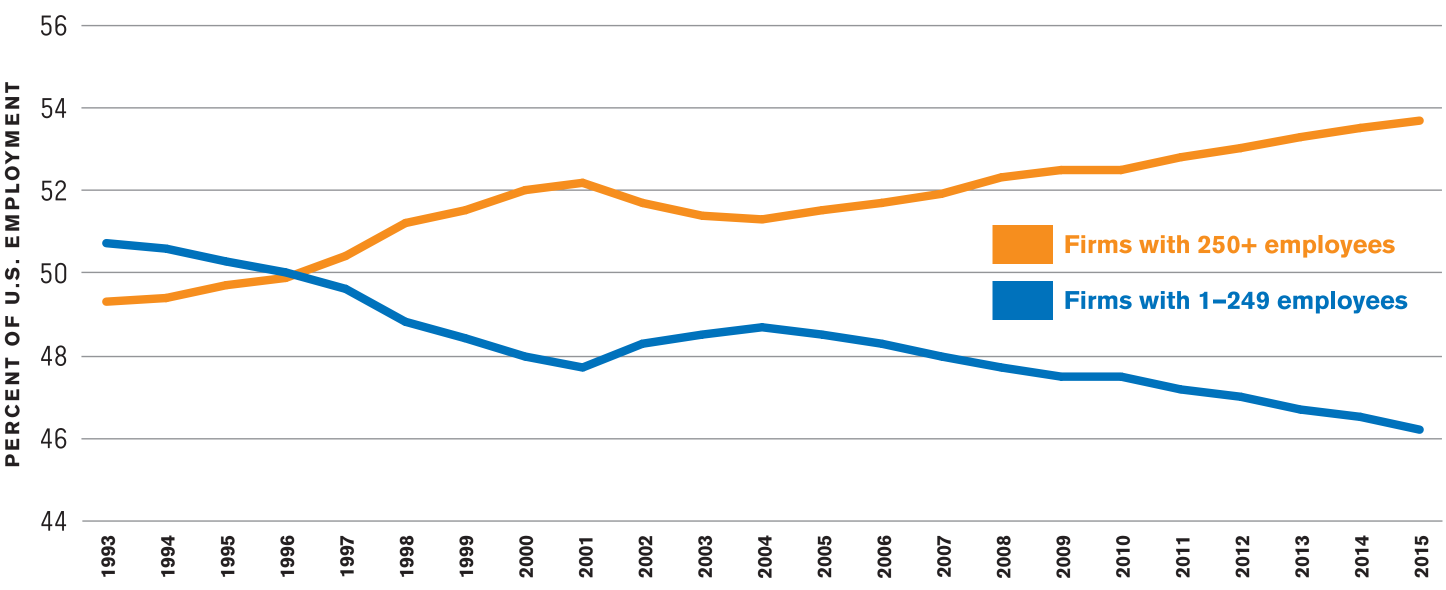
However, labor market fluidity has declined in the U.S. economy. Worker reallocation and churn rates have declined since 2000, and the job reallocation and employment share of young firms have declined significantly in high-tech industries,[4] and in private sector employment overall. The distribution of the workforce across small and large firms are changing as well (Figure 2). Small businesses are typically the entry point for entrepreneurs as they develop ideas and build a customer base before expanding. This trend raises concerns about the dynamic process of innovation-driven creative-destruction in the United States, given its key role in productivity growth.

But, the disruption left in the wake of major technological change and reorganization in the economy has effects at many other levels of the economy that can affect the workforce. As so dramatically illustrated by the digital revolution, disruptive technologies can drive a reordering of production at every level of the economy—from the workplace to the labor market to the mix of industries in a community or country—creating new opportunities but also hardships for some workers. The process of reorganization may create new jobs while eliminating others, create new occupations, or change the occupational mix, tasks to be performed and the skills in demand. Many workers struggle to get new skills and find new jobs, and some communities struggle with difficult changes in their economic fortunes in a rapidly transforming economy.

There are numerous areas of policy that affect or are affected by technology-driven reorganization of the economy, including regulation, infrastructure, safety and environmental issues, standards, ease of new business formation, etc. For example, technologies for autonomous transportation systems are advancing rapidly. But, the rate of advancement is outpacing the ability of regulators to react to these new technology developments, and the regulatory response has not yet enabled an environment for automation in transportation to thrive, creating a widening gap between the promise of technology and its realistic applications. This is forcing technology leaders to challenge laws that currently cannot accommodate innovations and that constrain their pathway to the marketplace. Such regulatory uncertainty can create a climate that discourages investment, new business formation and technology adoption.

Figure 2. Percent Distribution of Employment by Firm Size

Source: Business Employment Dynamics, Bureau of Labor Statistics



4 Davis, S., and Haltiwanger, J., Labor Market Fluidity and Economic Performance, NBER Working paper Series, National Bureau of Economic Research, September 2014.

In another example of the interaction of innovation and regulation, in the heathcare wearables market, the United States has strict regulations in place regarding the electronic exchange, privacy and security of health information.

Potentially, the greatest inhibiter of adoption of new technology is the innovation model, institutions and organizational systems currently in place. The systemic nature of this barrier is not about technology per se, but rather organizational design, systems and talent. Institutions, public and private alike, often rely on an entrenched and risk-averse operating structure. This limits their ability to embrace major change, which can limit the adoption of new technology and slow regulatory response to a rapidly changing technology landscape. For example, automation in the movement of goods and people up-ends basic assumptions about transportation infrastructure such as the extent of human input.

Organizations and the public are cautious in their adoption of new technology because of how they have learned to tolerate risk. The public is more tolerant of automation where they have not been in direct control, such as air travel, while tolerance for risk in uncommon activities, such as spaceflight, remains low.

Distribution of Gains from Technology and Innovation

Innovation's impact on individuals can be different based on level of income or educational attainment. For example, the prosperity unleashed by recent digital innovations is disproportionately benefitting the highest skilled workers and owners of capital rather than being widely distributed across the population. Automation has eliminated many middle-skill jobs that underpinned 20th century middle-class life. The manufacturing sector is an illustrative example. During the 20th century, manufacturing was a source of well-paying low- and middle-skill jobs underpinning a middle-class lifestyle for millions of Americans.

But millions of jobs in manufacturing have been lost since 2000,[5] many of them to productivity-enhancing technologies. And many of the jobs that remain in manufacturing require greater education and skills (Figure 3).

The price of automation has fallen significantly in the past few decades, both in absolute terms and relative to the cost of labor.[6] As the cost of labor rises, and the cost of automation declines, it becomes more attractive to automate work and eliminate some jobs. For example, labor inputs to multifactor productivity in manufacturing have been dropping, while purchased business services and capital investments have been on the rise. The manufacturing sector is reorganizing production—becoming less labor intensive and more capital intensive—shedding jobs along the way.[7] Automation has eliminated many routine assembly jobs; fewer than 39 percent of the workers in U.S. manufacturing establishments are now directly engaged in production.[8]

Some studies suggest that many more jobs could be threatened by automation in the years ahead. For example, a recent analysis used U.S. Department of Labor data to identify jobs that either are or are not susceptible to automation. The analysis estimated that 47 percent of U.S. employment is at risk of being automated in the next 10-20 years.[9]

For many Americans, accelerating technological innovation has not translated into more and better opportunities. On the contrary, it is contributing to several difficult trends facing our nation including income inequality, polarization of the labor market and bifurcation of the workforce, and social distrust. These trends, directly or indirectly, threaten our ability

5 Employment, Hours, and Earnings in Manufacturing, Current Employment Survey, Bureau of Labor Statistics.

6 Job Polarization Leaves Middle-Skilled Workers Out in the Cold, Maria E. Canon and Elise Marifian, The Regional Economist, Federal Reserve Bank of St. Louis, January 2013.

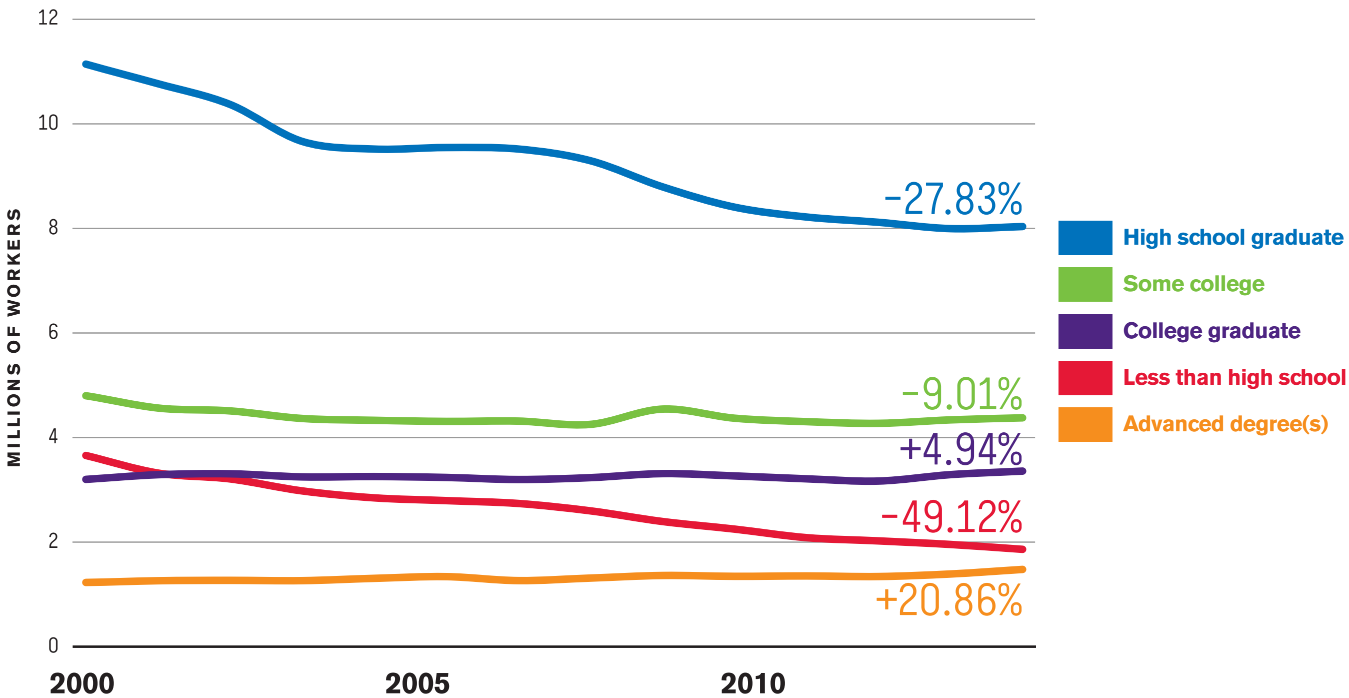
7 The Compensation-Productivity Gap: A Visual Essay, Monthly Labor Review, January 2011.

8 U.S. Manufacturing in International Perspective, Congressional Research Service, March 17, 2015.

9 The Future of Employment: How Susceptible Are Jobs to Computerisation, by Carl Benedikt Frey and Michael A. Osborne, University of Oxford, September 17, 2013.

Figure 3. Manufacturing Jobs by Educational Achievement

Source: Steven Ruggles, J. Trent Alexander, Katie Genadek, Ronald Goeken, Matthew B. Schroeder, and Matthew Sobek. Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]. Minneapolis: University of Minnesota, 2010.



to innovate. Taken together, these structural challenges tarnish the public's opinion of innovation in a way that could reduce the mandate to policymakers to invest in science, technology and innovation.

Adapting to Rapid Technological Change with Education and Entrepreneurship

The best way to boost public opinion of science, technology and innovation is to ensure all Americans benefit from the changing economy. And, the path to more equitable distribution of innovation's benefits is through education, training and entrepreneurship, enabling individuals to engage with, adapt to and benefit from new innovations.

However, education is suffering its own inequality in the ability of many students and other Americans to find quality education at an affordable cost. For example, the value of Pell Grants relative to the cost of education has fallen dramatically, creating distance in educational opportunities between those reliant on grants and loans to fund their education compared to those without similar restrictions.

Moreover, the world is changing faster than education infrastructure can adapt, making it difficult to supply students with the skills they need to start a career or build their own company. For example, a Ph.D. student on the verge of completing his or her degree faces technology that has changed so quickly during his or her ten years time in academia that entirely new courses of study may have been built around concepts that did not exist when he or she began. Moreover, students have been trained through their education to apply for work as a professional, but are rarely prepared for the tasks the job entails. Often, on-the-job-training is required for students to transform into productive members of the organization.

Outside the traditional model of education, the digital revolution can democratize access to education. For example, Massive Open Online Courses (MOOCs) are an option to drive down the cost of teaching and for reaching a great number of students for relatively low cost. While MOOCs can make education more widely available, they are hampered by their inability to interactively engage students, and students who have not yet learned how to learn are not best served. Self-driven learning from platforms like MOOCs has the greatest success with people who already have college degrees. Also, the kinds of skills needed for the contemporary economy—critical thinking, communication and listening—are not necessarily those conveyed best in MOOCs, which are especially good at transmitting information. Other alternative methods of education may be more robust, but are significantly more costly, limiting their adoption to institutions with more resources. In contrast, less expensive alternatives, such as MOOCs, are often adopted at education institutions, such as state universities and community colleges, where students often need more support.

Apprenticeships are an appropriate alternative method of education which would teach the skills required by employers, as would spaces open to anyone to explore their interests, such as MakerSpaces, which create opportunities for individuals to experience the newest technology hands-on as it becomes available and to learn from others.

Finally, entrepreneurship is the critical "last mile" on the path from idea to prosperity. An infrastructure that nurtures entrepreneurs is critical to developing an innovation ecosystem that more often translates to broad-based national prosperity.

Emerging Technology's Global Societal and Ethical Challenges

Beyond their potential for economic and industrial disruption, several emerging technologies—engineered healthcare innovations, CRISPR/gene-editing, big data/data analytics, autonomous systems and artificial intelligence—are presenting new ethical issues and questions about the limits of applying these technologies.

For example, the cost required to sequence a genome has fallen dramatically, opening up new possibilities to enhance human capabilities, treat disease and extend longevity, as well as boost agriculture and food production. Access to these technologies may, initially, be available only to those who can pay for new procedures, and may create divisive political debates over access and intellectual property rights in the face of life-and-death medical issues.[10] The rapid democratization of gene editing tools, and commodification of biotech knowledge and skills raise the risk of biotechnology use for malicious purposes and bio-labs operating outside the traditional scientific community. Even if not malicious, gene editing carries the risk of permanently changing the human genome, or gaining new levels of physical advantages over others. As engineered healthcare innovations advance, further ethical and moral questions are raised: should they serve to maintain human health or broaden the natural abilities of humans?

> "Some are saying in the next five years we'll see more change than we've seen in the last 50, [while others] say in the next 10 years we'll see more change than we have in the last 100."
>
> **Reuben Sarkar**
> Former Deputy Assistant Secretary for Transportation
> Office of Energy Efficiency and Renewable Energy
> U.S. Department of Energy

The use of digital technologies across every aspect of the physical and virtual world is creating new security vulnerabilities, for example, in physical infrastructure. The deployment of "smart technologies" is changing how people interact with machines and the world around them. Widespread collection of personal data and "digital exhaust" generated from the use of digital tools and media, and the use of data analytics, automated systems and algorithms for decision-making and authentication raise new questions about cyber security, data privacy and protec-

10 Global Trends 2035, Paradox of Progress, National Intelligence Council, 2017.

How Technology Can Affect Jobs and Workers

Task/Job Level	
Change skills needed on the job	• Machinists who once worked with manual lathes and drills need new skills to operate CNC machine tools. • More electric/hybrid vehicles on the road means automotive service technicians/mechanics must be able to work on high-voltage electrical systems, lithium-ion batteries, and electric generators.
Change way work is organized	• 20th century workplace characterized by hierarchy and work "place;" today, workplace characterized by networks; networks and mobile computing decoupling work from place; some workers have greater autonomy. • Customer on-line travel and ticket booking reducing demand for reservation and ticket agents. • Use of digitized self-service checkout lanes in groceries mean fewer hand packers and packagers needed to bag groceries.
Change tasks performed	• Instead of manual typesetting, printers use digital publishing/desk top printing. • Manual tasks in production have been reduced by automation; workers have become monitors of automated production lines. • Scientists using more computational tools in research, substituting human effort with computational techniques such as data analytics, and simulation and modeling.
Organizational Level	
Make workers more productive, so fewer workers are needed or jobs eliminated	• Fallers (who cut down trees) are more productive using complex machines instead of hand tools; logging companies expected to need fewer of these workers. • Demand for insurance underwriters expected to fall; underwriting software helps workers process insurance applications quickly.
Change mix of human capital and skills needed in the organization	• Industrial robots reduce need or eliminate jobs for assembly workers, but increase need for programmers and robot maintainers. • Use of electronic filing/data bases reduces need for file clerks, but increases need for data base administrators.

How Technology Can Affect Jobs and Workers

Industry Level	
Drive expansion in an existing industry's employment	• Fracking and horizontal drilling technology significantly raising oil and natural gas production, increasing employment in U.S. oil and gas industry by more than 40% over 2007-2015.
Create new industries with growing employment; drive declines and employment losses in other industries	• Personal computer drove employment growth in computer systems design and software publishing, but reduced/eliminated employment in computer mainframe industry. • Increased use of Internet, e-readers, and tablets expected to cause job losses in newspaper, periodical, book publishing industry. • Expanded use of e-mail, on-line bill pay, automatic mail sorting forecast to contribute to declines in Postal Service employment.
Occupational Level	
Create new or eliminate existing occupations	• Personal computing eliminated jobs for computer operators and data-entry keyers; new occupations established such as network administrator and help desk personnel. • Low cost gene sequencing creating genetic counselor occupation.
Labor Market Level	
Change what skills/occupations in demand	• Personal computing, networking, Internet expansion drove major growth in demand for IT professionals such as software engineers, computer systems analysts, and network administrators.
Change supply of skills/ occupations in the labor market	• Rapid employment growth and high demand for IT workers raised wages, motivating students to study computer science in college, and others to participate in wide range of IT training increasing skills availability in the market place.
Change labor market value of skills	• IT workers with "hot" or the latest skills are in high demand and command wage premium in the labor market

tion, data ownership and cross-border data flows. Social media has been used to spread propaganda and misinformation, organize disruptive events and as a vehicle for harassment. There are also concerns about cyber security and vulnerabilities in autonomous systems, and ensuring that on-board data and sensors are not compromised.

In another example, autonomous vehicles are advancing rapidly. There is a significant body of knowledge about what humans do in vehicles. However, there is relatively little knowledge and data about what robots and autonomous vehicles will do on the road. Moreover, as technology enables greater autonomy in transportation, the role of the individual during transportation will change. The rate of accidents caused by human operators is expected to drop as the share of autonomous transportation grows. However, the greatest concern is the period in-between, as autonomous modes of transport are mixed with human operators; humans will act differently knowing there is a computer driving the car, which could create dangerous situations for both those in the vehicle and pedestrians.

The fast pace of development is likely to challenge governments and the scientific community in efforts to develop regulatory regimes and norms for responsible use of these powerful technologies. Ethical principles vary across countries, regions, cities and individuals, shaped by experiences and identity. Countries hold different entities responsible to different levels. For example, U.S. public institutions are set to one standard while private companies have greater freedom, and there is a very different expectation in Europe, such as in Germany which is particularly sensitive after experiences during World War II.

These differences in ethics create challenges for researchers, as collaborative R&D is increasingly unbounded by geography. For example, globally, the percentage of publications with authors from different countries rose from 13.2 percent to 19.2 percent between 2000 and 2013. In biological sciences, international co-authorship is above 20 percent. Almost one-third of U.S. science and engineering articles are internationally coauthored and, most frequently, with authors from the second-largest producer of science and engineering publications, China, the country of co-authorship for 18.7 percent of U.S. internationally coauthored publications in 2013. In biological sciences, about 40 percent of U.S. science and engineering articles involve international co-authorship.[11]

It is important to solidify self-imposed technological limitations now that satisfy our ethical and moral codes. However, creating a common ethical boundary is challenging. Whose cultural norms, value systems and ethics will guide the limits in using these powerful technologies? Moreover, few organizations have the range of expertise needed to deal with their societal effects. To maintain competitiveness as a pioneer and global leader in this realm of game changing technologies, the United States should lead efforts to set the standards for appropriate uses.

Cooperation, and the pooling of knowledge and expertise will be required to anticipate and address the challenges ahead, and the need to balance risk and progress. As these technologies evolve, stronger participation from social sciences and ethicists globally will help ensure that the value created is not limited to those with the lowest common moral denominator.

Assuming technology is ethically acceptable it must show a significant benefit and be unobtrusive to the user to gain broad acceptance. Using engineered healthcare as a sample case, any new technology must be easy and simple to use, not impede the user or patient's normal activities, protect any information collected. Failing any one of those increases the likelihood of a technology not being permanently adopted and ultimately discarded, limiting the effectiveness and market potential of the technology. Appropriately capturing and disseminating information, and making effective use of the data collected are essential, and getting design right early is critical to getting innovations to the patient. The regula-

11 Science and Engineering Indicators 2016, National Science Foundation.

tory hurdles are such that industry and researchers cannot afford to continually invest their time and resources without bringing a product to market. This requires that designers ask current and potential patients what they are willing to wear and what information they are comfortable with being collected as part of this participatory design. Participatory design and community design, and with the involvement of social scientists, can also incorporate ethical concerns into the development process and build innovations that are more likely to succeed in the marketplace.

Mr. Chad Evans, Executive Vice President, Council on Competitiveness; Dr. Mark Wrighton, Chancellor and Professor of Chemistry, Washington University in St. Louis; The Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness; Dr. Holden Thorp, Provost and Executive Vice Chancellor for Academic Affairs; Rita Levi-Montalcini, Distinguished University Professor, Washington University in St. Louis; The Honorable France Córdova, Director, National Science Foundation; Dr. Dedric Carter, Vice Chancellor for Operations and Technology Transfer, Washington University in St. Louis; and Mr. Brian Stone, Chief of Staff to the Director, National Science Foundation.

Recommendations

Elevate technological innovation's standing on the national agenda and in the U.S. social consciousness commensurate with its importance to national prosperity. This includes its priority in policy and national investment.

- Create a better understanding among the American population of the linkage between technology and innovation, and national prosperity, productivity and job creation, as well as the societal benefits of innovation and entrepreneurship.
- U.S. policy makers should pay greater attention to meeting the challenges of an economy ever reorganizing around new technology and how Americans can keep pace. This includes policies that ease Americans' ability to adapt to and recover from the turbulence of technological change and a reorganizing economy. It also includes a focus on easing the process of economic reorganization, for example, ensuring it is easy to start a new business and developing needed regulations in a timeframe matching the accelerating rate of emerging technologies.
- Develop a data set that provides insight on a reorganizing economy, such as introduction of new process innovations, number of firms active and employment growth in new technology sectors, growth of industry clusters, establishment births and deaths and related employment change, etc.
- Boost federal support for research and development, including targeting federal investments in high-risk, high-payoff opportunities (e.g., DARPA) across federal agencies.
- Create a non-governmental mechanism for the Nation to make strategic investments in critical industries, sectors and technologies.
- More quickly identify and more fully understand the economic and societal implications of game-changing emerging technologies.
- Adopt a multi-disciplinary approach to examining the implications and challenges of emerging technologies, and in developing policies needed to meet those challenges.

New Models and Systems of Innovation

Since the early 2000s, new models of innovation have emerged and others have matured in response to the transformation of the global competitive landscape that began in the 1980s. These models of innovation have expanded the scope of participants in the innovation ecosystem, and ways in which companies, innovators and entrepreneurs pursue innovation.

Competition in the 21st century, technology convergence and the nature of global challenges require models of innovation built on internal resources, external collaboration, and a larger, more diverse innovation skill set.

New Models and Major Changes Disrupting Systems of Innovation
Many businesses have shifted their R&D away from exploratory research toward nearer-term research that supports business units. Today, technology breakthroughs are just as likely to come from universities, national laboratories and small start-ups, causing businesses to look externally as well as internally for sources of invention and innovation.
Regional, state and local communities increasingly see innovation as a major source of economic growth and job creation, and expect institutions of higher education to contribute to economic growth. These communities are investing in technology and innovation initiatives (proof-of-concept centers, technology demonstration centers, innovation hubs, academic-industry partnerships, etc.) as major elements of their economic development strategies.
The democratization of innovation through self-organization (maker spaces, desk-top manufacturing, DIY biotech), crowd funding, citizen science and open source digital platforms—including platforms that connect problem-solvers with solution seekers—have expanded the universe of innovators.
Innovation is de-linking from institutions. It is now possible for someone to imagine, develop and scale a disruptive technology independent of traditional institutions of innovation.
Big data, data analytics, modeling and simulation are providing powerful new tools for the researcher and innovator, allowing a scale of research, discovery and experimentation impossible in the laboratory. These tools are also increasingly used to explore and select innovation pathways with the highest likelihood of success, while avoiding unsuccessful and expensive trials that do not bear fruit.

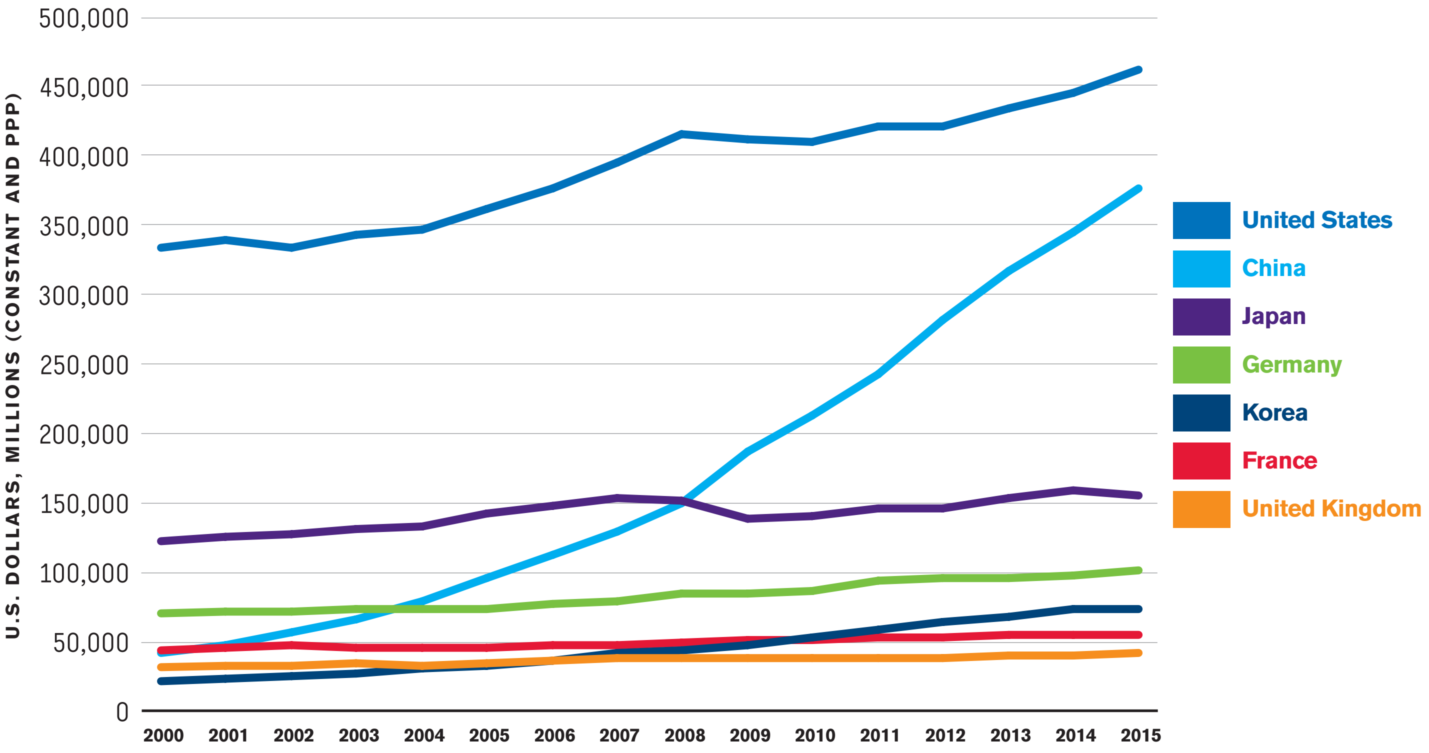
As companies have moved away from exploratory research toward nearer-term applied research and technology development that supports business units, foundational technology breakthroughs increasingly come from universities, national laboratories and small start-up companies that are disproportionately supported by public R&D investments. While the public role in the innovation ecosystem has increased in importance, public investment has not kept pace.

The United States remains the world's largest spender on research and development (Figure 4)—but the rate of China's research and development

"I really hope the federal government will continue to sponsor basic research, because nobody else will. Foreign governments will, and it is a really core competitive issue for the United States."

Dr. Mark Little
Former Senior Vice President
Director of GE Global Research
Chief Technology Officer
GE—Global Research Center

Figure 4. Total Spend on R&D Among Select Countries
Source: OECD Main Science and Technology Indicators



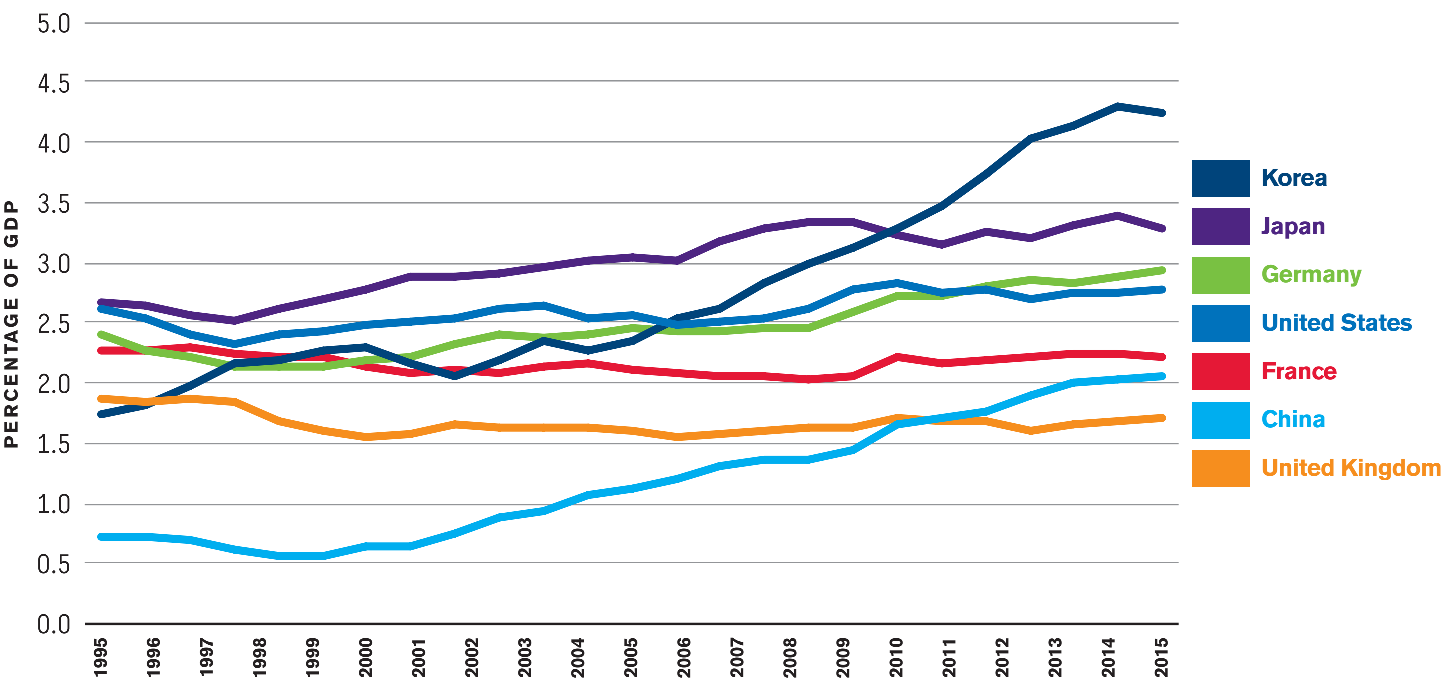
investment growth has the nation potentially on track to overtake the total U.S. annual investment before the end of this decade.

And, the United States has been gradually slipping down the global ranks of research and development (R&D) as a percentage of GDP—a metric of national R&D "intensity." Among R&D spending countries, the United States held the 6th position in national R&D intensity in 2007, but the U.S. ranking slipped to 10th by 2015, and below several of our major competitors (Figure 5).

Contributing to this decline, Federal investment in R&D as a percentage of GDP has being falling for decades (Figure 6). The historically low levels of Federal investment in basic research are troubling, especially at a time when there is bipartisan agreement that an innovation-driven economy is critical to U.S. economic and national security.

Exploratory research does not need a clear end-state to ultimately be a valuable endeavor, as innovation comes from new and novel applications of knowledge. Basic research may not be well understood at the genesis of research projects, but the knowledge it generates may, over time, enable groundbreaking advancements as scientists and engineers employ this information in their work. And the value of that basic research may be enhanced as its usefulness grows in other fields, and may open new pathways to innovation there.

Figure 5. R&D as a Percentage of GDP Among Select Countries
Source: OECD Main Science and Technology Indicators

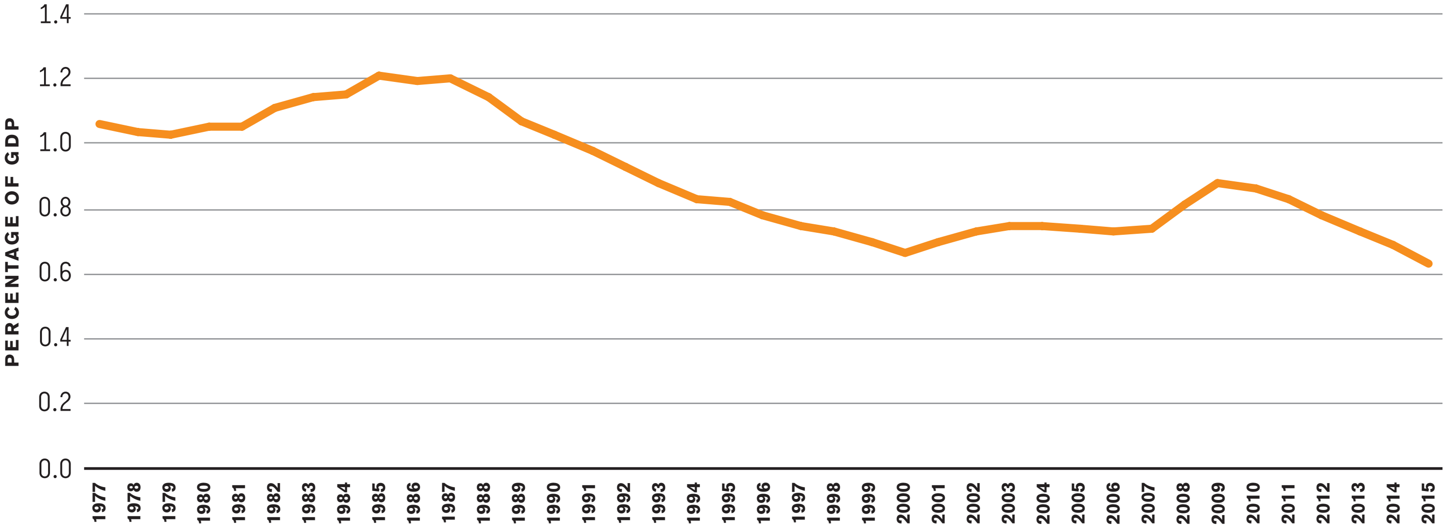


Innovation is an iterative process. It creates opportunities for further innovations, where creative uses of new technology drive further innovation in ways unintended or in unimagined directions. Similarly, investing in basic research to support innovation cannot be predictive, and often the full importance of such investments manifest long after the initial investment is made. For example, in the 1970s, the Department of Energy conducted research on diamonds to better understand their properties. The fossil energy industry had done studies suggesting that diamonds could be used to make better drills, and better drills would allow the drill to go down and turn a corner and, if a drill could turn a corner, it would unleash a whole new wealth of energy. The application of the Department of Energy's research on diamonds married with research from the fossil energy industry led to the development of diamond drill bits and was a game changer. Before diamond technology, drill bits would take 24-30 days to drill a horizontal well and bits would be switched out to match the density and hardness of material. Now the same process takes seven days, all using the same drill bit. This led to a dramatic productivity increase in the cultivation of energy resources.

Similarly, smartphones have revolutionized communications and information distribution. Bright, creative people leveraged years of basic research and government-funded programs in areas such as GPS and the Internet to make these smart phones functional. Work on mathematical modeling supported by the National Science Foundation in the early 1970s led to the technologies that now form the basis for 3D printing and additive manufacturing. The costs of these tools have dropped so dramatically that individuals can access these technologies for manufac-

Figure 6. United States R&D Investment as a Percentage of GDP

Source: National Patterns of R&D Resources, National Science Foundation



turing, cultivating a do-it-yourself mentality that has blossomed into the “Maker Movement” and greater entrepreneurship, further democratizing the process of innovation.

The unclear end-state for fundamental research can create obstacles to its funding, particularly in industry that seeks a clear and high-probability return on investment. The challenge in government is one of competing national priorities. While there is broad agreement among public and private leaders that innovation is critical to U.S. economic and national security, there are numerous priority issues for the business community, and representatives in Congress are balancing budgetary pressures from a myriad of other important national investments.

Strategic Partnerships

In today’s technology and competitive environment, and as companies shift their focus to nearer-term R&D, they increasingly seek technological innovations outside of the company and outside of their industry. There is often little incentive to invest in high-risk, high-reward research, driving firms to look outside the firm for breakthrough innovation.

Strategic partnerships are key models for accessing research and technology outside of the firm. These partnerships can take different forms—ranging from company-to-company or company-university arrangements to industrial consortia—and have different purposes, such as collaborative R&D, acquisition or sharing of intellectual property, access to advanced manufacturing capabilities, or equity investments to nurture and support small innovative start-ups developing technologies of interest.

Both large and small companies can gain from partnering with each other. For example, large companies can access unique thinking unconstrained by industry standards or norms, or entrenched ways of thinking and doing in their own organization. Additionally, they can help validate the technology of small companies and innovators, and provide an avenue for scaling as well as gain access to cutting edge innovations and outside-the-box solutions without the cost and risk of building R&D capabilities in-house. Seeking solutions from outside of the company holds the potential to identify a leapfrog rather than incremental solution. One large company participating in the EIFI dialogue reported that its outside portfolio of high-potential impact technologies and collaborations with customers, universities and entrepreneurs is richer than it has been at any point in the past, opening up an expanse of possibilities for future planning that was once unimaginable. The challenge is how do small, innovative firms with solutions connect and capture the attention of large firms, and then forge strategic partnerships that add value for both parties.

Changes in industry structure have led to challenges in sustaining innovation in the manufacturing sector, which may require strategic partnerships and innovation in business models. Over the past several decades, as companies moved away from vertically-integrated structures to networks of suppliers across a distributed value chain, single firms often cannot capture adequate returns on investments in developing enabling technologies and innovations, because returns may be distributed across a supply chain that is not part of or controlled by the company. Suppliers are focused on their own portion of the supply chain rather than taking a systematic approach to

"General Electric recently had a competition worldwide to try and redesign the relative components of their jet engines. That design came from an individual; it didn't come from an organization. It came from an individual that used the unique properties of 3D printing—additive manufacturing—to create a design that, if using subtractive manufacturing—or so-called traditional manufacturing schemes—would not have been possible. That network of capabilities is bringing new innovative thought contributions and capabilities to the table that simply didn't exist previously."

Barry Johnson
Acting Assistant Director, Engineering Directorate
IIP Division Director
National Science Foundation

Dr. Michel Kinch, Center for Research innovation in Business, Washington University in St. Louis; Dr. Patty Hagen, Executive Director, T-REX; Mr. Harry Arader, Director, BioSTL; Mr. Ken Harrington, Innovation Ecosystem Expert and Entrepreneur's Guide; and Dr. Barry Johnson, Acting Assistant Director, Engineering Directorate and IIP Division Director, National Science Foundation.

the final product or putting the onus for innovation on upstream producers. This fragmentation of industry means companies must look for common shared infrastructure as a means to promote innovation. For many manufacturers, this means working with stakeholders, customers, suppliers, academia and perhaps even direct competitors on pre-competitive research. This raises the question of how to bring stakeholders to the table, then step back and compete in the marketplace.

The acquisition of intellectual property has become an important driver of merger and acquisitions activity, a common example being large companies acquiring small start-ups to gain access to their innovations. In an era of rapid and accelerating technological change, it is often easier for large organizations to use the innovation of an outside firm through acquisition or technology licensing. This is not to say

Dr. Elizabeth Cantwell, Vice President for Research Development, Office of Knowledge Enterprise Development, Arizona State University.

"Rather than building our own research infrastructure, we have invested our own money on top of the resources inside the university to build up their capabilities."

Dr. Mark Little
Former Senior Vice President
Director of GE Global Research
Chief Technology Officer
GE—Global Research Center

leaps in technology are not created in the laboratories of large research institutions; however, there may be less institutional resistance when intellectual property is available outside the organization compared to cultivating new efforts within the organization.

Scaling innovations presents challenges that can vary widely, based on tolerance for risk when financing scaling efforts. Tolerance for risk is high when capital investment is low, such as scaling user capacity for software services hosted in the cloud, a type of lower risk that can be attractive to investors. Tolerance for risk is low when capital investment is high, for example, in manufacturing or large-scale energy innovations. To innovate in an industrial environment requires significant de-risking, and reducing the costs associated with scaling an innovation may require a new range of science and technology. This makes scaling in manufacturing, especially for new innovations untested in the marketplace, very difficult. Those directing private investments require proof of an innovation's viability. While Silicon Valley tolerates, even celebrates failure, in the capital-intensive manufacturing sector, failure isn't an option. Due to risk and uncertainty about future scaling, researchers have fewer incentives to undertake efforts that would develop game-changing innovations that move industry beyond its legacy technology. Strategic partnerships and public-private collaboration have become models for scaling innovations and helping bridge this technology "valley of death."

Government can play a role. For example, the National Science Foundation's (NSF) Industry-University Cooperative Research Centers Program came along at the time when places such as Bell Labs—a once vital basic R&D enterprise—were closing. The new model for basic research was for industry to invest directly in universities, and the Centers Program is heavy leveraged by the private sector.

In a complementary development, young innovators entering into the STEM workforce—raised in a hyper-connected, digital and social environment—expect to

Energy Industry Benefits from Innovations Developed Outside the Industry

The energy industry, historically a low investor in R&D, has benefitted enormously from new technologies. But, much of the industry's recent productivity gains have come from existing technology that had not been invented to operate in the oil industry. This includes computers on drill-string tools operating five miles underground at 400° Fahrenheit and 2500 PSI, possibly in an acidic environment.

In another example, analyzing materials in wells down-well with laboratory efficiency was thought to be impossible. However, an optical sensor innovation from the food industry was ruggedized and applied to analyzing materials in oil and gas wells in real time.

Previously, samples would be retrieved from the well, and shipped to a lab for analysis, which could take several months. The technology—originally invented to measure impurities in dog food—resulted in dramatic productivity improvements.

In another example, the oil and gas industry turned fiber optic technology into a "microphone" that could measure temperature, pressure and the acoustic signature of a well. Now, what is happening down-well can be controlled with a much higher level of precision, enabling greater productivity, environmental safety and the ability to intervene in real time when the extraction process is not working as intended. Another innovation used in hydraulic fracturing was based on technology from the electrochemical battery industry.

Dr. Gregory Powers, Vice President of Technology, Halliburton.

"In the oil and gas industry, we're trying to take what the Shockleys of the world have invented and make them work in the oil and gas environment.

"…as the problems Halliburton tries to solve become more complex, we've had to turn more toward open innovation, meaning the solution can come from anyone, anywhere, and not necessarily in oil and gas."

Dr. Gregory Powers
Vice President of Technology
Halliburton

work in a highly networked and collaborative environment. Companies and other innovating organizations will need to adapt to the work style preferences of next generation innovators.

Regional Innovation Systems

Regions around the country are implementing multi-organizational models of innovation to build innovation ecosystems that leverage local and regional innovation assets and competitive strengths to stimulate economic development and job creation. Research universities often serve as the anchor for these models, and universities and community colleges are increasingly expected to be active centers for economic development. Integrating these models of innovation into regional strategic planning is important.

For example, New York State has worked to develop an innovation economy, anchored at SUNY Polytechnic Institute in Albany. By leveraging resources from industry and government, private and public sector partners established the SUNY Colleges of Nanoscale Science and Engineering (CNSE) in 2004, which has become a world-class center for semiconductor basic research. The success of CNSE is based on its ability to become a platform (i.e., innovation infrastructure) upon which the university, government and hundreds of companies have continued to build.

Similarly, founded in 2010, the Atlanta-based Global Center for Medical Innovation (GCMI) is a comprehensive medical device innovation center, dedicated to accelerating technology development, building businesses and improving health. In a broader sense, the GCMI is innovation infrastructure. Public and private leaders in Atlanta recognized a need to fill the

National Science Foundation Catalyzes Academic-Industry Research Partnerships

Source: National Science Foundation

NSF's Industry-University Cooperative Research Centers Program develops long-term partnerships among industry, academia and government. The Centers are catalyzed by an investment from NSF and are primarily supported by industry members, with NSF taking a supporting role in the development and evolution of the Center. Each Center is established to conduct research that is of interest to both the industry members and the Center faculty. These centers focus on a range of cutting-edge technologies that are of interest to industry such as machine learning, biomanufacturing, food and beverage product processing and packaging, coatings, sensors, robotics, advanced vehicles, bioplastics, logistics and distribution, advanced materials, unmanned aircraft, cyber-physical systems, and advanced manufacturing. The centers have more than 1,200 members, about half representing large firms and about a quarter representing small firms, and almost 47 percent of Center funding comes from industry members or other industry participants.

gap between invention and the medical device market. Local leaders built a network of support from the U.S. Department of Commerce Economic Development Administration, the Georgia Research Alliance and several universities in the region.

One benefit of developing regional models of innovation is that proximity promotes knowledge transfer between innovation stakeholders. A successful example of this outside the U.S. is evident from the close proximity of GE's Munich Research Center to the Technical University of Munich (TUM) leading to improved outcomes. Through relatively effortless human capital exchange, Ph.D. students from TUM frequently work at GE's research center, and GE engineers and scientists take advantage of TUM testing facilities run by faculty and students.

However, research and research teams are reaching beyond the boundaries of regions; a research university on one coast may have a campus on the other coast or in other places around the world. Communication technology is ubiquitous, blurring geographic limitations. Researchers can connect, in most cases, no matter where they are located.

Multidisciplinary Teaming

Technology convergence is driving collaboration among different scientific and technical disciplines, communities and domains of human activity to create new knowledge, competencies, technologies and solutions. The most important problems facing our nation and the world—public health, climate change, energy sustainability, education, etc.—require distinct domains to work together, increasing their collective power to solve complex problems or create new knowledge and ideas in areas in which underlying science may not exist. As a result, external relationships that allow companies to scale competencies quickly are much more important than in the past.

For example, the development and deployment of autonomous transportation systems is complex and cuts across different disciplines, yet it is difficult to bring together cross-disciplinary groups to advance the technology; that type of effort goes against the grain of the common methodology of departmentally solving problems. Also, there is growing demand for computer scientists and artificial intelligence experts to work on these systems, and significant competition for talent.

In another example, engineers teaming with physicians has led to new technology. Adding some engineering to a doctor's toolkit in his or her education could help bring more technology into clinical practice and improve the co-design process, as doctors are closer to patients and more aware of their concerns. For example, input from diverse sources of knowledge and experience improves contextual awareness in the development of new health-related wearable and implantable technology, leading to improved understanding of what people are willing to interact with and the information they are willing to share.

Breaking down siloes across both industries and domains within the same organization is needed to develop innovations at the intersection of disciplines, but also to include a greater diversity of expertise in solving problems that are increasingly multidisciplinary in nature. Lockheed Martin seeks to train its leadership to think differently about team dynamics and construction—particularly focusing on building teams with multiple disciplines, multiple generations and different backgrounds—to get diversity of

Mr. Mike Krupka, Managing Director, Bain Capital; Mr. Dougan Sherwood, Co-Founder and Managing Director, Cambridge Innovation Center, St. Louis; Mr. David Karandish, Former CEO, Answers Corp.; and Dr. Dedric Carter, Vice Chancellor Operations and Technology Transfer, Washington University in St. Louis.

thought. Structuring projects in the form of a challenge—instead of prescribing a technology or solution—drives innovation thinking and provides a focal point for the application and integration of knowledge and skills from multiple disciplines.

Big Data

Big data, data analytics, modeling and simulation are providing powerful new tools for the researcher and innovator, allowing a scale of research, discovery and experimentation impossible in the laboratory. These tools are also increasingly used by R&D personnel in corporate laboratories to explore and select innovation pathways with the highest likelihood of success, while avoiding expensive trials that do not bear fruit, which could provide significant competitive advantages to organizations that perfect the use of this technology.

Industry is using these powerful tools in innovative ways. For example, in the oil and gas industry, one well produces two terabytes of noise in one day that needs to be identified. When you filter out noise from the audio from the well, trucks going by, earthquakes on the other side of the planet, and all sorts of things are heard. In response, Halliburton developed a catalogue of the sounds of activities the company is trying to induce. This has been revelatory and changed the course of the company's decision-making to ensure it is actually doing what customers ask it to do.

Encouraging New Models of Innovation

New models of innovation need to be deployed that foster partnerships between American companies and others, such as universities, in an innovation ecosystem capable of quickly scaling new technologies.

Behavior and culture are important. A culture of openness is needed to encourage the flow and exchange of new knowledge, new thinking and technology expertise that help make partnerships and collaborations successful. This includes openness to industry problems as an acceptable academic endeavor, and openness to sharing resources without significant intellectual property barriers. Multi-organizational innovation models and physical co-working spaces can facilitate collaboration.

Some organizations face significant barriers to developing a more collaborative innovation environment. For example, some companies and research organizations—such as defense contractors and some national laboratories—have safety and national security issues than often cannot be overcome.

Academics have been contributing for decades to the field of corporate management. Today, there is increasing attention to the management and structures involved in the innovation process, transfer and deployment of technology.

Recommendations

- Develop and proliferate across multiple sectors low-cost, easy-to-use tools that promote the self-organization of innovation ecosystems.
- Expand and scale the NSF's I-Corps™ program.
- Encourage greater research on the processes, models and organizational structures involved in the innovation process.

Mr. Ahmed Mahmoud, Chief Information Officer, Global Purchasing and Supply Chain, Customer Care and Aftersales & Quality IT, General Motors Company; Dr. J. Karl Hedrick, Fellow, Texas A&M Institute for Advanced Study, James Marshall Wells Professor of Mechanical Engineering, University of California, Berkeley; Dr. Dominic "Tony" Antonelli, Chief Technologist, Exploration Systems, Lockheed Martin Civil Space; Dr. C. Michael Walton, Ernest H. Cockrell Centennial Chair in Engineering, University of Texas at Austin; Mr. Reuben Sarkar, Senior Fellow, Council on Competitiveness; Former Deputy Assistant Secretary for Transportation, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Building an Innovation Nation Through a More Inclusive Innovation Ecosystem

Mr. Mark Lytle, Vice Chancellor for Economic Development Board of Regents, University System of Georgia; Dr. Greg Hyslop, Vice President General Manager of Boeing Research & Technology, The Boeing Company; Dr. Stephen Cross, Executive Vice President for Research, Georgia Institute of Technology; Mr. Al Bunshaft, Senior Vice President, Global Affairs, Dassault Systèmes; and Dr. Judy Genshaft, President and CEO/Corporate Secretary, University of South Florida.

A foundational theme and major discussion during the EIFI dialogues revolved around the lack of demographic and socio-economic diversity in the science, technology and innovation ecosystem. As innovation becomes ever more the engine of economic growth, wider access to innovation ecosystems becomes ever more critical to national and personal prosperity.

The Challenge of Increasing Diversity in the U.S. Innovation Ecosystem

The diverse communities that will increase their share of the U.S. population in the decades ahead are largely disconnected from the innovation ecosystem and are underrepresented in STEM[12] education. This underrepresentation constrains the diversity of the STEM workforce and future faculty.

"We have created a situation where we have a far too narrow band of students who are qualified to enter the system."

Al Bunshaft
Senior Vice President, Global Affairs
Dassault Systèmes

Historically, women and people of color have been underrepresented in STEM higher education. Women have made significant progress in the United States, increasing their share of STEM bachelor's degrees from 23 percent in 1966, to 54 percent in 2015, and their share of STEM doctoral degrees from 6 percent to 40 percent over the same period.

Progress in undergraduate and graduate level science and engineering education has been slower for minority groups, with the exception of Hispanic/Latino students who have more than doubled their share of STEM bachelor's degrees (Figure 7).

About 30 percent of all bachelor's degrees awarded in the United States each year are STEM degrees (natural and physical sciences, mathematics, computer science and engineering). By demographic, of the bachelor's degrees earned by male students and Asian/Pacific Islander students, more than 30 percent are in STEM with STEM accounting for 44 percent of the bachelor's degrees earned by the latter student group. STEM's share of bachelor's degrees earned by other student demographic groups ranges from 24-30 percent (Figure 8).

12 Natural and physical sciences, mathematics, computer science and engineering.

Figure 7. Share of STEM Bachelor's Degrees by Demographic
Source: National Science Foundation Webcaspar/IPEDS

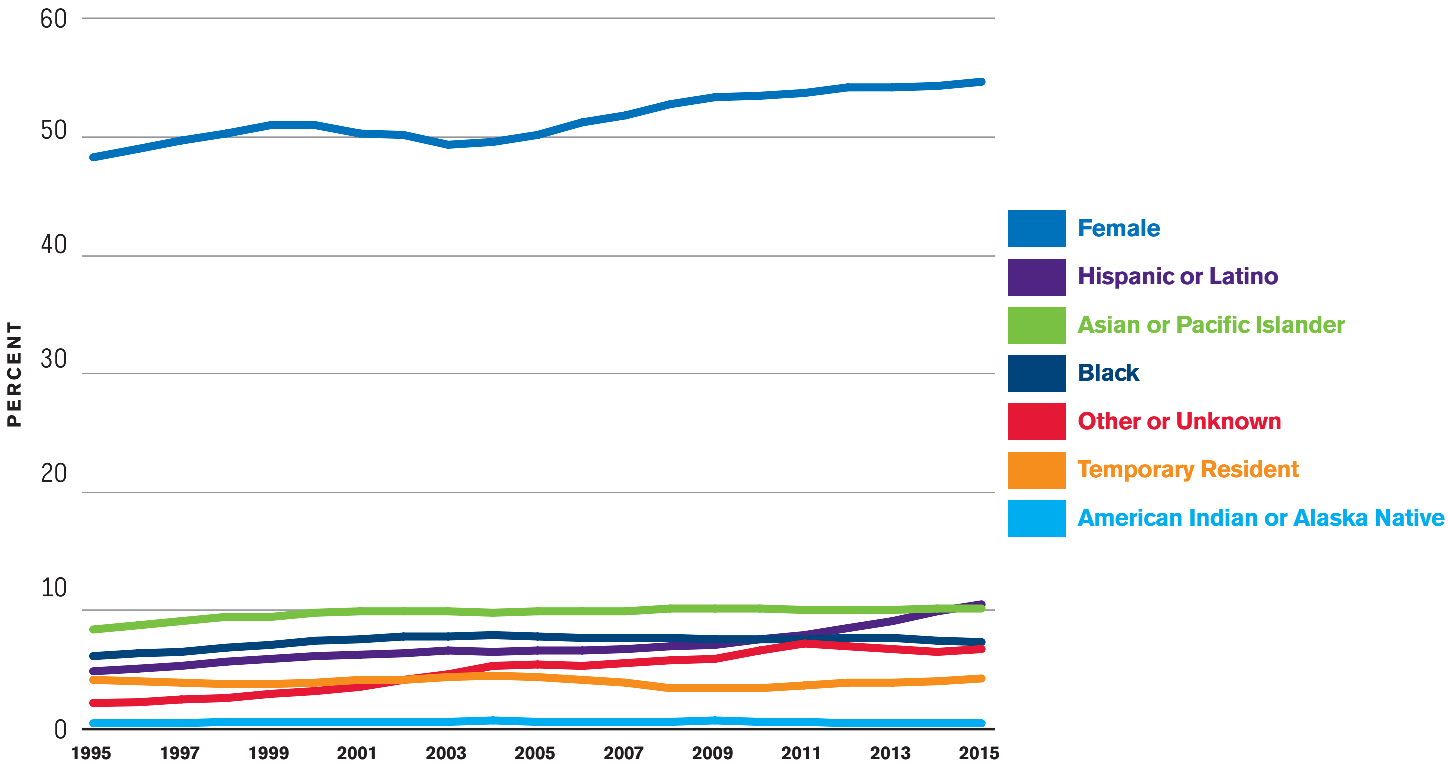
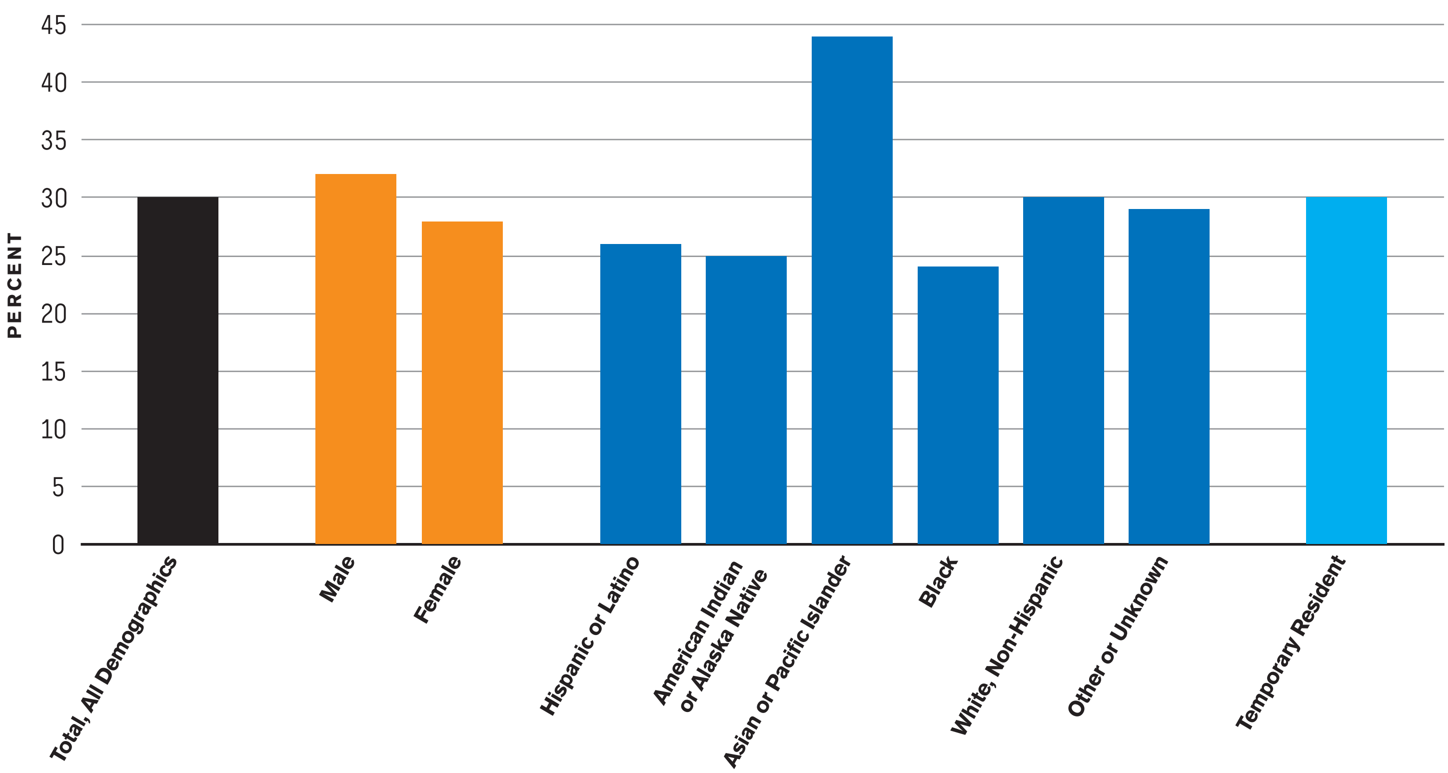


Figure 8. STEM as Percent of Bachelors Degrees Earned by Demographic
Source: National Science Foundation Webcaspar/IPEDS



However, these percentages mask some important differences at the discipline level. Women earn more bachelor's degrees awarded in the United States than men, 57 percent in 2015, and many women are prepared for science and engineering studies in college, but their pursuit of STEM studies is uneven across STEM disciplines. For example, women earn 60 percent of bachelor-level degrees in biosciences, and earn them at a higher rate than men. However, men are more likely than women to earn a bachelor's degree in engineering, for example, about: 10 times more likely to earn a bachelor's degree in aerospace, electrical engineering or mechanical engineering; 4 times more likely to earn a bachelor's degree in civil engineering or materials engineering; and 3 times more likely to earn a bachelor's degree in chemical engineering.

The pattern of participation in STEM higher education is somewhat different for under represented racial and ethnic minorities than the pattern for women. For example, Hispanic students who attain a bachelor's degree attain them in civil engineering, electrical engineering and industrial engineering at rates equal to white students, and black students who earn bachelor's degrees earn them in computer science at rates equal to white students. However, black, Hispanic, and American Indian/Alaskan Native students graduate from high school and/or college at lower rates than white or Asian students do, creating a relatively smaller pool of students in college who could pursue STEM studies and degrees. Increasing the college-going population among these underrepresented groups would likely increase their STEM participation, with K-12 education a key leverage point.

The non-Hispanic white population is projected to peak in 2024, at 199.6 million, up from 197.8 million in 2012. Unlike other racial or ethnic groups, however, its population is projected to slowly decrease, falling by nearly 20.6 million from 2024 to 2060. The Hispanic population is projected to more than double, from 53.3 million in 2012 to 128.8 million in 2060. Consequently, by the end of the period, nearly one in three U.S. residents would be Hispanic, up from about one in six today. The total minority population would more than double, from 116.2 million to 241.3 million over the period.[13]

The U.S. innovation ecosystem is out of step with our shifting demographics. And, diversity represents unique perspectives that inject new ideas into existing problems, increasing opportunities for innovation; the lack of diversity in STEM will artificially limit U.S. innovation potential.

While the U.S. innovation ecosystem is not inherently exclusionary, national trends in participation are troubling. Too many students are lacking foundational skills such as numeracy and literacy, and a core belief in the value of education that are required to pursue higher education and careers in STEM. The National Science Foundation is committed to broadening participation in science and engineering, and invests $700-$800 million annually to help meet this challenge.

"I've realized that this access is a privilege not afforded to everyone, especially people who do not historically have these extensive communities of support. How do we ensure that the pool of future innovators isn't shrinking, as today's minorities are tomorrow's majority?"

Jasmine Burton
Founder and President
Wish for Wash
Recent graduate of Georgia Tech

13 U.S. Census Bureau Projections Show a Slower Growing, Older, More Diverse nation a Half Century from Now, U.S. Bureau of the Census, December 12, 2012.

"The way we talk about engineering to our youth is incorrect and, quite frankly, off-putting. If a young woman or underrepresented minority student had a negative impression of engineering by third grade, the likelihood that they will move into an engineering or technical field is minimal. So the problem with K-12 is that we start talking about engineering in high school. We've already lost those children. So what we need to do is start thinking about how we can integrate engineering into kindergarten and develop curricula that will allow teachers to do that."

Dr. M. Katherine Banks
Vice Chancellor for Engineering
The Texas A&M University System
Dean of Engineering, Texas A&M University

Distinctive barriers to access the innovation ecosystem exist for people of color, women and low-income students. For example, an extensive community of support—family, friends and mentors—with knowledge of and ties to the innovation ecosystem can be a critical success factor. However, this science, technology and innovation-savvy community of support is often lacking for women and people of color.

Dr. M. Katherine Banks, Vice Chancellor for Engineering, Texas A&M University System, and Dean of the College of Engineering, Texas A&M University.

Engaging Young Students in STEM

Diversity is a step removed from the challenge of spurring interest in STEM disciplines, and helping young students understand what opportunities exist in STEM fields.

The most important time for developing an interest in STEM is at a very young age, building a deep passion for the topic that will help motivate students through challenging STEM studies. Yet, many students from groups underrepresented in STEM do not see adults that look like them in STEM in academia or in the workplace, and they are less encouraged to pursue a STEM education as a result.

If a young female or underrepresented minority student has a negative impression about science or engineering in elementary school, the likelihood they will move into a STEM field is diminished. Talking about STEM in high school is too late.

Diverse groups of students do show interest in STEM at an early age but, through some form of attrition, lose sight of STEM as an academic or professional career path. This may be the result of students not being properly mentored or not discovering their passion; a single teacher may inspire or discourage students, having a large impact; or students may be interested in a field of study, but do not feel there is a future for them should they follow that path.

Dr. Susan Wessler, Home Secretary, National Academy of Sciences, and Neil A. and Rochelle A. Campbell Presidential Chair for Innovations in Science Education, University of California.

Teachers may show an unconscious bias with respect to underrepresented minorities; if teachers do not believe that students can do the work, they may provide a substandard education to them. This leaves students poorly prepared for college, if they have not been discouraged from attending at all. There must be support systems to show students they are capable in STEM environments and give them the opportunity to succeed.

In the 19th century, schools were never designed to be exciting places to foster innovation. This has not changed much. Standardized testing is increasingly how schools are judged, and drives how they organize themselves. As a result, there may be impediments that are inculcated into our institutions supported by the very communities that need to be more engaged in STEM and innovation.

One simple approach involves creating partnerships and networks to expose students to new ideas they may not have had an opportunity to explore before, such as bringing high school students into science labs so they can be closer to STEM careers, especially for underrepresented students, and engaging with STEM professionals to generate interest in more technical areas of study.

Big companies are doing what they can to help, partnering with education institutions at all education levels to inspire young people, creating high school internships, and supporting undergraduate and grad-

"I taught my first undergraduate class, Intro Biology, with 400 students, and I absolutely hated it. I left the students downstairs and walked upstairs to my research lab where students, undergraduates, graduate students, and post-docs were literally bouncing off the walls with excitement. This led me to realize that our research universities are really composed of two worlds. We have the upstairs, which are the research labs that are recognized as the best in the world, period. Upstairs we're expected to be creative, innovative and use cutting-edge technology…the downstairs is a different situation. It's the undergraduate classrooms and labs…the introductory courses are huge. There's usually the 'sage on the stage,' impersonal. Our student labs are, for the most part, using old equipment. To speak in generalities, they're pretty boring and taught by a TA who is usually an international student from 'upstairs.' "

Dr. Susan Wessler
Home Secretary, National Academy of Sciences; and
Neil A. and Rochelle A. Campbell Presidential Chair for Innovations in Science Education
University of California, Riverside

Mr. Mark Lytle, Vice Chancellor for Economic Development Board of Regents, University System of Georgia; Dr. Greg Hyslop, Vice President General Manager of Boeing Research & Technology, The Boeing Company; Dr. Stephen Cross, Executive Vice President for Research, Georgia Institute of Technology; Mr. Al Bunshaft, Senior Vice President, Global Affairs, Dassault Systèmes; and Dr. Judy Genshaft, President and CEO/Corporate Secretary, University of South Florida.

"It is really a matter of us inspiring people at an earlier age to take the right courses. We can't expect someone going into the 11th grade that has not had math for three years and decide suddenly that they want to be an engineer or that they are going to have the skills going forward."

Mark Lytle
Vice Chancellor for Economic Development
Board of Regents
University System of Georgia

uate students. Efforts specifically targeting diversity include strategic partnerships with historically black colleges, and affiliations with numerous external groups targeting Hispanic and African-American participation in the STEM community.

Undergraduate and Graduate STEM Education

Exacerbating the problem is attracting students to universities with demographics with which students may not be comfortable, that require relocating to an area out of their comfort zone, or where there may be a lack of a support group on which to rely. University STEM studies may be out of step with family expectations.

It is important to bridge the high school and undergraduate experiences to create cohorts of support for students who may be at elevated risk of failing if they move away from home to begin their undergraduate education. For example, Texas A&M operates several programs at community colleges around the state, where students are co-enrolled at the community college and Texas A&M, learning from Texas A&M faculty and establishing connections to the school. Ideally, these students create their own mentoring and support networks, so they and their families are more comfortable when they matriculate as a group to Texas A&M.

Another challenge is the nature of undergraduate STEM education, characterized by large and boring introductory courses with impersonal instruction often delivered by a teaching assistant, and labs with old equipment. This is in contrast to the experiences of graduate students and post-docs working in some of the world's best research labs, using cutting edge technologies to carrying out exciting research projects. In those labs, students are expected to be creative and innovative. We may need to change the notion that the goal of these large introductory STEM classes is to weed out students. Many undergraduate STEM students come from the top of their classes and should be nurtured rather than weeded out.

Faculty may contribute to this challenge, as they do not feel teaching is their role. Promotion and tenure guidelines tend to favor faculty research over teaching. Excellence in teaching does not count nearly as much as excellence in research.

In addition, curriculum is a major driver of the university—who is hired, the kinds of students that seek entry to the university, and what faculty and students do—playing a major role in defining the university experience. Often, this experience does not ignite excitement in students for the world of STEM, and curriculum is difficult to change.

More broadly, experimentation in undergraduate STEM programs is often discouraged. In order to experiment in education, universities need to collect data on student outcomes. There are funding opportunities for experimentation, but they demand rigorous, well-controlled experiments that require data from the university with no guarantee students will learn the required material.

When STEM students look to the next steps after attaining their undergraduate degree, they may face difficult choices—a job market with questionable employment prospects or continuing in academia for another several years to complete an advanced degree to attain the credentials preferred by many employers. This constantly connected generation has more information available to them than any previous generation, many are aware of the challenges women and minorities face in science and engineering with many opting to pursue other career paths based on this information. To keep them engaged, they must believe there are jobs waiting for them after graduation that do not require Ph.Ds. Industry creates the employment pull, and should connect more tightly with students coming out of universities.

Bringing more practical experience into the classroom—for example, engineering "professors of practice" with 10-15 years in a field—while also ensuring schools are teaching material employers find useful, would help smooth the transition from academia to the workplace. Currently, many professors have no industry experience. Regularly bringing in new, expe-

Early Exposure to Research Experiences at the University of California at Riverside

The University of California at Riverside has developed programming to provide undergraduate students with a more engaging and enriching STEM education experience. At the Neil A. Campbell Learning Laboratory, an innovative facility that combines computational and experimental laboratories, about 300 freshman a year take the Dynamic Genome (DG) course, participating in the kind of research usually reserved for graduate students or upperclassmen. They learn how to do cutting-edge research, using techniques such as those used in a real research laboratory, performing small projects linked to ongoing faculty research. Students participate in the discovery process, and learn how to design and conduct experiments, analyze data and write about the results. Freshman students are offered significant career counseling. Those who complete the DG course have an opportunity to serve as undergraduate laboratory assistants in the course and peer mentors. Such an early exposure to experimental science can encourage persistence in STEM studies and a choice of a science career.

Most DG students come from Southern California and most want to stay there. However, if they went into academia, very few would be able to stay. Fortunately, DG graduates can be selected to participate in a hybrid summer program carried out in partnership with the Keck Graduate Institute, which offers professional masters in bioscience management program. Keck graduates have significant success in attaining jobs and a competitive salary. In the hybrid program, selected DG graduates stay on campus, and receive room and board and a stipend. Keck faculty and students come and teach the GD graduates. A component of the program is focused on the science industry, in which students learn about intellectual property, regulatory affairs, how to put together a business plan, how to raise capital, production, and other things never taught in a typical STEM course.

rienced staff from industry to interact with students also creates a feedback loop: higher education programs are aware of industry needs, and industry can hire with the knowledge that their new employees have been exposed to desired skills.

Socioeconomic Diversity in Higher Education

The rapidly rising cost of higher education is threatening its socio-economic diversity, and could limit the future potential of innovation in the United States. Schools are caught between the opposing forces of increasing demand for student resources and decreasing financial support from government. Schools are forced to pass costs onto students in the form of higher tuition, limiting accessibility and, ultimately, diversity in higher education.

It is becoming increasingly difficult for college applicants to access the crown jewels of the U.S. innovation ecosystem—research-grade universities. These institutions are a major source of knowledge creation and technological innovation that drive American productivity, competitiveness and prosperity. Yet, the student population at these universities represents a shrinking share of U.S. undergraduates. While there is no formal taxonomy for the Nation's top-tier research universities, using proxies such as membership in the American Association of Universities and U.S. News & World Report rankings, the President of the University of Arizona and Council on Competitiveness Vice Chair, Michael Crow, estimated that roughly one in ten undergraduates are currently enrolled in first-tier public and private research universities.[14] This comes at time when demand for college enrollment is increasing and acceptance rates are falling at research-grade education institutions. For example, between 1989 and 2013, the ratio of freshmen applicants to admitted students at the University of California-Berkeley declined

14 Michael M. Crow and William B. Debars, "A New Model for the American Research University." Issues in Science and Technology, Volume XXXI, Issue 3, Spring 2015.

America's Primary and Secondary Education Must Be as Prized as America's Higher Education System

"If we think just about the higher education system, our research capabilities leading the world in discovery remain pretty much unchallenged. We have a great research innovation operation and a culture that supports it.

"By contrast, the curriculum is just the opposite. One of the most defining characteristics of a university is the curriculum. Once a university writes down the curriculum, it's pretty much set. And it stays untouched in its core for years and generally decades. In large part, it determines who will be hired, the kinds of students that want to go to the university and how we spend our time once we're there. Very unlike the research side, we have not build a culture around our curriculum that invites and encourages innovation. When we think about ways of including and exciting students into this new economy and into the world of ideas and science, we have a challenge. It is, I believe, the curriculum…

"And, if it's true for higher education, it's probably equally or, perhaps, more the case for K-12. There, the curriculum is even more difficult to change because it's not just a matter of the teachers; it's a matter of the school board, the politicians and the citizens."

Dr. Kim Wilcox
Chancellor
University of California, Riverside

from 40 percent to 16 percent.[15] The University of California at Riverside, host of the Southwestern EIFI dialogue, is an affordable, world-class research institution, and more than half of its students have a family income of less than $40,000 per year.

In this financially constrained environment as schools try to rein in costs, when there is increased demand for STEM courses, section sizes may go up or students may not get the classes they need on time. However, opening more sections is costly, requiring more faculty and space, and increasing class size leads to each student getting less attention. The end result is the degrading of accessibility to higher education for students.

Moreover, financial concerns are placing pressure on a student's willingness and ability to pursue further education for fear of the amount of debt accumulated by the end of their academic career. Students who have trouble navigating cost issues at the undergraduate level may not be able or willing to take on the additional financial burden of continuing their education at the graduate level, less they risk missing other financial milestones related to the American dream such as purchasing a home. These financial challenges threaten the future STEM pipeline. If students see fewer STEM graduates, they may not consider STEM as a viable academic or professional career path, further constraining growth.

Providing the greater support that could help students succeed costs money. However, the school districts, communities and universities in greatest need of such support are the ones that struggle the most for money.

Geographic Diversity in the U.S. Innovation Ecosystem

The United States has some of the most creative, productive and robust innovation clusters in the world. At the heart of these clusters are the innovators—scientists, engineers and entrepreneurs who provide the ideas and energy that drive these dynamic communities. However, it can be challenging to replicate these centers of innovation elsewhere and, as a result, communities around the country do not have the same access to the U.S. innovation ecosystem.

"Many of our legislators come from rural places. When we talk about innovation, about investing more money in R&D or you talk about supporting innovation centers and so forth, rural legislators do not see themselves in this."

Dr. Wayne Clough
President Emeritus
Georgia Institute of Technology

Some regions are more likely to attract innovative individuals and companies than others by virtue of their characteristics (climate, access to higher education, availability of high-skill talent, etc.). And new centers of innovation often arise around other centers of innovation, because the support systems and resources for fostering innovation are more mature, and have been more tightly integrated throughout the community and with economic development strategies. Similar resources exist in many communities around the country, but have not yet been connected in a way that innovators can leverage to their advantage, draws innovators to their location or captures the attention of the community to invest in STEM. Creating an environment conducive to forming partnerships across and within academic, industrial and governmental silos represents critical infrastructure for potential investment from outside the community.

In the northeastern U.S., Boston, MA —a hotbed for science, technology and innovation—has 60 universities, some of them the world's finest, that draw 400,000 new students to the region each fall. And while corporations tend to form their partnerships

15 Michael M. Crow and William B. Debars, "A New Model for the American Research University." Issues in Science and Technology, Volume XXXI, Issue 3, Spring 2015.

"The lack of that hardware infrastructure is the kind of a barrier to tapping huge innovation capacity that does exist in all American cities, large and small. Why can't we create next generation products 'Innovation Hubs' next to each Campus or Community College…just like we see a number 'Software Tech Parks' everywhere?"

Suresh Sharma
Research Associate
Georgia Institute of Technology

with top research universities, there are communities and universities that are very diverse with untapped innovation potential that are often over looked.

In addition, there is a lack of geographic diversity in the allocation of financial capital for innovation, with large concentrations of R&D investment and risk capital in well-established innovation hubs. For example, about 70 percent of the venture capital invested in 2016 was invested in Silicon Valley/San Francisco/Los Angeles, Boston and New York/Northern New Jersey.[16] Half of U.S. R&D is concentrated in just seven states, with one third in California, Massachusetts and New York alone.[17]

Successful and thriving innovation clusters have often benefitted from long-term political support at the state, regional and local levels. But, if legislators see innovation efforts as the territory of urban centers and research institutions, this would be a considerable barrier to scaling innovation across the nation.

Many municipalities and regions have tried to develop their community as a contributor to the innovation ecosystem in the United States, only to fall short of their goals. This is despite the fact that, in many cases, the assets and resources to develop and support innovation in a community are present.

One need is to integrate these innovation and entrepreneurial resources more fully with the education system. For example, many Ph.Ds. come out of academia with the faculty-inspired attitude that any career other than an academic career is giving up your science. Instead, students should see multiple career pathways, and understand the critical role they could play in innovation by bringing their expertise to the problems experienced in the community, and in support of the economy and national competitiveness.

Opportunities to see the world outside of academia can be developed locally through partnerships. For example, an innovation ecosystem, anchored by research institutions, is taking hold in Riverside, California and surrounding areas. ExCITE is a unique acceleration program created in collaboration among business leaders, the City and County of Riverside, and the University of California-Riverside. A growing start-up community now has easier access to risk capital, and opportunities to collaborate with peers in co-working spaces and a new technology incubator. Riverside is helping students and recent graduates bring their ideas to market. Following the broader trend of democratizing innovation, maker spaces are also taking hold in the region. Taken together, investors are optimistic about the trajectory of the region due, in large part, to innovation-driven sectors such as IT and biotech.

Existing organizations can be incentivized to act as a catalyst to transform communities. For example, academic organizations or companies may move into new geographic territory in search of less expensive real estate as they establish more campuses. This creates tremendous opportunities to add depth to communities looking to establish their place in innovation ecosystems. Sometimes this can require some prodding, or creating incentives for companies to move. For example, InSoCal Connect created an

16 National Venture Capital Association Yearbook 2017, Data Pack.

17 Appendix Table 4-11, U.S. R&D and Gross Domestic Product, by State, Science and Engineering Indicators 2016, National Science Board.

innovation center fashioned after incubator models with shared space, making the draw about more than just inexpensive real estate.

Communities should not wait for others to realize an innovation ecosystem has emerged in a region; it is important to broadcast progress. Showing others how the community is creating a new environment will attract attention.

Ultimately, the most important aspect of developing a successful innovation community in different regions across the United States is to actively engage a spectrum of individuals and organizations to build better partnerships across a region.

Recommendations

Foster greater engagement of young students in science and engineering, especially in hands-on activities and exposure to the working world of science and technology.

- Expand and support the pool of STEM-literate teachers.
- Reward young inventors with incentives and prizes.
- Establish 21st Century shop class in high schools across America.
- Catalyze a culture shift that de-stigmatizes vocational education in the United States.

Develop new ways to open the pipeline for STEM higher education and to make it more affordable.

- Invest in programs proven to boost access to STEM fields for underrepresented communities.
- Cap student debt through work programs and grants.
- As diverse service industries in the United States have done, adopt new management and organizational approaches, and technology to improve productivity in and reduce the cost of higher education. Identify and scale education models that bend the cost curve down, allowing more Americans access to higher education, and reducing the burden of debt accrued during higher education.
- Bringing more practical experience into the classroom—for example, engineering "professors of practice" with 10-15 years in a field to help ensure what is taught is industrially relevant, to help smooth the transition from academia to the workplace, and to help ensure graduating students have the skills employers need.

Expand the geographic spread of innovation ecosystems.

- Encourage coordinated multi-stakeholder (public-private) regional strategic planning to attract resources to communities outside the innovation system.

Nurturing American Entrepreneurship

America's entrepreneurial heritage is legendary. From the beginning of the United States, entrepreneurial energy has fueled the American economy. Passed about one year after the Constitution of the United States was ratified, the 1790 Patent Act, which granted individuals the sole and exclusive right to their inventions, unleashed the entrepreneurial spirit across the country. Invention and entrepreneurship became prominent endeavors of many Americans and an outpouring of ingenuity generated a cascade of innovations. U.S. patents soared from about 40 issued in 1800 to 24,600 annually in 1900.[18]

American entrepreneurs and venturing investors leveraged the convergence of rail, oil, steel and electricity to drive American industrialization, profoundly changing the country and ushering in a new era of U.S. industrial might and wealth. In the 20th century, a new generation of American innovators and entrepreneurs changed the world launching the personal computing, Internet and social media revolutions. As we move into the 21st century the American economy is ever more knowledge and technology intensive, represented by knowledge and technology industries accounting for 40 percent of U.S. GDP.[19]

Today, perhaps more than ever before, in the midst of great revolutions in science and disruptive technology, the United States needs entrepreneurs to turn this new knowledge and technology into economic impact. Years of research can yield any number of useful and productive innovations, but require a means to move those innovations out of the lab and into the marketplace. Entrepreneurs create that path, applying new technology in novel ways, and creating the start-ups and new business ventures that move these innovations to the marketplace, extracting the value from long-term investments in R&D and development of the science and engineering talent pool. Without entrepreneurs, and the establishment and growth of new businesses, U.S.-based capital is at risk of moving to emerging markets, and American-developed intellectual property and start-ups are vulnerable to foreign acquisition.

A nation's entrepreneurial power is fueled by talent, a pool of innovations on which to draw, and support for establishing and growing a business. Research shows that economic and employment growth is highly connected with an abundance of small, entrepreneurial firms.[20] However, evidence suggests that the U.S. entrepreneurial punch has weakened, as U.S. start-ups appear to be on the decline (Figure 9).

Many people of all races with high levels of entrepreneurial potential are sitting on the sidelines instead of establishing and running a business. The gap is especially wide for black and Hispanic minority groups, despite the fact that data show no racial differences in entrepreneurial potential.[21] The data imply that the education system and economy are failing to encourage, train and provide the incentives to bring more entrepreneurs into the economy. The lower rates of entrepreneurship in the black and Hispanic communities deprive these communities and the country of new companies and jobs.[22]

18 Bicentennial Edition Historical Statistics of the United States, Colonial Times to 1970, Part 2, U.S. Bureau of the Census, U.S. Department of Commerce, 1975.

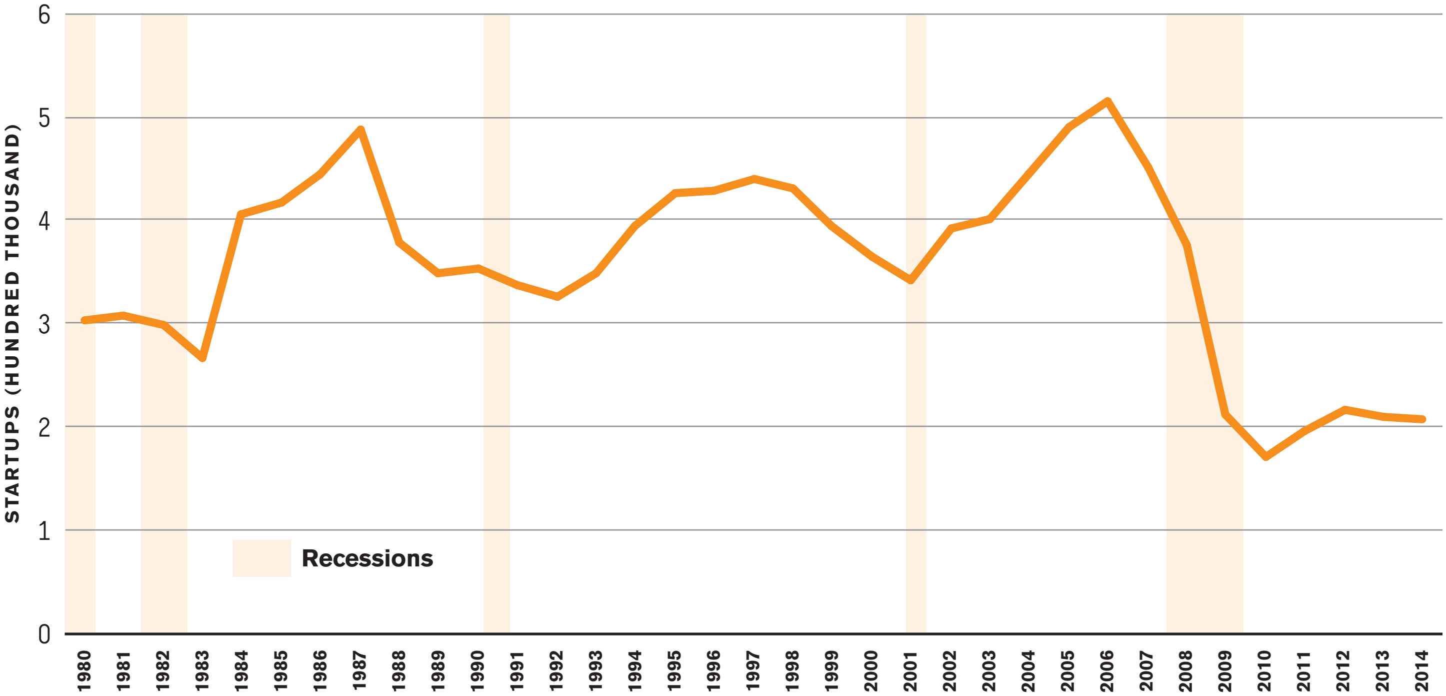
19 WORK: Thriving in a Turbulent, Technological and Transformed Global Economy, Council on Competitiveness, 2016.

20 Glaeser, E., Kerr, W., Ponzetto, G., Clusters of Entrepreneurship, NBER Working Paper Series, National Bureau of Economic Research, September 2009.

21 Entrepreneurial Profile 10, Gallup.

22 Rothwell, J., No Recovery, An Analysis of Long-Term Productivity Decline, Gallup, Inc., 2016.

Figure 9. Number of Firms Less than One Year Old Established Each Year
Source: Business Dynamic Statistics, U.S. Bureau of the Census



Challenges to Entrepreneurship and Business Building

Entrepreneurs can encounter a number of challenges in establishing a start-up and growing their business. While each new business faces unique challenges within their industry, common challenges include: access to capital; the risk and challenge of establishing a venture; validation of the business in the marketplace; setting the right metrics for success; and finding the right talent and skills sets needed as the business is founded, responds to market developments and matures. As companies overcome early challenges and de-risk the business, they increase their ability to compete for quality hires, customers and possible acquisitions.

When the Skandalaris Center at Washington University in St. Louis assists new organizations, they are asked to write down their biggest risks—business, scientific or other risks—and the Center will connect the new organizations with individuals in its network who can help these new ventures address these risks.

Making the Leap into Entrepreneurship

Potential entrepreneurs face the difficulty and unfamiliarity of embarking on a new initiative. Ways are needed to socialize this ambiguity so entrepreneurs are not lost or demoralized when there is no clear path forward. This socialization should start early in an academic setting where children are exposed to entrepreneurship to grow familiar with challenges associated with executing an idea and building something new. Moreover, current and nascent technologies are a democratizing force in entrepreneurship, enabling younger generations to envision and build something new with fewer initial hurdles than ever before. However, some level of technical training is required to equip students with the foundational tools and resources that help propel them to future success.

Translating an Idea into a Business

Ready to venture into entrepreneurship, individual innovators and entrepreneurial staff at larger organizations encounter difficulties translating their idea into a business and determining its viability in the marketplace. Many ideas fail because entrepreneurs are so involved in creating the product or service they are unable to identify the right metric that will signal success, such as customer acquisition trajectory, growth strategy or other relevant goal. Finding the right success metric is critical to start-ups that need this feedback to adjust their business plan to meet the needs of their customers or attract large organizations willing to be the first customer.

Getting Access to Capital

Access to capital to finance business building is a key driver of entrepreneurship, but that access can be affected by general economic conditions, perceived risk in the business or innovation, and investors' time horizon for expected returns. For example, for small businesses that do not have access to capital markets, banks are a key source of financing. However, on the heels of the 2007-2009 financial crisis, while interest rates dropped significantly, bank lending to businesses also dropped, as banks tightened underwriting standards and lending terms, and businesses faced a weak economy and uncertain economic outlook.[23]

Venture capital is an important source of early stage funding for start-ups and entrepreneurs. Yet, venture capital investment is highly concentrated in certain geographic regions of the United States. For example, three states—California, New York and Massachusetts—accounted for 75 percent of the venture capital invested in the United States in 2016; about 70 percent went to the Silicon Valley/San Francisco/ Los Angeles, Boston and New York/Northern New Jersey regions (Figure 10). Also, almost two-thirds of venture capital funding in 2016 went to software and life science companies. While the United States continues to attract the most venture capital investment globally, its share has dropped from 81 percent in 2006 to 54 percent in 2016.[24]

Dr. Paulette Brown-Hinds, Founding Partner, Voice Media Ventures.

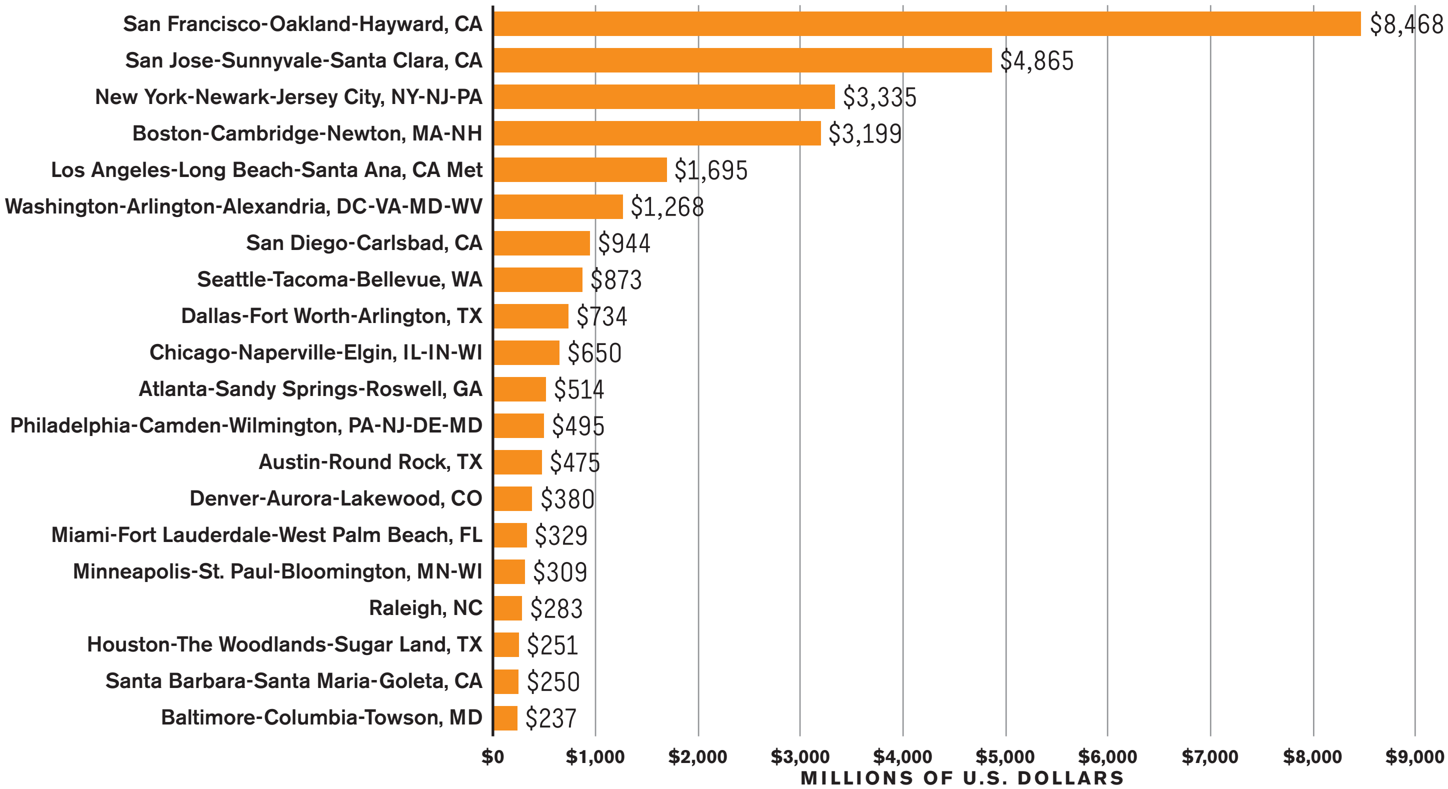
With venture capital concentrated on America's East and West Coasts, other parts of the country see little. Regions seeking to strengthen their economies and spur innovation must find ways to attract and grow investment, either by coaxing more venture capital away from the coasts by creating a thriving entrepreneurial base, or finding other means to support new businesses.

In areas that lack private capital for new ventures, the public sector can play a role in increasing the flow of venturing capital into a region. Funding from the public sector can serve as a key signal, validating the technology and business plans for a new venture, attracting other investors. For example, the Missouri Technology Corporation (MTC) is a public-private partnership created by the Missouri General Assembly to promote entrepreneurship and foster the growth of new and emerging high-tech companies, in industries such as biosciences, software and IT, clean energy, defense and homeland security. MTC has several funds that make cost-matched

23 Long-Road to Normal for Bank Business Lending, Economic Letter, Federal Reserve Bank of San Francisco, August 4, 2014.

24 National Venture Capital Association Yearbook 2017.

Figure 10. Top 20 U.S. Metro Areas for Venture Capital Investment
Source: Martin Prosperity Institute



investments to support scalable high-tech start-ups, with each fund correlated to a different stage of the start-up life cycle:

- Missouri TechLaunch: up to $100,000 in pre-seed funding to entrepreneurial start-ups for intellectual property development and evaluation, including in-depth analysis of market potential, competitive analysis, establishing proof of concept of a scientific discovery, prototype design and development, and related activities.
- Seed Capital Co-Investment Program: up to $500,000 for further intellectual property development and evaluation, market and competitive analyses, proof of concept work, prototyping, R&D needed to attract venture capital financing, hiring key personnel, and related activities.
- Venture Capital Co-Investment Program: up to $2.5 million for similar activities.
- High-Tech Industrial Expansion Program: up to $3M that can be used to purchase equipment, facilitate construction and hire key personnel.

Since the MTC's launch in 2011, these funds have invested more than $30 million, with the companies receiving this funding raising more than $350 million in additional private capital.[25]

The Timeline for Building a Business

The timeline for building a business presents another challenge. Entrepreneurs must move quickly to hone their business plan, addressing changes in their market and the needs of customers, but success is slow and never guaranteed. It is a very long road between an idea and a business, and the number of companies that get to $1 million is less than one

25 2016 Annual Report, Missouri Technology Corporation.

percent. Yet, younger entrepreneurs are perceived to be moving more quickly into new projects than previous generations. With the long time horizon for businesses to achieve success, the increasing speed at which entrepreneurs start and discard businesses limits potential start-up growth, as potentially profitable ideas are not fully explored in the marketplace. However, there is also importance to failing fast. Tools are being developed to help entrepreneurs quickly assess the probability of their venture's success. For example, it is possible to use big data to predict which teams and products are more likely to succeed.

Washington University in St. Louis and the broader St. Louis region have made concerted efforts to create an ecosystem that helps new entrepreneurs accelerate market entry for their innovations, for example, by connecting them with mentors, capital and other resources. The university created a blanket intellectual property agreement for university-sponsored research to enable staff and faculty to quickly pursue new ventures based on successful efforts in the laboratory, without a drawn out procedure. Most institutions spend a significant amount of time and resources constructing agreements between the school and individuals regarding intellectual property rights, as schools fear the loss of discoveries or inventions with market potential as well as outside commitments attempting to avoid conflicts of interest as professors, researchers and professional staff build a start-up. This process is long, expensive and unwieldy, dampening the enthusiasm of energized innovators.

Finding the Needed Talent

For start-up companies to flourish, they need different skills over time as the company matures. The skill sets needed to found, grow and operate a business can be very different.

Entrepreneurship too often focuses on the founder, but the "joiners" or early employees and advisors are just as important. It is critical to create an environment that encourages founders and joiners to come together, increasing the collective intellectual capacity of the organization. This takes time, which can cause friction among start-up stakeholders as 5-10 year plans are balanced against short-term goals, and the monthly and annual targets necessary to show growth and attract investment.

As companies approach and surpass tiers of growth, they encounter the additional challenge of attracting senior managers, due to both the risk associated with leading a growing business as well as attracting the right senior management talent to a region where there might be comparatively fewer opportunities. Bringing in senior managers who have experience scaling companies can greatly enhance an innovative organization's chance of success. However, as these companies grow, they may be acquired, stalling their growth into a larger company.

This need for different skill sets over time is also challenge for those organizations encouraging and assisting entrepreneurial development. They typically focus on helping innovators build a skill set for founding a company, but often do not have the resources to help successful entrepreneurs build the skills necessary to lead the next stage of the business.

Overcoming barriers to entrepreneurship and new business formation is critical to unleashing America's innovation capacity and creativity in the marketplace. But a supportive ecosystem must be in place for continued generation of new businesses to drive investment and catalyze job creation in a region.

Building Ecosystems that Cultivate Entrepreneurship and Support Entrepreneurs in Regions and Communities

The future prosperity of the United States is inextricably tied to entrepreneurs leveraging the opportunities in America's innovation ecosystems. There must be a focus on building regional capacity that gives

"You may have incredible technical folks and maybe they have very good technical mentors, but they do not have the business acumen to understand what it would take to actually bring their idea to market."

Dr. Keoki Jackson
Vice President and Chief Technology Officer
Lockheed Martin

"They are people who know their stuff, but they are not necessarily able to talk about the value proposition of, for example, water hydraulics."

Dr. G. Wayne Clough
President Emeritus
Georgia Institute of Technology

aspiring entrepreneurs the tools, business environment and confidence to embark on a new venture and fosters their success.

A supportive entrepreneurial ecosystem is, perhaps, the greatest determining factor in the success of entrepreneurs. There are many constituent elements in that ecosystem, and stakeholders that play a range of roles:

- Academic institutions that create new ideas, knowledge and technology with market potential, and develop and train talent;
- Small, medium and large organizations that invest in new businesses and, as early customers, act as market validators of young firms;
- Community entrepreneur development organizations that encourage and catalyzing growth in new businesses;
- A public sector at the local, state and national levels that helps create an environment conducive to entrepreneurial risk taking; and
- A public that ensures entrepreneurs have access to entrepreneurial resources.

America's universities and, in particular, large research universities are crown jewels of the U.S. innovation ecosystem, and a key source of knowledge and technology that entrepreneurs turn into market and economic impact. Illustrating the dominance of America's university system, when ranking innovative universities using measures such as number of patents filed and granted, global patents, the importance of patents in terms of citations and influence, science and engineering papers, and paper co-authorship with industry (which suggests economic potential), 17 of the top 25, and 8 of the top 10 are American universities.[26]

Many of these research universities play important roles in the ecosystems of the local and regional areas in which they reside, serving as local sources of innovation and future entrepreneurs, increasing the economic value of their communities and the economic potential of their students. Across the country, there are increased demands that universities nurture and support entrepreneurial activity with seed funds, facilities and curriculum. While it can be challenging to get academic and laboratory researchers to think and act entrepreneurially, students and faculty at some universities are engaging in entrepreneurial activities and starting companies.

Ultimately, it is the relationships and partnerships among these stakeholders that create the web of resources, networks and support that fosters a thriving regional entrepreneurial economy; the whole is

26 Reuters Top 100: The World's Most Innovative Universities 2016, September 28, 2016.

National Science Foundation Promotes Tech Entrepreneurship

The National Science Foundation (NSF) I-Corps™ program prepares scientists and engineers to extend their focus beyond the university laboratory, and accelerates the economic and societal benefits of NSF-funded basic-research projects that are ready to move toward commercialization. Through I-Corps™, NSF grantees learn to identify valuable product opportunities that can emerge from academic research, and gain skills in entrepreneurship through training in customer discovery and guidance from established entrepreneurs. Through the I-Corps™ program, NSF also promotes regional coordination and linkages, and develops networks.

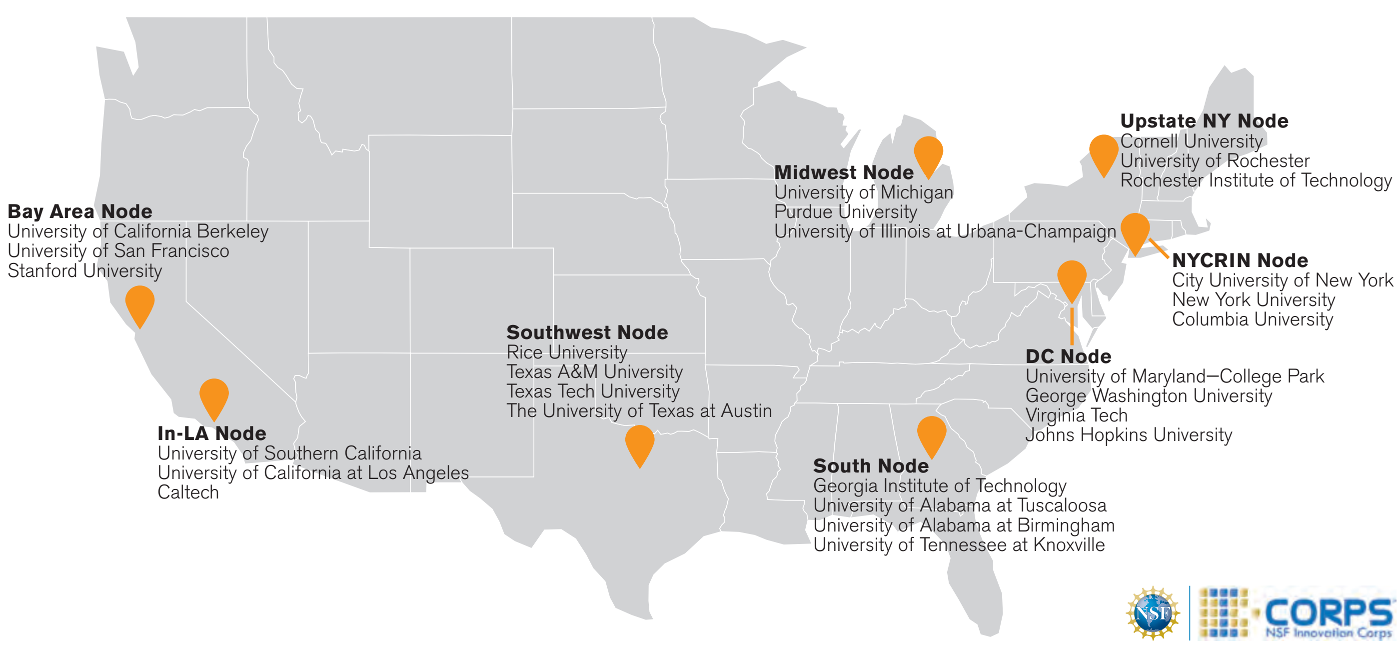
I-Corps™ Teams participate in the seven-week I-Corps™ curriculum, built on a special accelerated version of Stanford University's Lean LaunchPad course with additional elements designed just for I-Corps™ grantees. Each team learns what it will take to achieve a commercial impact with their innovation. The I-Corps™ curriculum enables teams to systematically identify and address knowledge gaps in order to understand the most appropriate path forward for their technology concept. At the end of the curriculum, teams are expected to have performed at least 100 face-to-face interviews with potential customers and potential partners from their proposed target market(s).

I-Corp Sites nurture and support multiple local teams in transitioning their technology concepts into the marketplace. The Sites provide infrastructure, advice, resources, networking opportunities, training and modest funding to enable groups transition their work into the marketplace or into becoming I-Corps™ Team applicants. Sites are single-institution efforts to support innovation locally. I-Core Nodes support regional needs for innovation education, infrastructure and research. Nodes are single- or multi-institution efforts that support innovation regionally.

From Fiscal Years 2011-2016, 905 teams, involving more than 2,900 individuals have participated in I-Corps™. Teams have created about 400 startups and begun to raise money from private investors. More than half have new collaborations with industry and a quarter with investors. More than $100 million has been raised, with $30 million from private sources.

Venturewell I-Corps™ Nodes

Source: Venturewell



"We went through an accelerator, raised a couple rounds [of venture funding], and received orders…and through the whole experience, really none of it would have happened without my mentors and the people around me that molded my value system."

Partha Unnava
CEO, Better Walk Inc.
Former Undergraduate
Georgia Institute of Technology

greater than the sum of its parts. However, it takes time and patience for these relationships to form and mature. An honest broker can be a catalyst in building these relationships by matching interests, needs and capabilities. Strengthening relationships requires few resources to implement, and partnership-building efforts are easy to replicate elsewhere.

Moreover, as regions build these entrepreneurial networks, programs and partnerships, and as successful start-ups and growing businesses expand the resource base within the region, the region becomes more attractive to other entrepreneurs within and outside the region, and further lowers barriers and risks to those entrepreneurs.

Building successful ecosystems can present challenges. Sometimes, as these innovation and entrepreneurial ecosystems mature, they become more specialized in their programs, service providers, networks and events, for example, in IT or biopharmaceuticals. As a result, some young and established firms are provided fewer opportunities to build relationships and share ideas across domains that may be meaningful to them.

In another area of challenge, institutions and entrepreneurs often operate at different speeds. Large commercial and educational institutions have numerous components, legacy modes of operating, commitments to existing customers or student constituents, embedded systems of accountability, etc. Universities change at a glacial pace, while entrepreneurs change very quickly. For example, entrepreneurs seeking to validate a technology or service in the marketplace may be hampered by inflexible intellectual property or licensing regimes emanating from large organizations.

Many regions around the United States are working to cultivate entrepreneurs and foster new business formation. St. Louis, host of the Midwest EIFI dialogue, has implemented a range of efforts to create an environment that engenders entrepreneurial spirit, and an ecosystem in which entrepreneurs feel confident enough to take a risk and invest in new projects. St. Louis start-ups have access to venture funding, accelerators, incubators and start-up investors, including those actively engaging underrepresented communities.

For example, Washington University in St. Louis is notable for its clear and strong commitment to promoting entrepreneurship on campus with its Skandalaris Center for Interdisciplinary Innovation and Entrepreneurship, and the Hatchery course at Olin Business School which teaches students how to pursue their own business idea or support community entrepreneurs. The university further bolsters regional innovation and entrepreneurship through its continuing partnership with the Cortex Innovation Community and local businesses; support of BioSTL (a regional coalition focused on bioscience) and BioGenerator (a health and plant sciences accelerator); and through business plan competitions, workshops and support for student, faculty and staff start-ups.

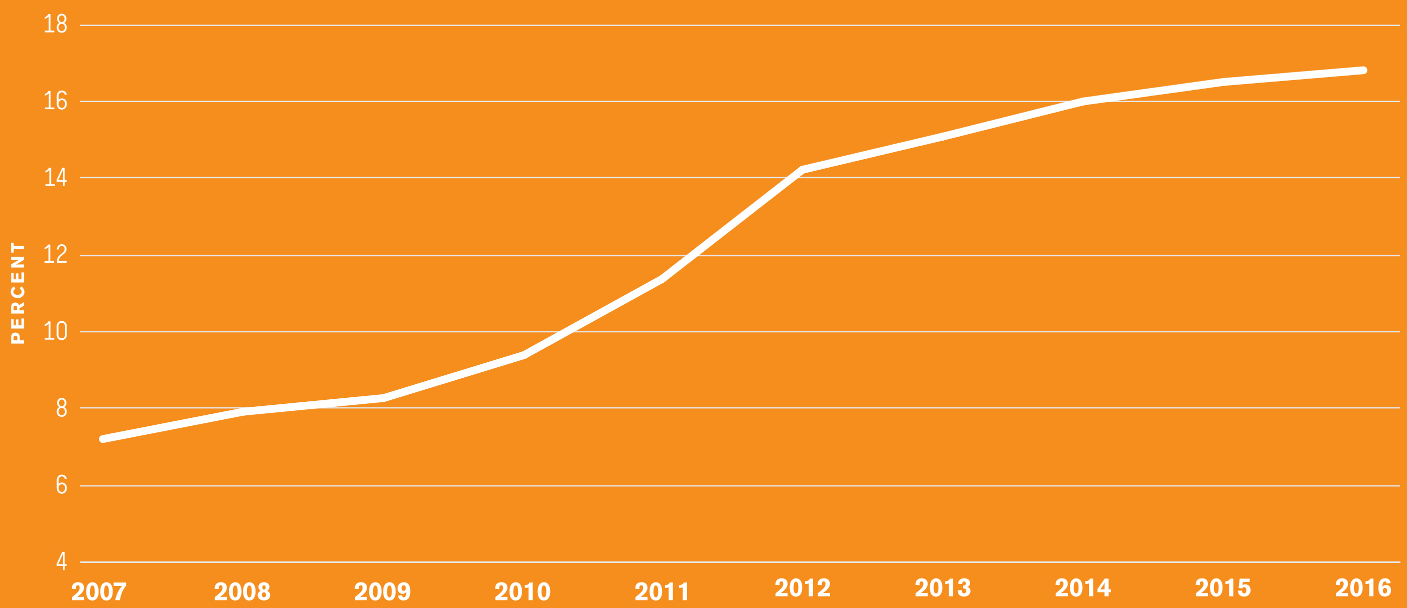
Other initiatives such as Arch Grants and T-Rex were created to lure and grow new businesses in St. Louis, and to create a space for local businesses to make connections.

In 2012, a group of St. Louis community leaders read a study that ranked cities for their number of female-led entrepreneurial businesses. They expected to see St. Louis ranked somewhere in the middle-to-top, but were shocked to see St. Louis ranked last.

Venture Funding on the Rise for Women-led Businesses

According to data from Pitchbook, a data collection and analysis service, the percentage of U.S. venture capital deals to companies with a female founder grew by 133 percent in the decade between 2007 and 2016. However, as of 2016, the number was still very low compared to the percentage of VC deals to companies with a male founder.

Percentage of U.S. Venture Capital Deals to Companies with a Female Founder
Source: Pitchbook



They considered what is could mean for a region if 50 percent of its population felt more empowered to reach their economic potential. The Prosper Women Entrepreneurs Startup Accelerator was established as a for-profit organization focused on increasing women entrepreneurs' access to growth capital. The Startup Accelerator invests $50,000 and provides a three-month business development program for selected women-led companies. In addition to capital, the program matches the companies to mentors, networks and other resources that enable their growth. Office space is provided at the T-REX start-up co-working space in downtown St. Louis.

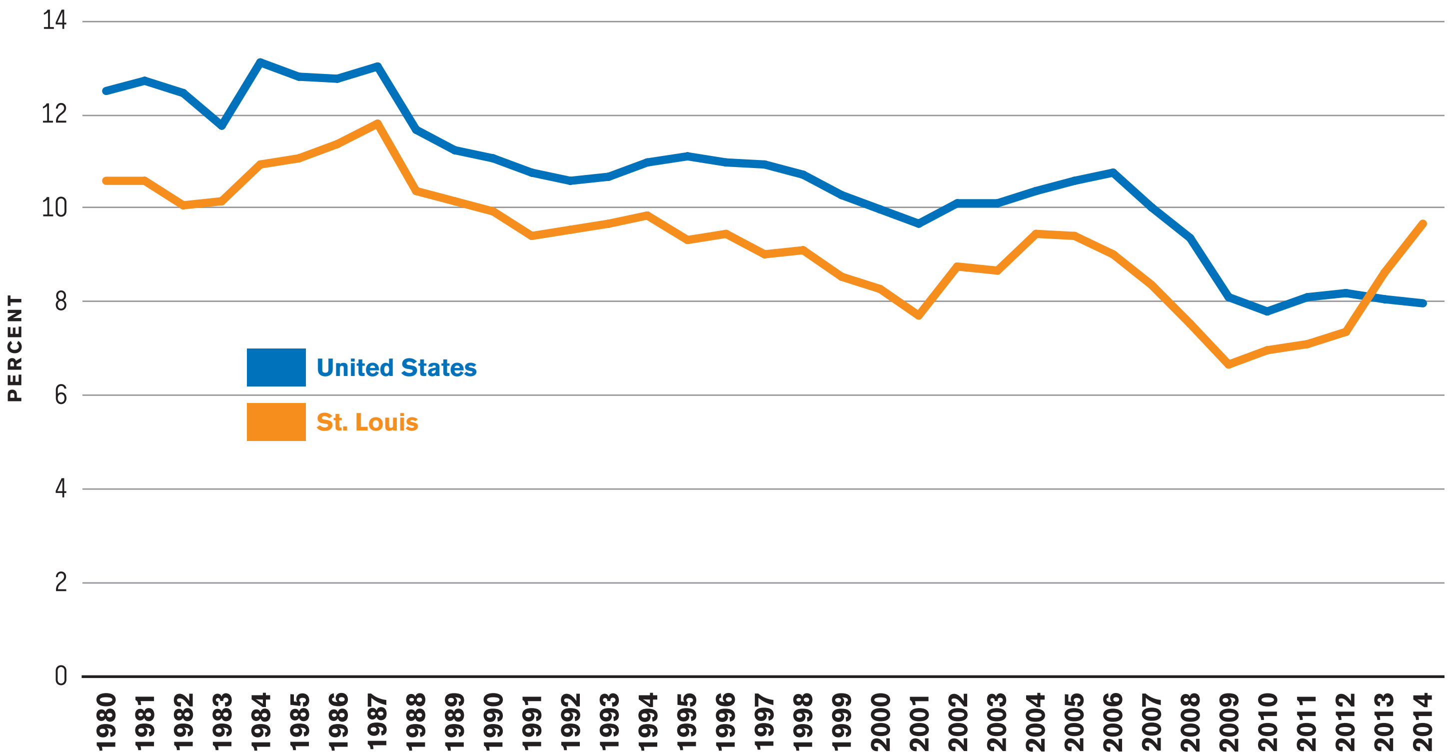
Overall, these initiatives in St. Louis are nurturing the population's sense of entrepreneurial possibility, building a strong entrepreneurial ecosystem and community, and building confidence for those who seek to establish themselves as entrepreneurs. These efforts garnered St. Louis the top spot in Popular Mechanics 2015 list of the "Best Start-up Cities in America."

In 2014, 9.7 percent of firms in the St. Louis area were less than one year old. While still below the level of new business formation in the 1980s, this represents a higher rate of new business formation than any point in the past two decades, and surpassed the rate of new business creation in the U.S. economy overall of 8 percent (Figure 11).[27]

27 Firm Age, and Firm Age by MSA, Business Dynamics Statistics, U.S. Census Bureau.

Figure 11. Percentage of Businesses that are Less than One Year Old, St. Louis vs. the United States

Source: U.S. Census Bureau



Company Efforts to Nurture Entrepreneurs and Start-ups

Corporations are also beginning to invest in enabling an entrepreneurial ecosystem and fostering start-up companies. These include General Mills' 301 INC, which identifies and nurtures emerging food brands, and includes a venture capital fund. It can provide a range of support for product development, marketing and channel development. Kellogg established the 1894capital fund for early stage venture investments in food related technology, packaging, etc. 1894 intends to invest approximately $100 million.

Recently, IKEA with partner Rainmaking established a start-up program called IKEA Bootcamp. Start-ups participate in a three-month program working closely with IKEA and Rainmaking to accelerate their start-up. Support includes: free housing in Almhult, Sweden, site of IKEA's co-working space for the Bootcamp; a 20,000 EUR grant to develop a product and start-up a business; a senior business leader mentor; domain expertise such as innovation engineers or value chain expertise; functional expertise in areas such as marketing or finance; start-up workshops and classes; and access to IKEA's prototype shop, test labs and advanced materials equipment.

Intel established Intel Capital in 1991 to back start-ups in a range of digital technologies. Since then, Intel Capital has invested $11.8 billion in 1,473 companies in 57 countries. In that timeframe, 620 portfolio companies have gone public or participated in a merger. In 2016, Intel Capital invested $455 million in 87 companies, including 34 new companies. This includes small investments in emerging technologies that are expected to be more mature and potentially useful to the company in 3-5 years.

For the companies providing this critical entrepreneurial support, these investments allow them to selectively identify and mature technologies and innovations outside of the company that may be useful for their business lines, without having to establish an internal research or innovation effort.

Mr. Jim Phillips, Chairman & CEO, NanoMech, Inc.; The Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness; Dr. Dimitris Lagoudas, Senior Associate Dean for Research, Texas A&M Engineering.

Mr. Michael van Ter Sluis, Former Vice President, Council on Competitiveness; Dr. Michael Pazzani, Vice Chancellor for Research and Economic Development, University of California, Riverside; Dr. Pramod Khargonekar, Vice Chancellor for Research and Distinguished Professor of Electrical Engineering and Computer Science, University of California, Irvine; Former Assistant Director, Directorate for Engineering, National Science Foundation; The Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness; Dr. Kim A. Wilcox, Chancellor, University of California, Riverside; Mr. Chad Evans, Executive Vice President, Council on Competitiveness; Dr. Grace Wang, Interim Provost and Vice Chancellor for Research & Economic Development, SUNY; Former Deputy Assistant Director - Directorate of Engineering, National Science Foundation.

Regions as Magnets for Innovative and Entrepreneurial Talent

Attracting talent to a region involves a mix of opportunities available to individuals as well as permanent physical characteristics desirable enough for talent to consider relocating. Regions have developed traits and institutions—formal and informal—that successfully attract individuals who fuel the local economy. Silicon Valley, for example, has become a hub of talent for information technology and New York is a center for the financial industry, much like Detroit is closely associated with automotive innovation and production.

Regions develop into hubs tied to a particular industry, which attracts individuals interested in that domain which, in turn, leads to a talent pool rich with particular skills. The increasing specialized assets of the innovation ecosystem create fertile ground for entrepreneurs and for them to capitalize on the specialized skills of the region's population. In this virtuous circle, the region serves as a magnet that attracts talent, retains talent and maintains the longevity of the innovation ecosystem.

One challenge regions face is attracting entrepreneurial and skilled talent away from the East and West Coasts of the United States, and major metropolitan hubs. Talent is drawn to the opportunities, industry, capital and resources that tend to be centered in these metropolitan hubs. Other regions can make themselves more economically competitive by investing locally, developing talent and improving access to resources that support entrepreneurship. These must be co-developed, as a region investing in talent alone will see their workforce leave for greater opportunity elsewhere, and a region investing in innovation infrastructure will lose industry if there is no talent pipeline. Regions can also invest in qualities that distinguish themselves from existing hubs, and showcase the business, leisure and personal opportunities available to residents.

Washington University in St. Louis has launched two initiatives to increase "stickiness" for retention of high-value, highly trained talent, such as graduate students, who have an interest in entrepreneurship. The Institute of Clinical and Translational Sciences (ICTS) created a post doc in entrepreneurship, ensuring ICTS investigators have access to state-of-the-art research infrastructure; financial support; relationships with local and regional academic, healthcare and community partners; and help in moving research findings from the initial discovery phase into new diagnostics, therapeutics and prevention strategies to improve human health.[28] The second is an entrepreneurship-in-residence program launched as part of a student group to keep highly trained graduates in the region. Both are making a significant impact, creating incentives to retain skilled talent and building value locally.

A key element to drawing and retaining talent in the region is clearly communicating to students, entrepreneurs, small businesses and industry about a region's positive attributes, the resources available to support entrepreneurship, and the personal and professional opportunities available to residents. Such communications helps potential new residents to be secure in their decision to move and settle in the region permanently. For example, the transformation of St. Louis as a magnet for talent has been supported by efforts to promote the region's geographic, economic, academic and intangible characteristics such as employment opportunities, high quality higher education, small business support, inexpensive real estate, and abundant recreational and entertainment activities.

Nurturing Entrepreneurship in St. Louis

St. Louis has numerous regional and local organizations working to foster local entrepreneurship. These efforts garnered St. Louis the top spot in Popular Mechanics 2015 list of the "Best Start-up Cities in America." These efforts include, for example:

Skandalaris Center for Interdisciplinary Innovation and Entrepreneurship, University of Washington in St. Louis: Provides students, alumni, faculty, staff and the community with support for entrepreneurship, such as mentoring; IdeaBounce, an on-line platform and events where entrepreneurs can receive feedback on their ideas; business plan competitions; training; and an entrepreneurial internship program. Depending on their program of study, undergraduates can declare a second major or a minor in entrepreneurship.

The Hatchery: A course offered by the Olin Business School in which student teams pursue their own business idea or support community entrepreneurs. Since 2008, 105 ventures have been launched, with 70 currently operating.

Information Technology Entrepreneurs Network (ITEN): Network in which experienced entrepreneurs help other entrepreneurs build successful technology ventures. Connections are formed through direct mentoring, a curriculum of graduated acceleration programs, and weekly and monthly networking programs. Programs include a Business Model Validation program and the Mock Angel program, which helps prepare entrepreneurs to make pitches to equity investors. Eighty percent of Mock Angel graduates have raised outside funding, $150 million since the program began in 2009. More than half of ITEN companies have first time founders.

Arch Grants: Non-profit organization operates a Global Start-up Competition, in which competitors with the most promising business plans receive $50,000 equity-free grants and pro-bono support services. Recipients must locate their headquarters or significant operations in St. Louis City for at least one year.

Cortex Innovation Community: 200-acre innovation hub and technology district in St. Louis, surrounded by universities and medical centers, formed to capture the commercial benefits of university and regional corporate research. Currently, there are about 250 companies at the Cortex. Start-ups have access to laboratory facilities and equipment at some of the area universities.

28 Washington University in St. Louis Institute of Clinical and Translational Sciences.

"A few years ago, an app start-up couldn't stay in St. Louis because the capital and talent needed was only available in California. But that is changing, and St. Louis could soon reasonably hope to retain those companies locally."

Dougan Sherwood
Co-Founder
Cambridge Innovation Center, St. Louis

However, different groups interpret and process information in various ways. Students use a different language to communicate than business people or academicians. Regions interested in attracting talent, must work to ensure their efforts are not being subdued from a lack of clarity when communicating to the intended audience. A good example is the ambiguous title of "Account Executive," which can mean many things to many organizations, but whose responsibilities are unclear to most potential applicants. The application of a common language has allowed St. Louis to improve the pairing of talent with local needs.

T-Rex: Co-working space and incubator for start-ups. Other entrepreneurial-nurturing organizations are located there, as well as about 200 start-up companies.

BioSTL: Leads efforts to build regional infrastructure to achieve St. Louis's potential in the biosciences. This includes building regional capacity in entrepreneurship through training and recruiting entrepreneurs, increasing venture capital investment in the region, marketing and branding, data collection, government relations, and guiding regional efforts to apply for large-scale public and private grants.

Bio-Research and Development Growth Park (BRDG): Located near the Danforth Plant Science Center, the park provides research, resources and support to help plant, life science and clean tech companies from the incubation stage through the post-incubation stage. Tenants have access to research grade greenhouses, growth rooms and chambers, and equipment. The park has attracted tenants from the St. Louis region as well as from other countries.

Ag Innovation Showcase: A joint effort between BRDG, the Danforth Center and the Larta Institute, the showcase is a gathering of innovators, investors and others in agricultural technology. Innovative and promising companies working in the agriculture sector present their innovations to Showcase audiences. Presenting companies have raised $510 million in funding after participating in a showcase.

BioGenerator: A privately funded, not-for-profit organization created to help build bioscience companies in St. Louis. The BioGenerator has provided seed money to nurture new ventures, while accelerator labs with shared equipment are available to early-stage client companies, enabling them to initiate proof-of-concept studies without having to raise capital to purchase most equipment or rent laboratory space. A pre-seed Spark Fund is available for early business and technology ideas not mature enough to qualify for seed funding. Spark Fund investments up to $50,000 are used to achieve business and technical milestones that will position the company to receive follow-on funding or become self-sustaining.

Attracting talent and companies to a region is often a process of courtship. Individuals may visit the region multiple times through their work or business partnership with a company located in the region. These visits and relationships can plant seeds, nurturing the idea and confidence that the region is a place worthy of locating to permanently. Also important is helping identify appropriate employment and education opportunities for immediate family members to help new residents integrate into the region, reducing the fears and frustrations of uprooting families.

In addition to attracting talent, investing in the development of a regional talent base can bring industry to a region. For example, through investments in science, technology, engineering and mathematics, the St. Louis region created a highly educated talent pool in discrete domains luring new industry and employers to the area. This is one way regions can work to combat shrinking rural and suburban economies around the United States suffering from a form of brain-drain, as many individuals leave the area in search of better opportunities in urban areas.

However, increasingly globalized innovation ecosystems means talent flows to opportunities across an expanding geography. With greater interaction and movement of ideas across wider distances, it is becoming harder for regions to attract and retain industry amid growing competition. Moreover, with the rapidly accelerating pace of innovation in telecommunications technology, individuals have access to new collaboration tools and modes of interaction with other people, and it may not be as important as it once was to keep a workforce within a particular region.

Recommendations

Encourage more Americans to participate in the economy as innovators and entrepreneurs.

- Expand entrepreneurship education. Provide basic knowledge, stories of success and simulations to introduce young students to the concept of entrepreneurship. Provide greater entrepreneurship education in high school and, in higher education, provide opportunities to put entrepreneurial knowledge and skills to work.
- Expand entrepreneurship mentorship networks nationally, with a particular focus on communities disconnected from innovation and entrepreneurial ecosystems.
- Leverage pop culture figures and entrepreneurial legends to encourage non-technical talent to become entrepreneurs.
- Create incentives for financial and human investment in entrepreneurial ecosystems.
- Encourage a culture that tolerates failure when necessary, while ensuring these failures facilitate a learning experience.

Develop models to help entrepreneurs scale their businesses.

- Create innovative finance models to boost entrepreneurs' access to risk capital.
- Develop innovative finance models to facilitate the scaling of manufacturing in the United States.

Future Areas of Research and Analysis

For decades, academics have contributed to the field of corporate management and, today, economists have new types of data allowing them to look at the economy in new ways. With the prime role of technology and innovation in the American economy, research could better inform a range of decision-makers and stakeholders on the management, structures and ecosystems involved in the innovation process, transfer and deployment of technology, and how best to leverage them for economic gains.

Impact of Technology on Economy and Society

Several game-changing technologies—gene editing, engineered healthcare, artificial intelligence and autonomous systems—are advancing rapidly, with expectations for transformational economic and societal effects. Their fast pace of development is likely to challenge governments and the scientific community in developing new policies, regulatory regimes and ethical norms needed in response, and few organizations have the range of expertise needed to deal with their diverse societal impacts. Cooperation, and the pooling of knowledge and expertise will be required to anticipate and address the challenges ahead.

- A multi-disciplinary team should map out the potential impacts more fully and develop potential strategies to more quickly address them if needed. Explore what can be learned from previous waves of technology-driven transformation in the United States.

Innovation is an active process undertaken by businesses and people. It is dynamic and inherently disruptive—both destroying and creating companies, markets and jobs. This reorganization of the economy is essential to leveraging innovation and new technology to generate the greatest benefits in terms of jobs, economic growth, productivity and wealth.

- Identify data and indicators that provide insight and could be used as a set of measures to inform policy-makers, businesses, educators and other stakeholders about the state and efficiency of a reorganizing U.S. economy, economic sectors and industries, labor markets, communities and society in technology-driven transformation. Examples of data include: introduction of new process innovations, number of firms active and employment growth in new technology sectors, growth of industry clusters, establishment births and deaths and related employment change, etc.

Regional Innovation Ecosystems

Beyond well-known clusters of innovation such as Silicon Valley and Boston, other communities have developed creative, productive and robust innovation clusters. Some of these communities were dying industrial regions that had once flourished anchored in agriculture and 20th century industrialization, but transformed themselves into new technology hubs. Yet, many other communities that have innovation assets have not integrated them with economic development strategies, or connected these assets in a way that innovators and entrepreneurs can leverage, or draw innovators and investment to their location.

- Identify key elements that came together to transform these fading economic communities, and establish and grow new innovation hubs. This includes regions that did not have a research university or institution.
- Identify the key sources of funding and investment that supported these transformations.
- Identify how these new innovation communities created or attracted talent to the region.
- In these regions and hubs, identify the origin and development of science, technology and innovation communities of support, how they function, and the likelihood they can be ignited and replicated in communities where they are not available.
- Explore whether these were unique situations or communities with distinctive assets, and whether these models can be scaled to other regions cost-effectively. In addition, examine the cost-effectiveness of these models and investments in rural areas with declining populations.
- Identify the degree to which the establishment and growth of a diverse set of hubs in the United States was fundamentally local or, to some degree or another, dependent on national level support or business investment. Explore how important different national policies, support mechanisms and investments were in the establishment and growth of these hubs and the transformation of these economic communities.
- Identify how these regions built the knowledge and capacity to design, implement and manage initiatives aimed at establishing and growing innovation ecosystems and innovation hubs.

Greater Diversity in STEM

Some racial and ethnic minorities and women are underrepresented in STEM. K-12 is seen as a key leverage point for both generating interest in STEM and preparing students for STEM studies in higher education.

- Identify the most effective interventions and methods of generating interest in STEM at early ages, and methods of encouraging persistence in STEM studies. Identify differences or the need for different incentives to attract studies of different genders, race or socio-economic backgrounds to STEM.
- Identify effective models for supporting student persistence in the STEM pipeline from high school through higher education and into the workforce.

Education System Alignment with the Need of a Diverse Population in an Innovation Economy

More Americans than ever before need and seek education and skill development at an affordable cost. However, the cost of education—especially higher education—has soared in recent decades. But evidence suggests that the quality of education has stagnated or even declined at both the K-12 level, and at colleges and universities.

At higher levels of education, the chief problem is not—as many have argued—that state governments have scaled back subsidies for tuition. The larger problem is an increase in costs, resulting in higher revenue needs per student for schools, and higher-costs for students and taxpayers. Schools are not held accountable for poor performance, because federal subsidies—in the form of loans and aid such as Pell Grants—do not discriminate between schools.

Moreover, across all institutions, colleges employ more workers per student than ever before and have shifted the types of workers they employ toward highly paid professionals, which now outnumber instructors. According to a recent study, a larger number of higher paid staff now supports each student. In 1988, there were 4.3 full-time equivalent students for every college employee—full and part time.[29] By 2012, this fell to 3.1. Looking at it another way, it now takes 31 staff to serve every 100 students when it used to take only 23. If these changes reflected a greater investment in faculty, it may have increased student outcomes and proven to be a worthwhile investment. Unfortunately, that is not the case. These data imply that many colleges face weak competitive pressure on price.

A wide range of management, organizational and technology innovations have allowed knowledge-based and service enterprises to improve productivity, quality and service to customers–including the ability to tailor services to individual needs and reach consumers in new ways–while reducing costs. Moreover, some education institutions have demonstrated that cost can be substantially reduced while improving student outcomes. In one case, using a course redesign model implemented in 156 completed projects, 72 percent of projects showed improved student-learning outcomes and the overall cost reduction was 34 percent.[30]

29 Rothwell, J., No Recovery: An Analysis of Long-Term U.S. Productivity Decline, Gallup, Inc., 2016.

30 National Center for Academic Transformation.

- Identify proven models for cost reduction in higher education that do not degrade student outcomes.
- Identify and examine barriers to organizational transformation in education, and what levers exist to encourage education institutions to adopt and institutionalize formal efforts to improve productivity, reduce costs and improve quality (as numerous other industries have done).
- Identify emerging models of education and training that appear to be better aligned with the economy's and society's needs.
- Among education institutions that have transformed educational programming and management, resulting in lower costs and higher or equal student outcomes, identify how they built capacity and systems internally to implement and manage the processes of change.

Nurturing American Entrepreneurship

Significant data is available on U.S. entrepreneurship through the Census Bureau's Annual Survey of Entrepreneurs.

- Mine this data set to identify and analyze key data related to the establishment, funding and growth of start-ups and firms, including their links to innovation.

There is growing interest in expanding the population of innovators and entrepreneurs in the United States. At the same time, new platforms, places and tools have emerged—outside of traditional innovation ecosystems—that are democratizing innovation and providing new sources of support for inventors, innovators and entrepreneurs. This new, but fragmented, support infrastructure includes: corporate and independent platforms that connect problem solvers with solution seekers, innovation challenges and contests, crowd-based sources of seed and venturing capital, independent and corporate start-up incubators and accelerators, maker spaces and tech shops, and new channels for product marketing and distribution. Some of these new resources enable innovators and entrepreneurs to connect with larger partners that can help advance their ideas and innovations.

- Map how these pieces form a new innovation ecosystem for individual inventors and innovators, small businesses and entrepreneurs. Develop a better understanding of the degree to which this emerging ecosystem is expanding innovation and entrepreneurship and participation in both, and identify how it can be leveraged to encourage and support more American innovators and entrepreneurs.
- Explore how Federal R&D investment, and other science, technology and economic development programs can better interface with this ecosystem.

Mr. Brian Stone, Chief of Staff to the Director, National Science Foundation; The Honorable France Córdova, Director, National Science Foundation; Dr. Mark Wrighton, Chancellor and Professor of Chemistry, Washington University in St. Louis; and the Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness.

The United States appears to be losing some of its entrepreneurial spirit, as the number of new start-up businesses has been on the decline.

- Identify what are the most significant barriers entrepreneurs are facing today in their decisions to take the risk of establishing a new business.

The frontier of innovation is in a constant state of change and expansion—and this frontier's expansion is occurring at an unprecedentedly fast and accelerating pace.

The recommendations put forth in *Transform* come from hundreds of leaders and innovation stakeholders across the United States—from industry (start-ups, small, medium, large); academia; labor; national laboratories; local, state and national government; and others. And they represent best-in-class thoughts and practices that are emerging across America's highly diverse, heterogenous, economic landscape. Together, the recommendations suggest a prioritized agenda for federal agencies—but also for the other stakeholders in the U.S. innovation ecosystem—providing academicians with direction for future research in innovation, educators and labor leaders with the knowledge of the skills necessary to innovate, businesses strategists with insights to inform innovation agendas and future business models, and policymakers with knowledge to enact public policies that create a supportive environment for next generation innovation

A critical meta-finding from this cross-country effort is that the very nature of innovation itself requires leaders in the United States constantly to reflect upon, evaluate and evolve national innovation priorities and initiatives. The effort to optimize America's innovation ecosystem is not a "once-in-a decade" exercise.

Rather, the growth of innovator nations worldwide—many with capabilities aimed at leapfrogging our own distinctive advantages—mandates the nation to be more vigilant and active in curating its innovation toolkit. *Transform* highlights potential areas for future research to enhance the nation's understanding of successful innovation models, and to sustain and grow America's global innovation leadership.

The United States finds itself at a critical juncture; the nation's innovation ecosystem represents the backbone of America's continued technological leadership and prosperity, yet the United States is at risk of losing that distinction as other nations dedicate a growing amount of resources toward strengthening their own innovation capabilities. America must focus on supporting a robust and dynamic innovation ecosystem where adaptive models for innovation can thrive.

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Who We Are

The Council on Competitiveness is a nonpartisan leadership group of CEOs, university presidents, labor leaders and national lab directors working to ensure U.S. prosperity. Together, we advance a pro-growth policy agenda and promote public-private partnerships in the emerging "innovation ecosystem" where new technologies are born.

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How We Operate

The Council Operates by:

- Identifying emerging competitive challenges.
- Generating new policy areas to shape the competitiveness debate.
- Forging public-private partnerships to drive consensus.
- Galvanizing stakeholders to translate policy into action and change.

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