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Council on Competitiveness

Advanced Technologies Initiative

Manufacturing & Innovation

Contents

Introduction

Background

Nations have long striven to advance to the next technology frontier and raise their economic well-being. In today's highly dynamic environment, advanced technologies have become even more essential in improving economic competitiveness and national prosperity. As a result, many nations, including the United States (US), have invested heavily in establishing national innovation ecosystems which connect people, resources, policies and organizations to collectively translate new ideas via advanced technologies into commercialized products and services.

A new global competitive environment has emerged in which America's technology and innovation leadership faces fresh and persistent challenges. Thus, it is imperative to analyze America's relative position within the global innovation environment, and identify and assess the myriad of challenges that threaten its competitive standing.

Research description

A key component of Deloitte Touche Tohmatsu Limited (Deloitte) and the Council on Competitiveness's (Council) multi-year Manufacturing Competitiveness Initiative, this study emanates from a year-long effort to understand and identify current and future trends in the United States and global scientific research and development (R&D). To this end, Deloitte and the Council interviewed nearly three dozen chief technology officers (CTOs), chief research officers (CROs), chief executive officers (CEOs), and company presidents from various manufacturing sectors, as well as nearly a dozen directors of US national laboratories and research facilities. In addition to identifying and exploring challenges facing US manufacturing and national labs, the initiative was designed to help identify the most promising advanced technologies in development within the United States. The interviewed executives and lab directors were also asked about technologies considered most critical to their company's competitiveness as well as high-level recommendations for reinvigorating America's industrial base.

Call to action

Though the United States remains a global technology leader, retaining its innovation leadership has become a paramount, long-term concern. While it still ranks first in total absolute R&D spending, its R&D intensity (R&D as a percent of Gross Domestic Product (GDP)) has been largely stagnant, with smaller economies like South Korea eclipsing the United States in this category.* In addition, R&D spending by the US federal government has not kept pace with US GDP growth.**

This relative lack of government funding for R&D may place constraints on basic and applied research that could threaten America's long-term economic prosperity. Thus, the United States requires a long-term strategy that, when aligned with short-term priorities, can foster the innovation ecosystem and help encourage the flow of required investments, growth in innovation capacity, the development of scientific talent, and the creation of high-value jobs.

* See Section 1 for more details.
** See Section 2 for more details.

Advanced Technologies Initiative: Report and next steps

The Advanced Technologies Initiative provides important insights on US and global innovation trends, and highlights the challenges faced by businesses in maintaining or improving their technology competitiveness. In addition, Deloitte and the Council have consolidated the interviewees' thoughts and perspectives to develop a set of high-priority recommendations detailing immediate and long-term critical needs to improve the national innovation ecosystem vital to sustaining US competitiveness. The study aims to increase attention and discussion on the current US science and technology system and pinpoint deficits to address its vitality. An ancillary aim is to spur an ongoing national dialogue among stakeholders on advanced technologies, industries, and foci of research from a systematic, versus siloed, perspective.

The report captures the voices and opinions of both government and industry leaders on US and global R&D, as well as innovation, trends. In addition, the study provides an overview of advanced manufacturing industries – from market size, and growth potential of various emerging technologies, to their overall impact – as well as critical success factors that underpin national innovation ecosystems, and the vital role that both corporations and government play in fostering a thriving science and technology system. The executives interviewed, in large, agreed advanced industries, propelled by advanced technologies, play a key role in enhancing economic prosperity through higher productivity and employee compensation, and increased high-tech exports. They noted these advanced industries are strongly linked to the entire innovation ecosystem, which also consists of universities, research institutions, other supporting industries, and the government. As well, while noting that businesses are the key sponsors of a majority of the R&D work in an innovation ecosystem, executives also stressed governments play an equally important role in innovation by devising supportive policies, providing tax incentives, and funding basic and applied research. A majority agreed a nation's R&D competitiveness rests on the smooth functioning of its innovation ecosystem, which, in turn, is dependent upon various initiatives and factors promoted by both businesses and government.

The report also highlights how other increasingly competitive nations like China have dramatically increased R&D spending to more closely align with investments made by developed countries like the United States. Executives agreed the gap between US innovation capabilities and those of certain emerging nations is rapidly narrowing, and the United States needs to revamp many aspects of its science and technology system. Of the most prominent challenges facing both US businesses and national labs, is the issue of the skills gap - the talent shortage - which garnered the most attention, followed by the competitive threat posed by competitive nations like China.

Finally, the report outlines key short- and long-term measures executives identified as critical to revitalizing and sustaining the US industrial base, a key driver of prosperity and economic strength. Executives consistently noted success hinges on the ability of the public and private sectors to work together and engage in open, honest, ongoing, productive dialogue about creating an environment in the United States that promotes competitive R&D work and advanced manufacturing. In particular, industry executives expressed the need for greater access to R&D work conducted at national labs and better engagement mechanisms with government-run research institutions.

Deloitte and the Council see this report as a foundation for ongoing dialogue with key stakeholders, such as industry, government, labor, academia, and national labs. The insights and recommendations developed here can further foster and enable an ecosystem in which research institutions and industry work together for mutual benefit and the betterment of society.

Highlights from the Advanced Technologies Initiative

The linkages between national prosperity and advanced technologies, manufacturing and the innovation ecosystem

- The US manufacturing industry, increasingly propelled by advanced technologies, comprises a large portion of the economy, and drives economic prosperity through higher levels of productivity, output, high value exports and higher income jobs than other industries.
- 21st century manufacturing competitiveness has fully converged the digital and physical worlds where advanced hardware combined with advanced software, sensors, big data and analytics results in smarter products, processes, and more closely connected customers, suppliers, and manufacturers.
- Across dozens of interviews and hundreds of survey responses, senior executives consistently stressed as their highest priority the importance of digital technology, including the use of advanced sensors, the 'Internet-of-Things' as well as 'Predictive Analytics,' in driving their future competitiveness. In addition, 'Advanced Material Science' was also a key priority.
- Many nations, including the United States, have invested heavily in establishing national innovation ecosystems which connect people, resources, policies and organizations to collectively translate new ideas into commercialized products and services.
- Executives indicated the US retains a leadership position in research, technology and innovation having created a strong foundation over the past century including: an educational system that fosters creative thinking, superior talent, world's leading universities, excellent research infrastructure, solid venture capitalist presence, and strong support for regional innovation clusters.

Global R&D trends and America's relative position

- Although the United States currently enjoys a leadership position, the gap in terms of R&D competitiveness is narrowing rapidly as countries, such as China, have been aggressive in attracting and nurturing STEM (Science, Technology, Engineering, and Math) talent, building domestic R&D capabilities, and offering attractive R&D incentives to foreign companies. In fact, some experts are projecting China may overtake the US in R&D spend by 2019.
- Nations have different research strategies and approaches. Both the United States and China have spread their R&D expenses across various industries including: computers & electronics, pharmaceuticals, and industrial machinery. However, other countries take a more focused approach – i.e., both Japan and Germany center their R&D efforts on the automotive and computers & electronics sectors, while more than half of South Korea's manufacturing R&D expenditure is in computer & electronics alone.
- Businesses account for the majority of R&D spend, an accelerating trend across leading nations. In addition, US companies dominate the global R&D spending landscape with 41 of the top 100 global companies (in terms of R&D spend).
- While US government spending on R&D has grown in real terms this past decade, it has declined as a percentage of the total federal budget, putting the basic and applied R&D leadership position of government-sponsored research institutes at risk.

Opportunities for US industry

- A host of promising long-term global trends will help provide opportunities for US companies to spur growth and innovation, including: an expanding middle class and rapid urbanization across Asia, increased global demand for commercial aircraft, the rapid technological advances in the auto industry (e.g., autonomous vehicles), increased output in the US chemicals and industrial machinery sectors.

Challenges for US industry

- Challenges faced by US companies include: a significant talent shortage and widening skills gap, alignment to foreign market conditions and business environments, coping with weak Intellectual Property (IP) regime globally, and the high cost and complexity of compliance in an uncertain US regulatory environment.

Industry Innovation Playbook

- In order for companies to grow and succeed in the highly competitive global innovation space, there are a number of key insights to guide solid business strategy development, including: thinking like a venture capitalist to adopt a risk tolerant portfolio approach, operating outside of traditional walls to take advantage of collaboration opportunities across the innovation ecosystem, and understanding there is no singular solution where the path to success is forged in synergistic solutions and perseverance.

List of executive interviewees

- **Le Tang, Ph.D.**—Vice President & Head of US Corporate Research Center, ABB
- **Darlene Solomon, Ph.D.**—Senior Vice President & Chief Technology Officer, Agilent Technologies
- **Christine Tovee**—Chief Technology Officer, Airbus North America
- **Peter B. Littlewood, Ph.D.**—Laboratory Director, Argonne National Lab
- **Barbara Burger, Ph.D.**—President, Chevron Technology Ventures
- **Carmelo Lo Faro, Ph.D.**—Vice President & Chief Technology Officer, Cytec Industries
- **Klaus G. Hoehn, Ph.D.**—Vice President, Advanced Technology & Engineering, Deere & Company
- **Dean Bartles, Ph.D.**—Executive Director, Digital Manufacturing and Design Innovation Institute
- **A.N. Sreeram, Ph.D.**—Corporate Vice President & Chief Technology Officer, The Dow Chemical Company
- **Stephen G. Crawford**—Senior Vice President & Chief Technology Officer, Eastman Chemical Company
- **Ram Ramakrishnan**—Executive Vice President & Chief Technology Officer, Eaton Corporation
- **Ken Washington, Ph.D.**—Vice President, Research & Advanced Engineering, Ford Motor Company
- **Mark M. Little, Ph.D.**—Former Senior Vice President, Director of Global Research & Chief Technology Officer, General Electric Company
- **Gregory Powers, Ph.D.**—Vice President of Technology, Halliburton Company
- **I.P. Park, Ph.D.**—Executive Vice President & Chief Technology Officer, Harman International
- **Alex Dickinson, Ph.D.**—Senior Vice President, Strategic Initiatives, Illumina, Inc.
- **Tilak Agerwala, Ph.D.**—Research Emeritus & Former Vice President, Data Centric Systems, International Business Machines Corporation (IBM)
- **Jan Ziskasen**—Chief Technology Officer, Kraft Foods Group, Inc.
- **Paul J. de Lia**—Corporate Vice President of Science and Technology & Chief Technology Officer, L-3 Communications Corporation
- **Horst Simon, Ph.D.**—Deputy Laboratory Director, Lawrence Berkeley National Lab (LBNL—'Berkeley Lab')
- **Bill Goldstein, Ph.D.**—Laboratory Director, Lawrence Livermore National Lab (LLNL)
- **John B. Rogers, Jr.**—CEO and Co-Founder, Local Motors
- **Ray O. Johnson, Ph.D.**—Former Senior Vice President & Chief Technology Officer, Lockheed Martin Corporation
- **Ajay P. Malshe, Ph.D.**—Founder, Executive Vice President and Chief Technology Officer, NanoMech, Inc.
- **Dan Arvizu, Ph.D.**—Former Laboratory Director & Chief Executive, National Renewable Energy Lab (NREL)
- **Thomas E. Mason, Ph.D.**—Laboratory Director, Oak Ridge National Laboratory (ORNL)
- **Steven Ashby, Ph.D.**—Laboratory Director, Pacific Northwest National Laboratory (PNNL)
- **Mehmood Khan, Ph.D.**—Vice Chairman & Chief Scientific Officer, Global Research & Development, PepsiCo, Inc.
- **Diego Olego, Ph.D.**—Senior Vice President & Chief Strategy and Innovation Officer, Philips Healthcare
- **Kurt G. Olson, Ph.D.**—R&D Fellow, PPG Industries
- **Paul Hommert, Ph.D.**—Former Laboratory Director, Sandia National Laboratories
- **Cyril Perducat**—Executive Vice President, Digital Services and IoT, Schneider Electric S.E.
- **Patrick J. Byrne**—President, Tektronix, Inc.
- **Douglas H. Smith**—Product Line Vice President, Tapered Roller Bearings, The Timken Company
- **David L. Britten**—Senior Vice President & Chief Technology Officer, United States Steel Corporation
- **J. Michael McQuade, Ph.D.**—Senior Vice President, Science and Technology, United Technologies Corporation
- **Martin Thall**—Executive Vice President & President, Electronics, Visteon Corporation
- **Timothy D. Leuliette**—Former President & CEO, Visteon Corporation

Approach and methodology

Voice of Industry

Between July 2014 and March 2015, on behalf of the Council, senior leaders at Deloitte held discussions, on a pro-bono basis, with approximately three dozen senior executives at some of the world's largest manufacturing organizations, as well as at a number of key small start-ups, where a great deal of technology innovation is scaled. These companies—both public and private enterprises—represent large swaths of manufacturing employment, including diversified manufacturing, process and industrial products, consumer products, automotive, aerospace and defense, technology, and life sciences. Participating companies included firms such as ABB, Kraft, Deere & Company, Dow Chemical Company, PepsiCo, Ford Motor Company, General Electric, IBM, and Lockheed Martin Corporation. Interviews were conducted on a one-to-one basis, primarily face-to-face in a given executive's office, with some discussions carried out over the telephone.

In these hour-long discussions, the project team sought each executive's views on:

- The US and global business environment for technology innovation, including incumbent technologies, talent/workforce issues, existing and emerging business models, and vulnerabilities/concerns relative to company- and country-level competition in technology leadership.

- Short- and long-term recommendations on what federal and state policy makers should do to foster the development of advanced technologies and innovation within the United States.

- Important areas individual companies must address to effectively compete in the global marketplace over the next five years.

In order to generate useful insights and provide recommendations in a broader context, the project team used a combination of primary and secondary research. In addition to the primary research described above, secondary research was used to supplement insights from the interviews by mining and analyzing quantitative data from credible sources such as the Organization for Economic Cooperation and Development (OECD), think tanks like the Brookings Institution, as well as key academic and industry literature.

Voice of National Labs

As part of this effort, Deloitte, on behalf of the Council, also conducted in-depth interviews and discussions with directors of eight US Department of Energy national laboratories and other officials at tech transfer offices, as well as with representatives from the newly created National Network of Manufacturing Innovation (NNMI) centers. These national labs conduct a significant amount of basic, as well as applied research in the United States; while some have specific focus areas like renewable energy, others carry out multifaceted R&D work. These interactions were held on an individual basis, either at the lab or over the telephone.

The following points were explored:

- Prospects for US technology innovation within the domestic and global innovation environment.
- Top concerns about the prospects for US technology leadership over the short- and long-term.
- Most promising, attractive, and impactful technologies, and the challenges associated with developing such technologies.
- Level of engagement with industry and recommendations for improving interactions.
- Important areas the United States must address to remain technologically competitive in the long term.

SECTION ONE

Importance of advanced industries and assessing America's competitive standing

Advanced industries* drive national prosperity

Executives interviewed expressed . . .

Innovation and advanced technologies are critical to company-level competitiveness: They differentiate businesses and help them thrive amid global competition by creating premium products, processes, and services that capture higher margins. Without differentiation through technology or innovation, companies are more likely to become cost-driven commodity businesses, making it difficult for them to succeed in the long run. The future growth potential of advanced technologies and the products and services they enable is sizable; this growth potential is a core component of many companies' overall future growth strategy.

Advanced manufacturing strengthens economies and creates higher-income jobs: Technologically advanced manufacturing industries employ a higher-skilled workforce that earns higher wages than workers employed by traditional industries. These industries create a greater proportion of jobs in the entire value chain, leading to a higher standard of living for the nation overall.

Innovation and economic growth have a compounding and symbiotic effect: A strong, innovative, and technology-savvy manufacturing base leads to long-term economic prosperity and growth. This industrial base flourishes when a country provides an integrated support structure (i.e., economic, trade, financial, infrastructure, policy, energy, and natural resource predictability and sustainability, as well as investments in innovation and education). A strong support structure attracts more businesses, which, in turn, creates more demand for high-paying jobs, thereby attracting more top-tier talent. These foundational elements build upon each other and become incrementally more valuable as the innovation ecosystem grows. This phenomenon presents both industry and government with a win-win situation that should encourage them to collaborate to build a strong and vibrant national innovation ecosystem.

In 2013, US advanced industries **supported 40.0 million workers** and accounted for **$2.7 trillion in output—17 percent of US GDP**

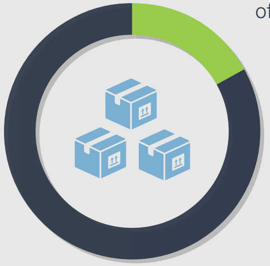
US Employment

70 percent of advanced industries in the United States are advanced manufacturing industries.

29%
of US employment
= 40 million jobs

US Output ($ trillion)

Advanced industries constitute a significant portion of the US economy.

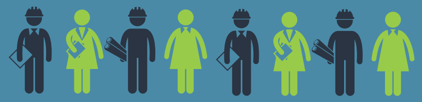


17%
of US GDP = $2.7 trillion

US advanced industries ...

… employ **80 percent** of the nation's engineers (~ 5 million) …

80%



… generate approximately **85 percent** of all US patents (~ 360,000) …

85%

… perform **90 percent** of private-sector R&D (~ $250 billion) …

90%

… and account for **60 percent** of US exports (~$600 billion).

60%

Source: Brookings Institution, World Bank and Bureau of Labor Statistics.[i]

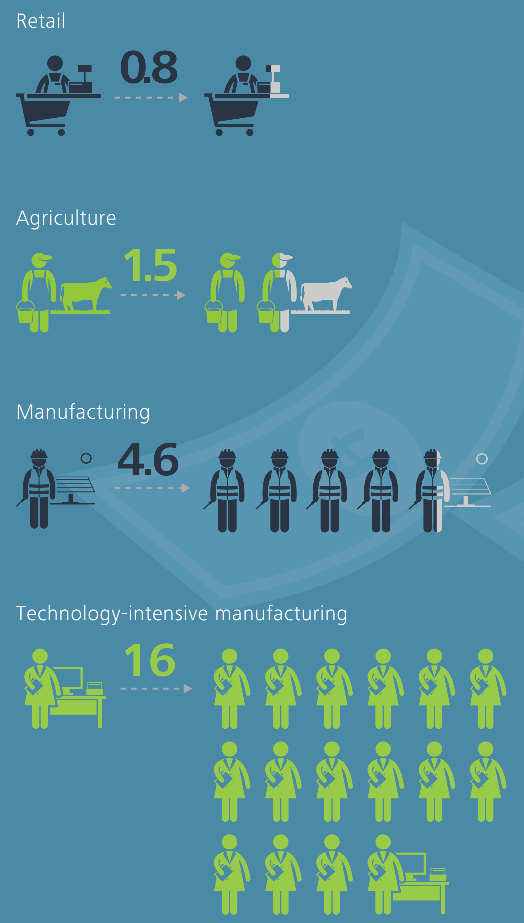
*Advanced industries as defined by Brookings Institution are based on two criteria: R&D spending per worker and share of workers working in occupations requiring high STEM knowledge. The industry's R&D spend per worker must fall in the 80th percentile of industries or higher, and it must have more than 21 percent of all workers, working in high-STEM knowledge requiring occupations - to be called an advanced industry.[1a]

Advanced industries generate more jobs, output, and worker compensation

> **"** The impact of next-generation technologies on advanced industries will be significantly high. From creating high-value jobs to increasing worker prosperity and productivity, they will alter the way these industries operate. **"**
>
> — Executive interviewee

Generates knock-off effect

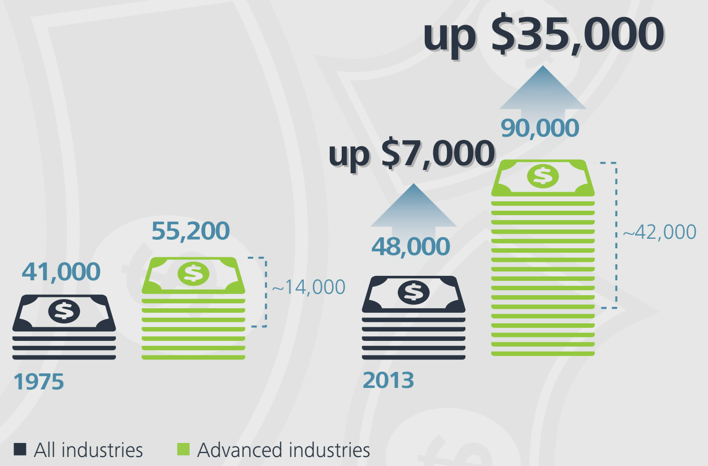
Every 1 direct job ... creates additional jobs



Source: US Bureau of Economic Analysis and Bloomberg.[ii]
Note: For detailed explanation of job multipliers, please see endnote 1b.

Average annual compensation per worker ($)

Average worker compensation in US advanced industries has increased **five times** that of all industries since 1975.



US output per employee

In 2013, GDP output per worker in advanced industries was **almost twice** that of all industries in the United States.

Source: Brookings Institution, World Bank and Bureau of Labor Statistics.[i]

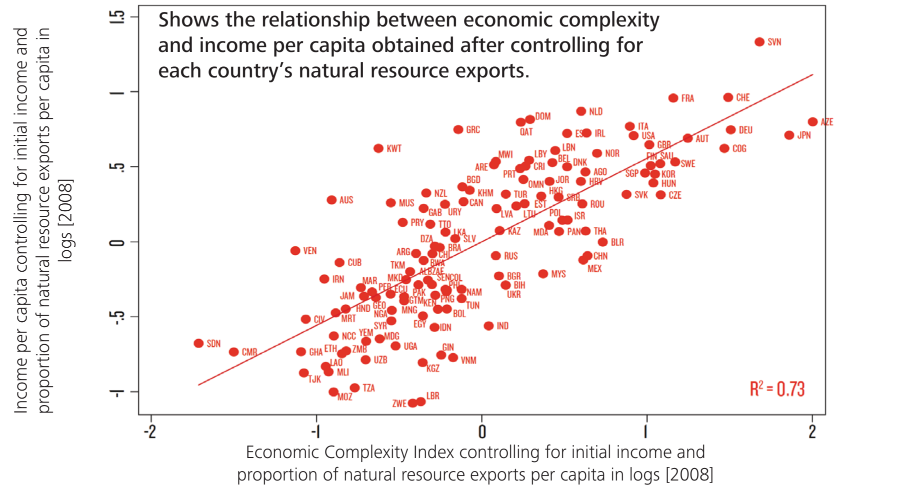
Use of advanced technologies to produce complex products enhances export competitiveness, leading to greater economic prosperity

Economic complexity leads to greater prosperity: Research by Harvard professor Ricardo Hausmann and MIT professor César Hidalgo confirms that producing more-complex products with high export potential, by developing and deploying more-advanced manufacturing processes, leads to greater economic prosperity for a nation and its citizens.[1c]

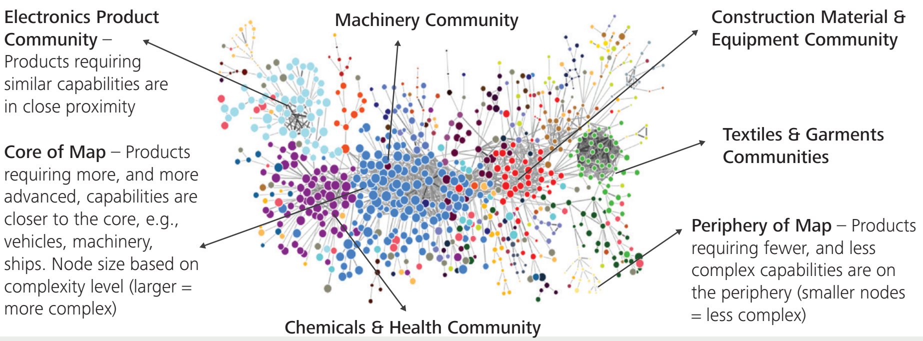
The economic complexity index by Hausmann and Hidalgo explains 73 percent of variation in income per capita (a measure of economic prosperity) across 128 nations—a level of accuracy which is much higher than other leading global indices.[1c]

- **What should countries do?[1]**
  - **The path to prosperity becomes easier by building unique knowledge and capabilities:** Economic complexity is directly related to acquiring and developing manufacturing capabilities. Nations that have accumulated knowledge around production processes and developed manufacturing capabilities that other economies do not possess, produce more sophisticated and exclusive products, boost their exports, and become more prosperous.
- **How should they do it?[1]**
  - **Nations need to continuously invest in research & development (R&D) to develop strong manufacturing know-how:** Advanced manufacturing capabilities, in turn, depend on a nation's investment in cutting-edge R&D activities. Realizing this indirect yet powerful link between economic prosperity and R&D investment, advanced economies – such as the United States, Japan, Germany, Korea, and Singapore – that have invested heavily in R&D and research talent, have also benefited from increased high-tech exports and higher productivity.

GDP per capita vs. Economic Complexity Index



Product Space Network - An Illustration



Source: The Atlas of Economic Complexity.[iii]

The product space network gives a snapshot of a nation's economic complexity. According to The Atlas of Economic Complexity, the more complex products a nation exports, the higher is its per capita income.

The path towards developing manufacturing complexity is slow and gradual and depends on developing "adjacent possibilities"[1]

- **Economic complexity results from product complexity:** More complex and diverse product sets mean more advanced manufacturing capabilities and a more complex economy. For example, a greater focus on making high-tech products like cars, electronics and aircraft parts for exports have made the economies of the United States and Germany more complex over time.

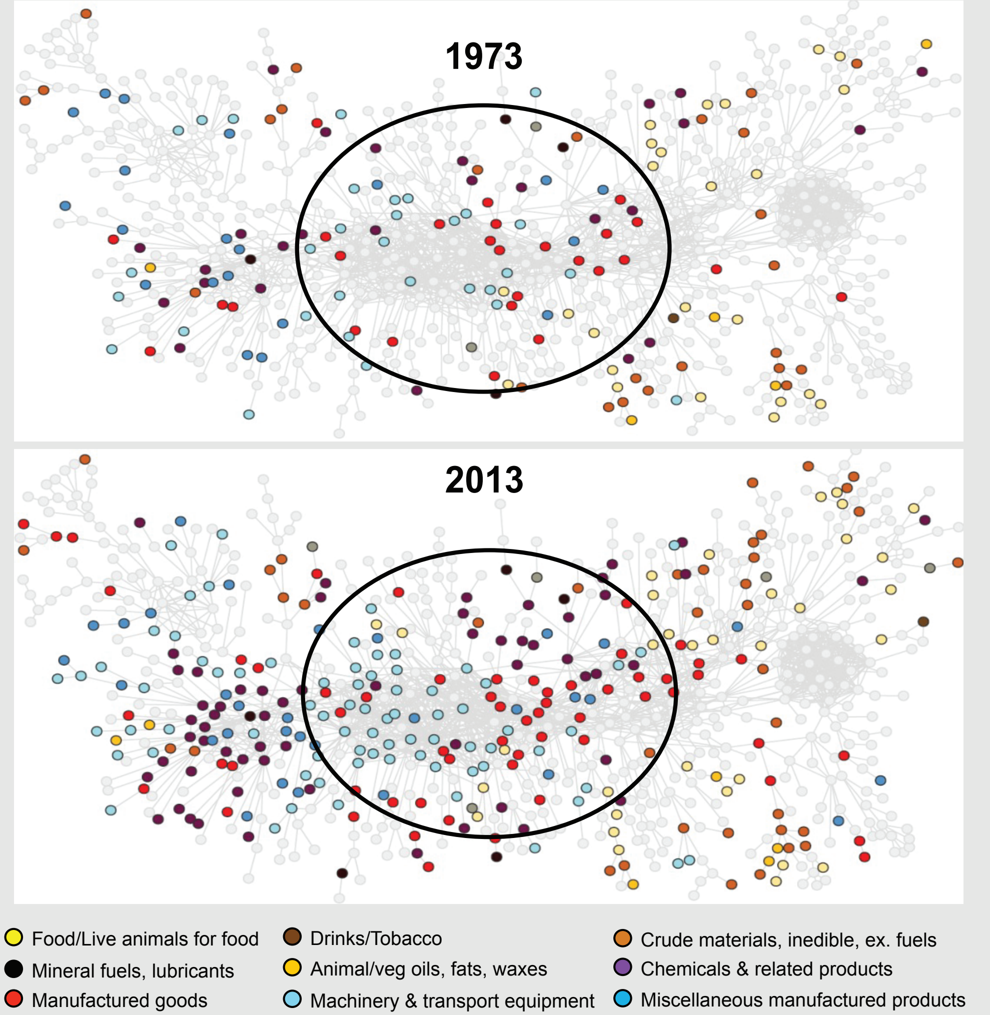
- **Economies find it easier to master new products that are similar to the ones they already make:** For example, it is easier for an economy that is good at assembling toys to start assembling televisions than to jump from making textiles to aerospace products. The feasibility of these jumps is defined as "adjacent possibilities."

- **The key lies in making the right "jumps":** By making the right jumps, a nation can advance its manufacturing knowledge and capabilities and thus produce advanced products and technologies that only a few nations might be capable of producing.

Concentration of products at the "core" has increased over the last four decades (1973 - 2013), indicating during that period, the United States has increasingly exported products that require more advanced capabilities, such as complex machinery and transport equipment.

> "While complexity is normally something manufacturing organizations try to avoid, complex economies based on sophisticated networks of manufacturing knowledge, capabilities, and product sets are a good thing."
> — The Future of Manufacturing, Deloitte and World Economic Forum[1]

Product space network - United States*



*Increase in concentration of dots at the core indicates gradual transition to a complex economy with sophisticated product networks.

Source: The Atlas of Economic Complexity.[iv]

Advanced technologies will unlock new opportunities…

21st century advanced manufacturing has fully converged the digital and physical worlds where advanced hardware combined with advanced software, sensors, and massive amounts of data and analytics results in smarter products, processes, and more closely connected customers, suppliers, and manufacturers.

United States

'Predictive Analytics,' 'Internet-of-Things' and 'Advanced Materials' are considered the most promising in the United States
Across dozens of interviews as well as hundreds of survey responses,[2] US executives consistently stressed as their highest priority the importance of digital technology, including the use of 'Predictive Analytics.' They were also looking to place significant focus on innovative, smart and connected products. While interviewees were highly engaged in discussing the question of which technologies are the most attractive and/or promising, and as most of the interviewed executives discussed and debated nearly every technology we asked them about, there was a strong collective focus on and interest in advanced manufacturing technologies such as 'Predictive Computing and Analytical Modeling,' 'Connected Technology/Sensors (i.e., the Internet-of-Things or the "IoT),' as well as 'Advanced Materials' such as 'Advanced Ceramics and Composites.' Collectively, the interviewees felt many of these advanced technologies were promising—especially when used together in a synergistic manner—and such technologies would be vital to their companies' future.

China

China is prioritizing 'Predictive Analytics' to close gap with the United States and create competitive advantage through 'High Performance Computing (HPC)'[2]
In China, the highest ranked forward-looking strategy for advanced manufacturing technologies centers on 'Predictive Analytics' which aligns with the top priority in the United States. Companies in China are also looking to extend their manufacturing competency with a focus on developing 'Smart Factories (IoT)' to close the gap with global leaders including the United States. However, in contrast to strategies being followed in both the United States and Europe, China is also prioritizing the focus on 'High Performance Computing (HPC)' going forward, creating a potential "blind spot" for American and European companies looking to maintain their competitive position on the global stage.

Europe

Integrated European priorities are very much aligned with "Industry 4.0"[2]
In European markets, the top strategic focus for advanced technology manufacturers is around creating an integrated and connected closed loop design and build process, with 'Smart Factories (IoT)' as their top focus. A second priority for companies in Europe centers on developing 'Smart Products' followed by increased efforts on the 'Digital Design and Simulation Technologies.' Considered as a group, these top three priorities represent a very integrated, strategic approach to advanced technologies going forward.

…and underpin global manufacturing competitiveness strategies

Ranking of future importance of advanced manufacturing technologies, by executives

Advanced Manufacturing Technologies	United States	China	Europe
Predictive Analytics	1	1	4
Smart, Connected Products (IoT)	2	7	2
Advanced Materials	3	4	5
Smart Factories (IoT)	4	2	1
Digital Design, Simulation, and Integration	5	5	3
High Performance Computing	6	3	7
Advanced Robotics	7	8	6
Additive Manufacturing (3D Printing)	8	11	9
Open-Source Design / Direct Customer Input	9	10	10
Augmented Reality (to improve quality, training, expert knowledge)	10	6	8
Augmented Reality (to increase customer service & experience)	11	9	11

Note: The 2016 Global Manufacturing Competitiveness Index (GMCI), conducted by Deloitte and Council on Competitiveness, studied perspectives from over 500 global executives around key drivers of manufacturing competitiveness, including advanced manufacturing technologies.

Source: 2016 Global Manufacturing Competitiveness Index, Deloitte and Council of Competitiveness.[2]

The United States is a global leader

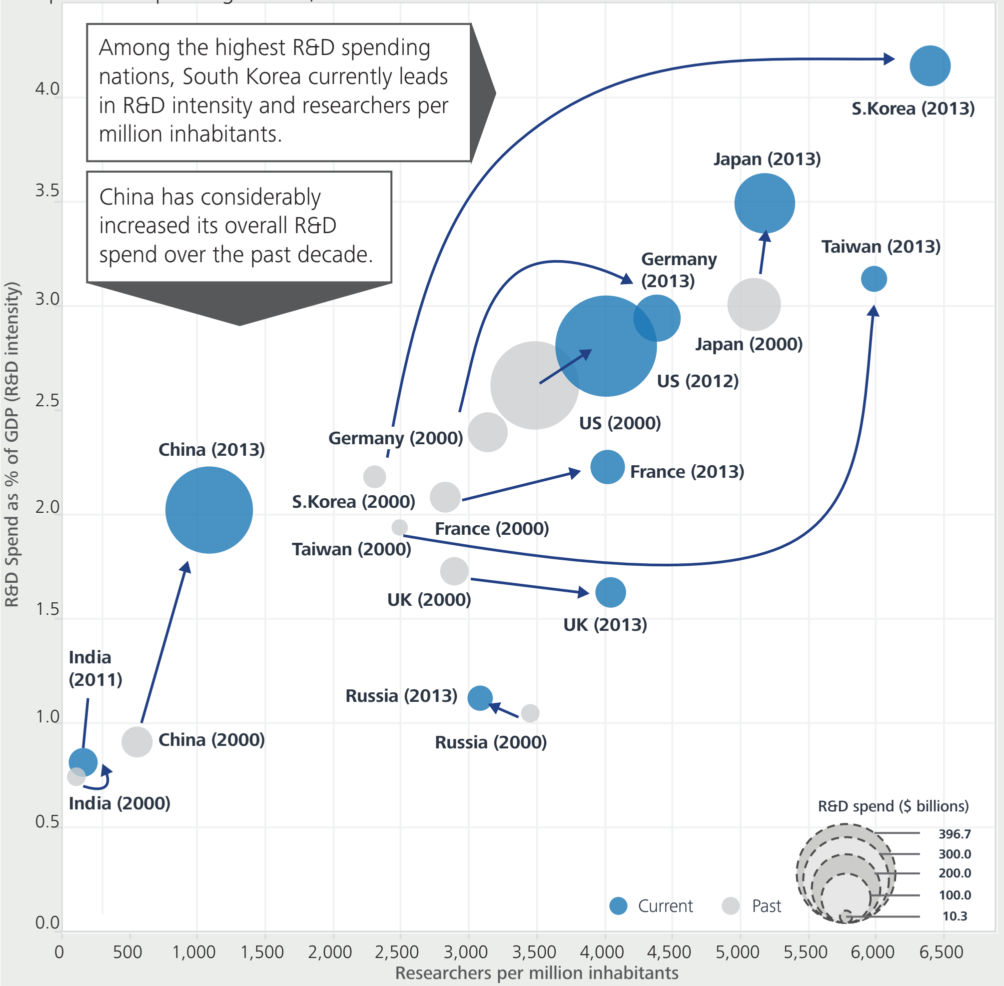
According to the executive interviews conducted, the United States is a global leader in research, technology and innovation. This positions the US well to actualize the substantial promise of advanced technologies and further strengthen its advanced industries. Specifically, the United States has:

- **First-rate research talent and infrastructure:** The United States has top-tier universities which provide requisite talent, while their dedicated research institutions and labs attract highly qualified researchers and scientists from around the world.
- **Top-notch technology firms:** From blue chips to successful start-ups, the United States is home to an enviable number of technologically advanced, innovative companies.
- **Strong, dedicated industrial clusters:** US industrial clusters act both as well-connected R&D centers and as manufacturing hubs characterized by strong collaboration among industry, research, entrepreneurs, and academia. Examples include the IT cluster (Silicon Valley) in San Francisco, the biotechnology cluster in Boston, and the automotive cluster in Detroit.

> "America's R&D leadership is due to its robust strength in academic and research institutions, the creativity of its people, and its entrepreneurial abilities."
>
> — Executive interviewee

The changing global R&D landscape

R&D as percentage of GDP vs. Researchers per million,
Top 10 R&D spending nations, 2000 and 2013



Note 1: Size of bubbles indicates absolute R&D spend in $billions in constant 2005.
Note 2: For the United States, 2012 R&D spend and R&D as % of GDP was the latest available data; For India, only 2011 data was available for all three metrics.

Source: Deloitte analysis based on OECD and UNESCO Institute for Statistics data.[vi]

But the gap is closing . . . especially with countries like China

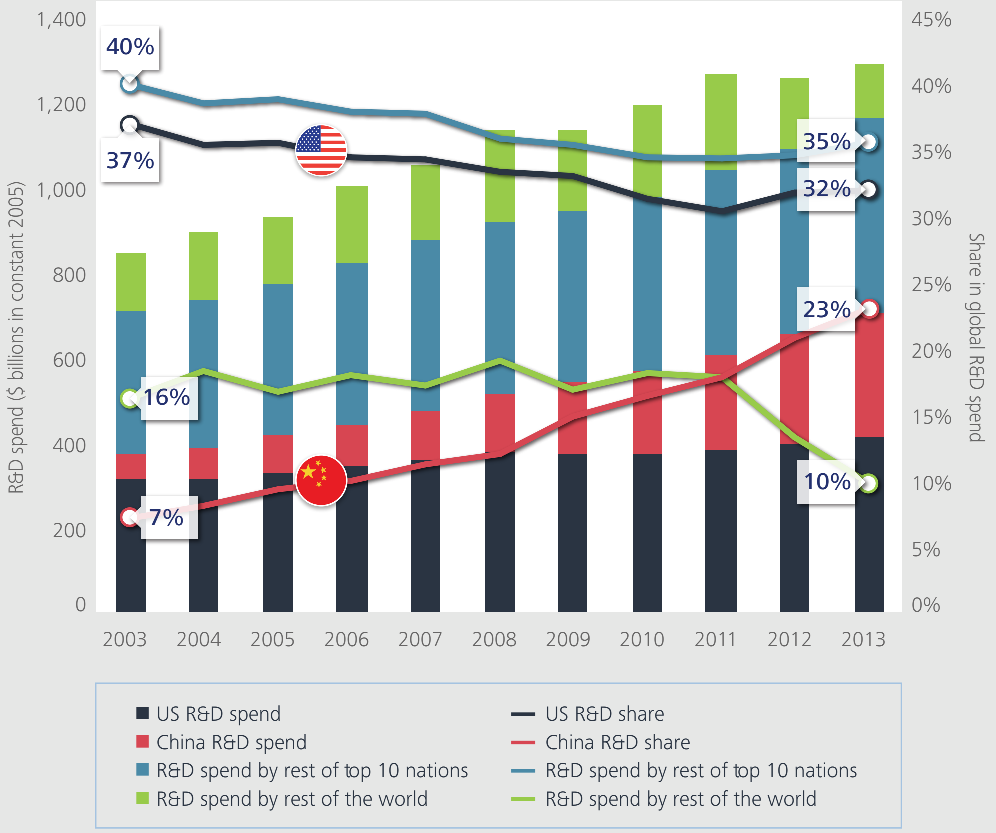
According to the executives interviewed, the gap between the United States and other nations in terms of R&D competitiveness is narrowing rapidly. Many attributed this phenomenon primarily to the growing competitiveness of emerging nations. These nations have been aggressive in attracting and nurturing STEM talent, building domestic R&D capabilities, and offering attractive R&D incentives to foreign companies. Meanwhile, slower economic growth, especially in developed nations, has curtailed R&D budgets, which has also significantly contributed to the narrowing of the gap.

An overwhelming majority of the interviewed executives and national lab directors indicated the United States still leads in technology innovation globally—but that the gap is closing.

> "China, in particular, has vastly improved its R&D capabilities since the 1990s, and is expected to overtake the United States as the nation with the highest R&D spend by 2019."
> — Organization for Economic Cooperation and Development (OECD)[3]

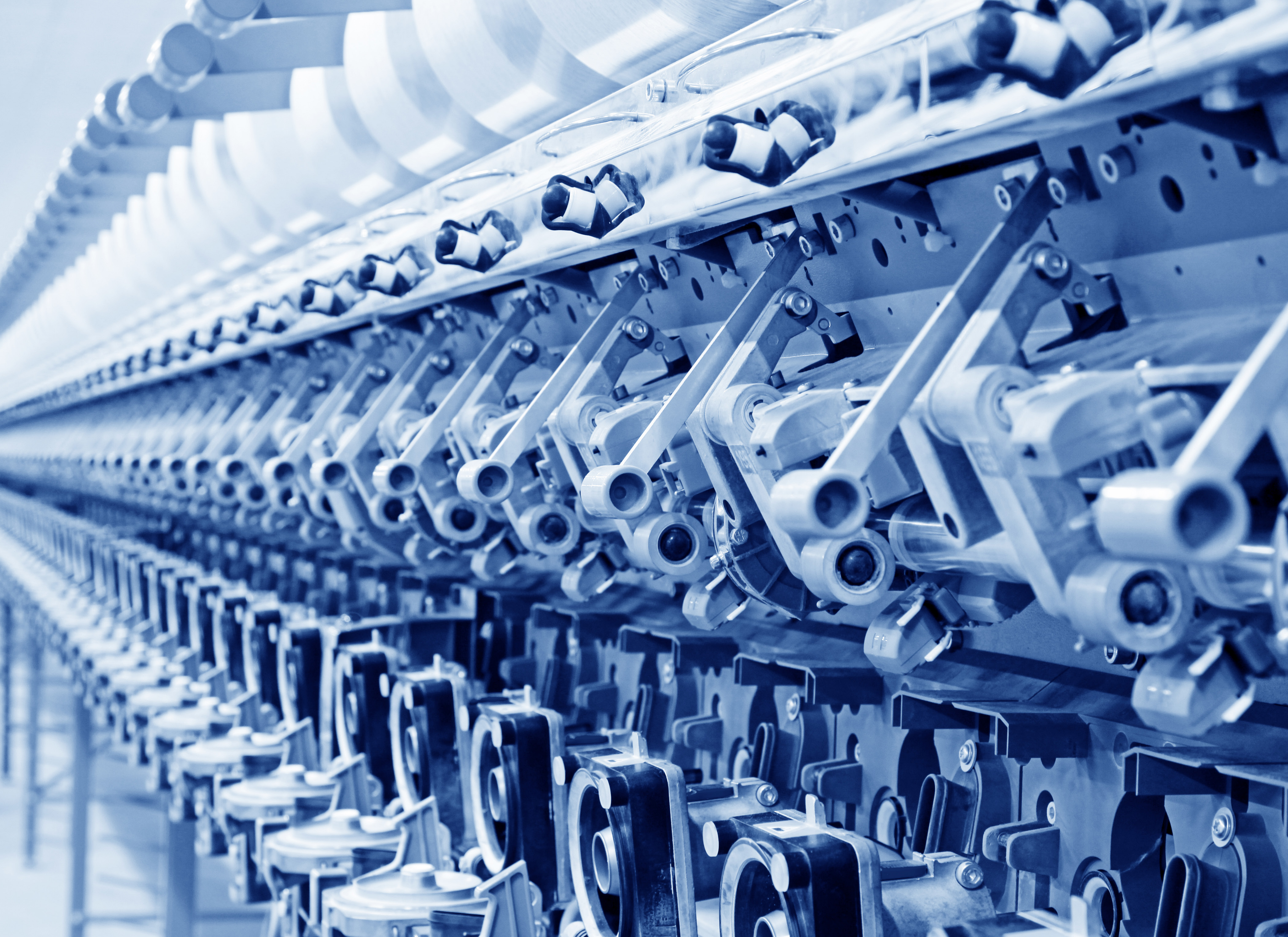
Rise of China within the global R&D landscape

R&D spend and share in global R&D spend, 2003–2013



Note: Rest of top 10 nations include Japan, Germany, Korea, France, United Kingdom, India, Taiwan, and Russia.

Source: Deloitte analysis based on OECD, Eurostat and UNESCO Institute for Statistics data.[vi]



The United States currently leads in many advanced industries

Source: Researcher survey conducted by Battelle and R&D Magazine.[vii]

SECTION TWO

Innovation—The ecosystem approach

Over the last century, the United States has created a strong foundation as an engine for innovation. However, the players and their roles, relationships, and technical focus have changed over the years . . .

Presence of big private monopolies and philanthropies

The beginning of second industrial revolution

1900s

Henry Ford introduces his Model T automobile

Business monopolies dominate US industries

Wright Brothers build the first engine-powered airplane

W.H. Carrier invents air conditioning

1910s

Texas becomes the hub of modern oil industry; Standard Oil's monopoly broken up

National Research Council (NRC) is created

First industrial research laboratories and large-scale mechanized industry started

World War-I brings additional applications of science and technology to weapons development

Ford builds the world's first assembly line

The age of depression and recovery

1920s

First successful launch of a liquid-fueled rocket by Goddard

Great Depression results in decline in all types of research

1930s

Prototype of the first digital computer gets built

Radio waves discovered

Dupont invents nylon

The beginning of computing age

1960s

IBM rolls out OS/360, the first mass-produced computer OS

NASA's Apollo 11 mission results in first human moon landing

The first laser is created at Hughes Research Lab

Maglev technology is patented by national labs

ARPANET, predecessor of the Internet, is invented at DARPA[4]

National labs launch vela satellites to detect nuclear detonations

1970s

First supercomputer, the Cray-1, is introduced

Corning glass invents fiber-optics that will later transform the communications industry

First shipments of bar-coded products arrive in American stores

Dissolution of big corporate R&D labs

1980s

The Internet, derived from the Defense's Advanced Research Projects Agency Network (ARPANET), has greater adoption

National labs pioneer advanced simulation and computing

First personal computer is introduced

NASA successfully launches and lands its reusable spacecraft, the Space Shuttle

AT&T corporation divests; Bell Labs downsizes and scales down its R&D profile

Industry overtakes govt. as the primary sponsor of R&D[5]

1990s

Space shuttle Discovery deploys the Hubble Space telescope

Human genome project starts

Google is founded

Researchers at national labs create ultra high-temperature ceramics

Online sales proliferate

New technology developed in hydrogen storage at national labs

2000s

Silicon Valley flourishes; Google X formed

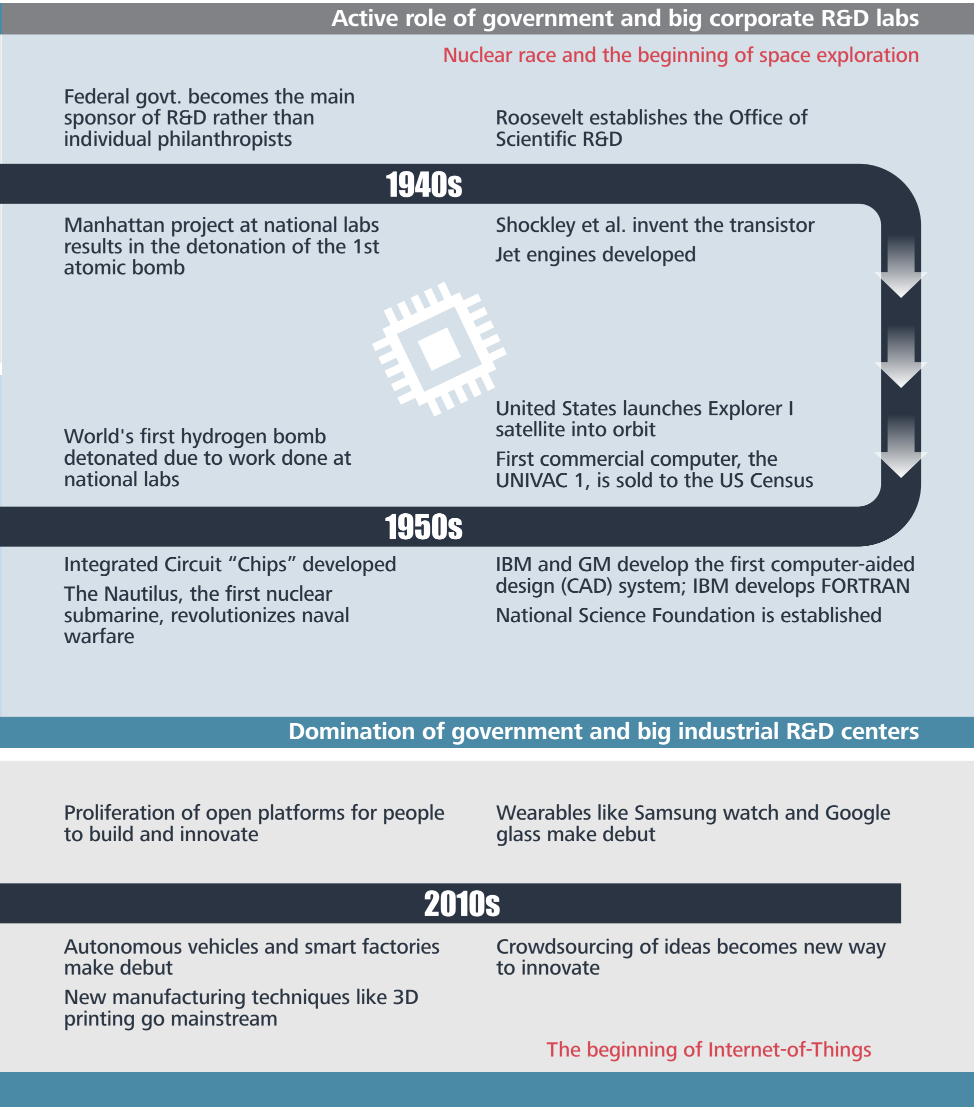
Some companies aim to capture half of their innovations from outsiders

Apple Inc. revolutionizes music listening by unveiling its iPod MP3 music player

Smartphones and tablets launched

The age of digital proliferation and internet era

Venture capital dominance, business R&D with short-term focus dominates and traditional borders blur



Sources: See endnote 6 for information.

...as physical and digital technologies converged and a historically "siloed" approach became collaborative

The US innovation ecosystem has evolved significantly over the last century, transitioning from business monopolies dominating R&D early last century, assertive government sponsorship mid-century, to the current environment, within a globally connected world, in which small and big businesses collaborate with universities, venture capitalists (VCs) and research institutions to drive the innovation ecosystem. Meanwhile, the **technological focus of R&D has followed a similar arc, shifting from the creation of physical to digital products, to the more recent digitization of physical products.**

- **Late 1800s to Pre-World War II: Big private monopolies dominated.** As big monopolies threatened consumer interests and thwarted competition, the US government passed the Sherman Antitrust Act of 1890 which gradually eroded the power of business monopolies. Despite this act, domestic monopolies did not completely vanish over the next half century, and its implementation was met with varying success. As a result, R&D funding for big industrial labs continued to come, predominantly, from monopolies and large corporations.[6a]
- **World War II and Post-War-Era: Government and large industrial labs (AT&T Bell Labs and Hughes Research Labs) became the main sponsors of basic research.** Basic and applied research agencies under the Department of Defense (DoD) and the Department of Energy (DOE) financed and performed a significant portion of the basic scientific R&D work which led to breakthrough innovations.[5]
- **21st Century:** With capital, Intellectual Property (IP) and talent flowing across borders with limited constraints, the United States faces fundamental questions of great importance to the future of its innovation ecosystem: How can it best cultivate the potential of advanced technologies to spur competitiveness? Can the United States continue to lead given the research spend and talent within other nations? Can the United States consistently find ways to bridge the valleys of death— between basic and applied research as well as applied research and commercialization?

Innovation ecosystems are important for sustaining a nation's global competitiveness

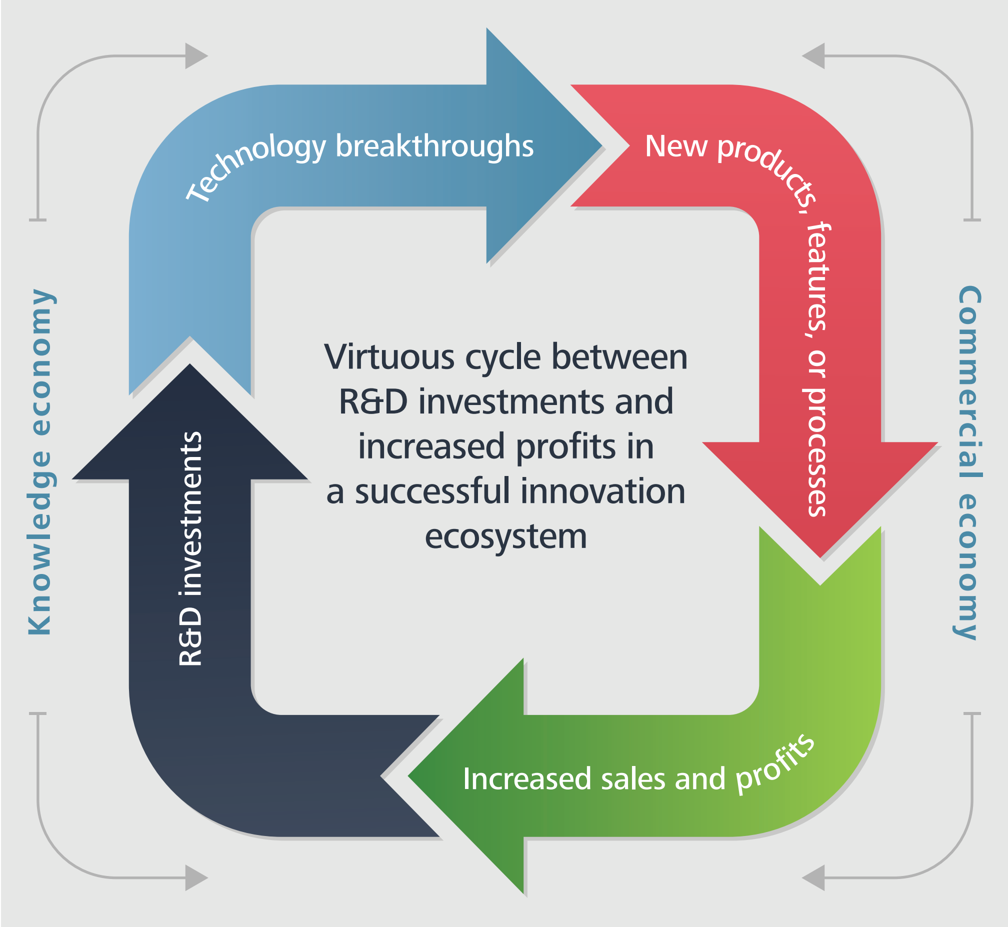
According to the executives interviewed, **the competitiveness of a nation ultimately depends upon the success of its national innovation ecosystem**. An innovation ecosystem is composed of people, resources, policies, and institutions that promote the translation of new ideas into tangible products, technologies, and services. Hence, a successful innovation ecosystem efficiently links resources invested in the knowledge economy to increased profits by creating new products, processes, and services.

These same executives also expressed **the current US innovation system possesses the critical attributes that positions it at the forefront of cutting-edge science, technology and innovation, namely through: an educational system that fosters creative thinking, superior talent, world's leading universities, excellent research infrastructure, solid venture capitalist presence, and strong support for regional innovation clusters.** All of these are instrumental in keeping America at the forefront of cutting-edge science, technology, and innovation.

> "The United States remains the epicenter of 'breakthrough innovations' thanks to the ready availability of excellent research infrastructure, highly skilled talent, and lower hurdles to innovation—all part of a smoothly functioning innovation ecosystem."

— Executive interviewee

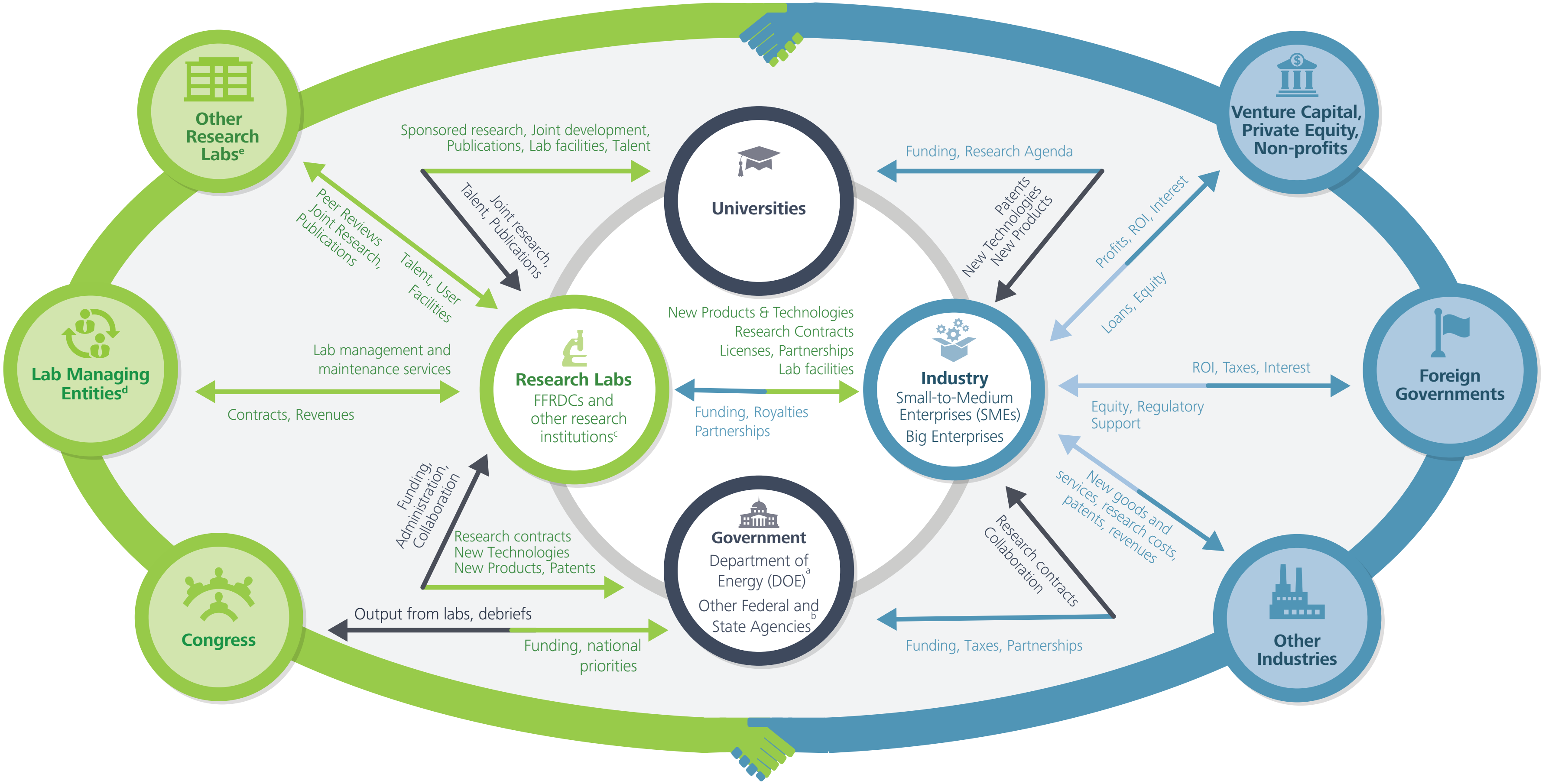
The Innovation Ecosystem - An illustration



Source: National Science Foundation.[viii]

An illustration of the current US innovation ecosystem

A byproduct of historical legacies and new market dynamics



a. DOE includes Office of Science, Office of Energy Efficiency & Renewable Energy (EERE), Office of Fossil Energy, Office of Nuclear Energy, National Nuclear Security Administration (NNSA), and Office of Environmental Management.

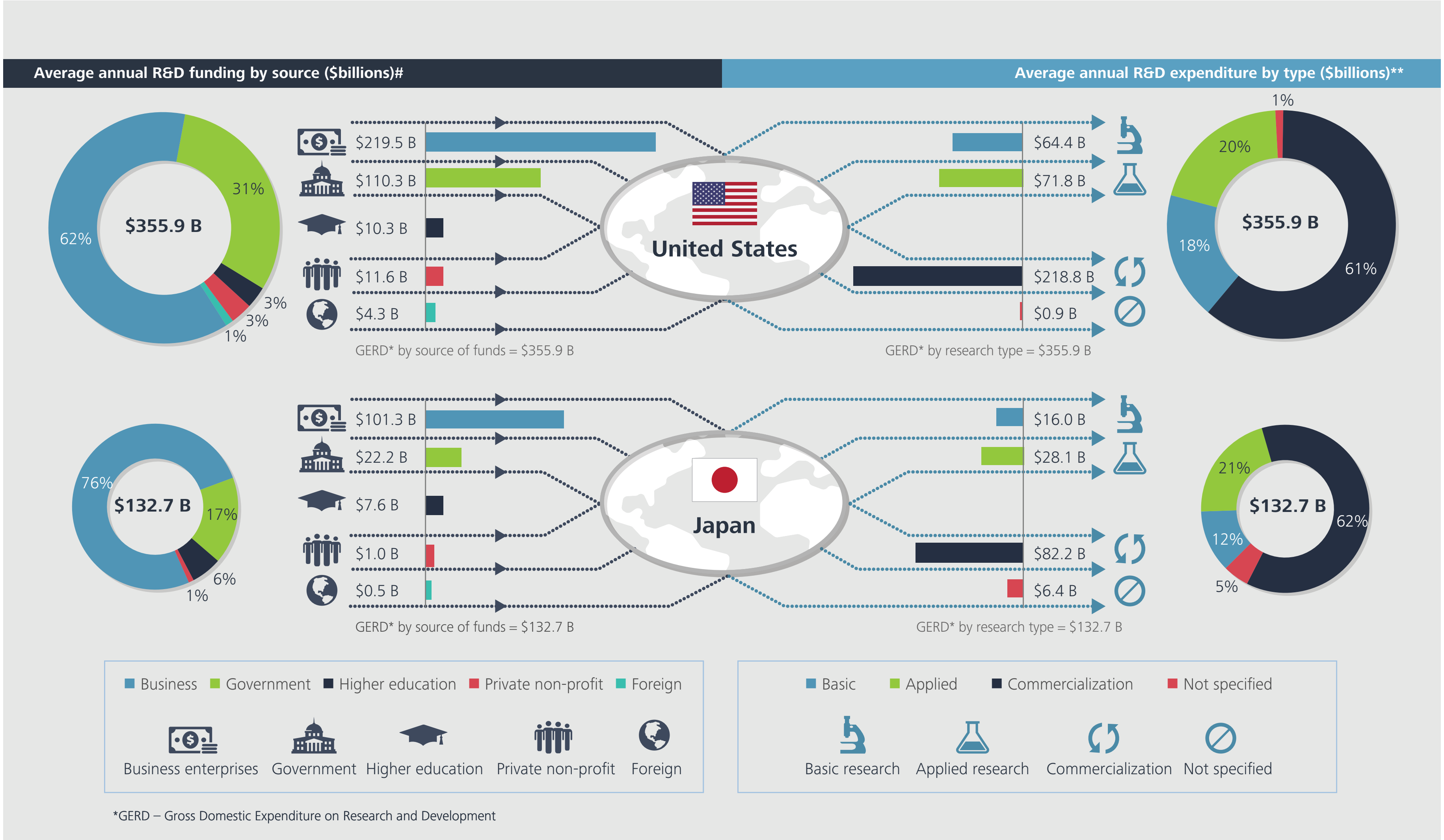
b. Other Federal and State Agencies mainly include National Institutes of Health (NIH), United States Department of Agriculture (USDA), Department of Defense (DoD), Department of Homeland Security (DHS), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), Office of Science and Technology Policy, and state governments.

c. National Labs include 17 federally funded R&D centers (FFRDCs) under DOE as well as a variety of other federally funded research labs.

d. Lab managing entities include: Battelle Memorial Institute, MRIGlobal, University of Chicago, Bechtel National, Inc., University of California, The Babcock & Wilcox Company, URS Corporation, University of Tennessee, University of California, and Lockheed Martin Corporation.

e. NNMI, DoD Labs, MIT Lincoln Lab, and other labs.

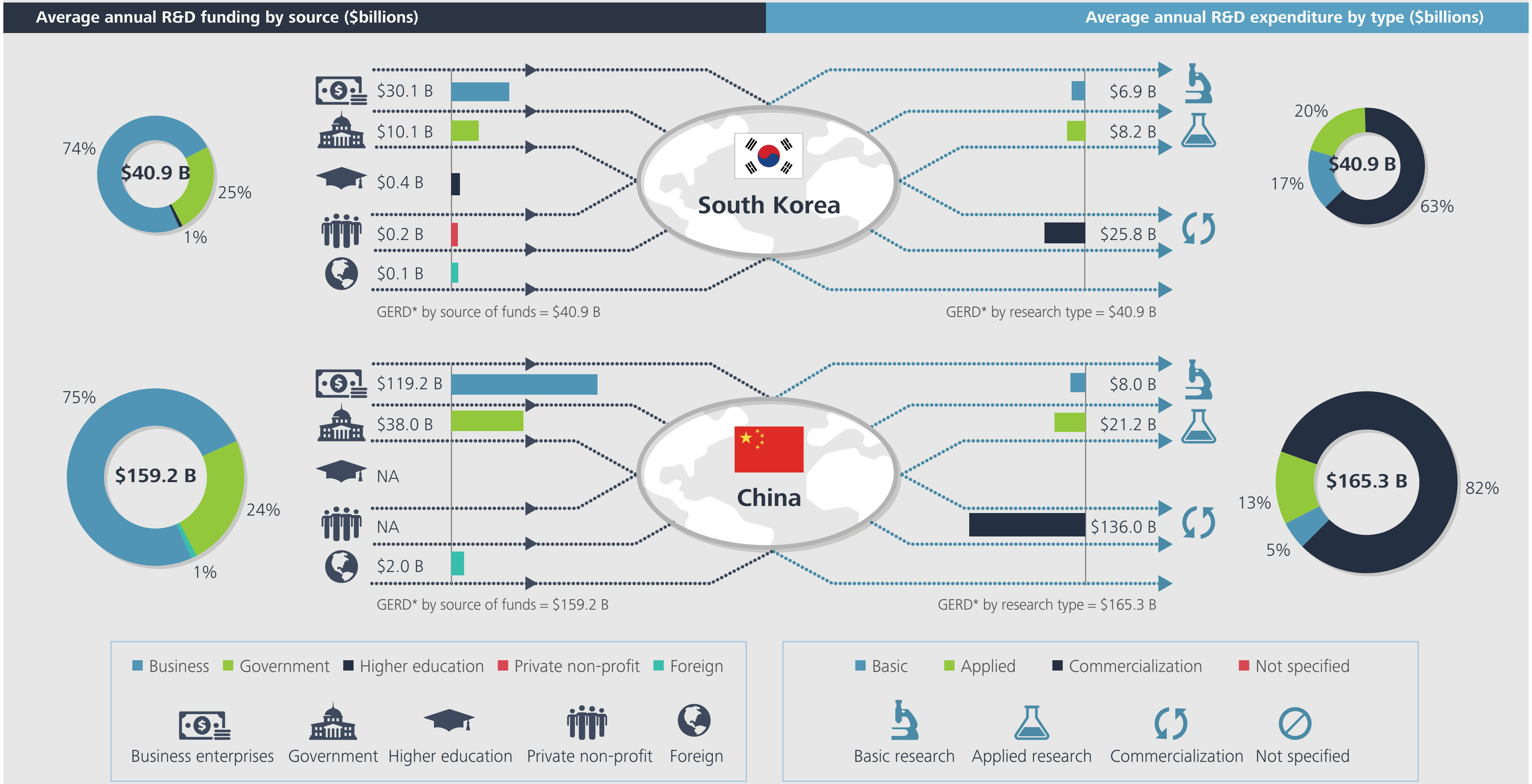
The US is still the biggest spender, especially in foundational areas like basic and applied research...



Source: Deloitte analysis based on UNESCO Institute for Statistics data.[ix]
Note: Data is based on 10-year averages, 2004-2013 (constant 2005 PPP dollars); for US, the average figures are for period 2003-2012.

Sources of R&D funds like business, government, higher education, private non-profit and foreign are explained in endnote 7.
** Types of research like Basic research, Applied research and Commercialization (experimental development) are defined in endnote 8.

...whereas the majority of R&D spend in China goes towards technology commercialization



Note: NA means not available.

* GERD - Gross Domestic Expenditure on Research and Development. For China, "GERD by source of funds" and "GERD by research type" do not match since R&D funds from higher education and private non-profit are not available from 2004 to 2013.

Source: Deloitte analysis based on UNESCO Institute for Statistics data.[ix]

Note: Data is based on 10-year averages, 2004-2013 (constant 2005 PPP dollars); for US, the average figures are for period 2003-2012.

The United States could further capitalize on its strengths—its prominent role in basic and applied research and geographic proximity of research to industry

- **The United States is a pioneer in basic and applied research and the government's role is to help maintain this position:** One of the most significant elements of basic research is we don't know how, when, or where the learnings will be precisely applied that lead to transformational breakthroughs, thereby making it more difficult for shorter term sector specific businesses to nurture it properly. Though US spending on basic research continues to outpace all other nations, **growth in its funding for basic and applied research domains has either declined or held flat over the last decade.** According to executives interviewed, a measure of the success of the US innovation ecosystem has been in part due to the government's unflinching focus on financing foundational basic and applied research, and supporting businesses involved in R&D through various incentives. However, executives also noted while government spending on R&D has grown in real terms this last decade, it has declined as a percentage of total federal budget, putting basic and applied R&D leadership position of research performed at government-sponsored research institutions at potential risk.

"As basic and applied research takes more time to deliver results in terms of tangible products and technologies, and businesses are mostly oriented toward obtaining short-term results, the onus of carrying out basic and applied research falls on the government."

— Executive interviewee

- **The US ecosystem should take advantage of its geographic proximity to national research assets:** US industries enjoy a competitive advantage over other nations as a significant amount of basic and applied research occurs within US borders. US businesses can help maintain this edge, and preempt competition, by bolstering mechanisms to translate these local research outputs into superior products and services before their competition does. This calls for efficient and effective collaborative mechanisms between industry, research labs, and other players in the ecosystem.

- **China currently focuses more on commercialization and less on basic and applied research:** In contrast to the United States, China's R&D budget tilts heavily toward spending on commercialization, with only a small portion allocated to basic and applied research. While this fast follower approach might not pose a significant threat to foundational innovation currently, should China switch gears and ramp up investments in foundational basic and applied research, it could pose a competitive threat to US leadership in the long run.

"Government support for applied research has been just as important to US industrial competitiveness as its support of basic research. Government-sponsored endeavors that have made a huge difference in the past three decades include DARPA's VLSI chip development program; DOE's Advanced Computing Initiatives; the DoD's and NASA's support of composite materials work; the NSF's funding of supercomputers and of NSFNET (an important contributor to the Internet); and the DoD's support of the Global Positioning System, to mention a handful."

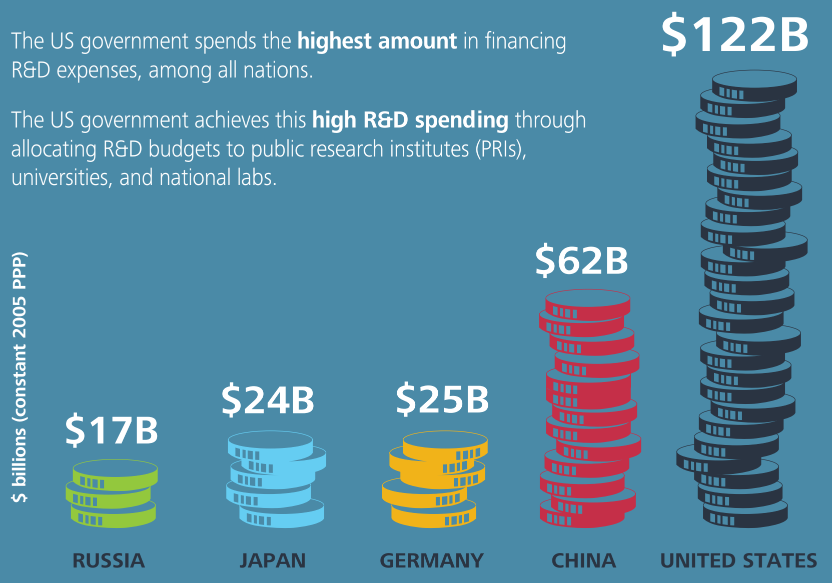
— Restoring American competitiveness, Harvard Business Review[9]

Though US federal funding of R&D is highest among nations, its basic and applied research spending has been flat or declining over the last decade

R&D financed by government ($billions), Top 5 nations, 2013

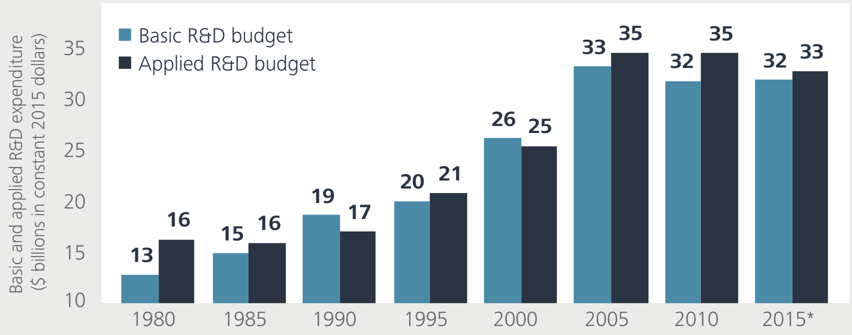
The US government spends the **highest amount** in financing R&D expenses, among all nations.

The US government achieves this **high R&D spending** through allocating R&D budgets to public research institutes (PRIs), universities, and national labs.

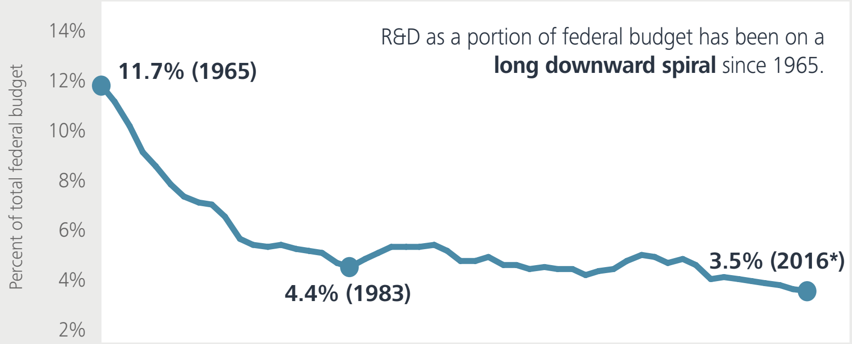


According to executives interviewed, despite the importance of basic and applied research in ensuring economic prosperity and national security, **budget allocations to key basic research agencies under the DoD and the DOE have been relatively flat or even declining over the years.**

Basic and Applied research funded by US government ($billions), 1980-2015



R&D budget as % of total federal budget, United States, 1965-2016



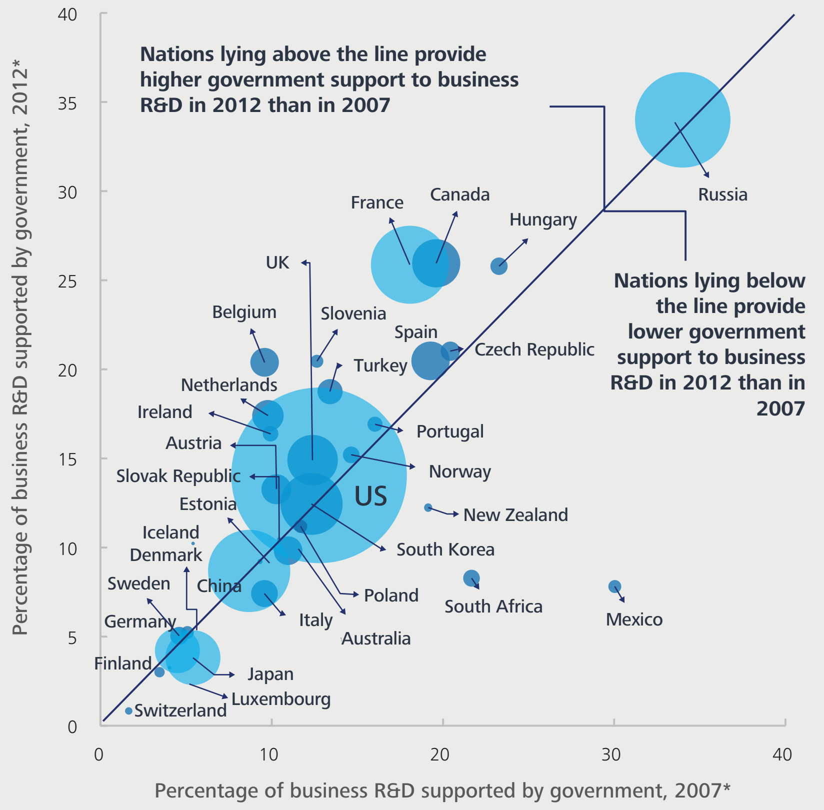
*Latest estimates

Source: Deloitte analysis based on data from UNESCO Institute for Statistics.[ix]

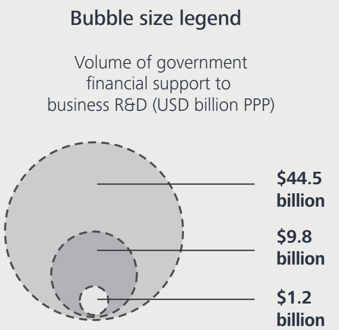
Source: Deloitte analysis based on data from American Association for the Advancement of Science (AAAS).[xi]

Many economies across the globe have increased their government R&D support to businesses

Percentage of total business R&D spend supported by government funds**, 2007 vs. 2012

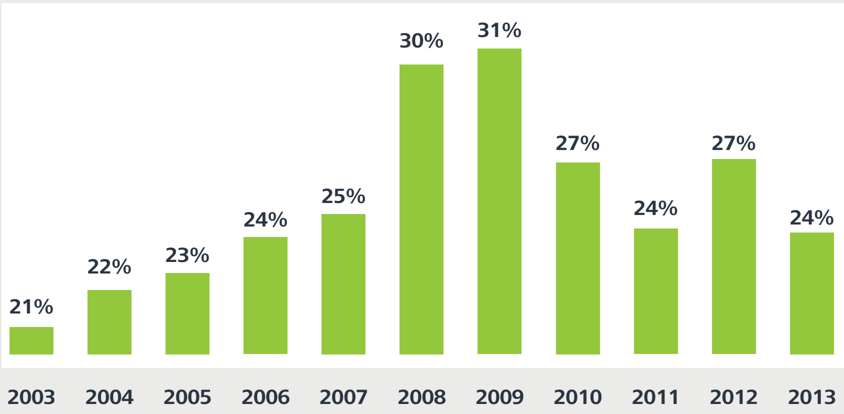


* or nearest available year
** Total government support for business includes both direct expenditures (funds to businesses) and indirect expenditures such as tax incentives.



Source: OECD Science, Technology and Industry Outlook 2014. (xii)

Percentage of total government R&D funds allocated to businesses, 2003 - 2013



Source: Deloitte analysis based on data from National Science Foundation (NSF). (xiii)

Globally, many nations seem to be encouraging businesses to carry out R&D by **directly providing funds and also by offering tax incentives on the research amount spent.**

Research shows R&D performed by businesses has a direct positive impact on GDP growth and generates higher commercial returns than publicly funded R&D

Research by OECD* indicates...

R&D performed by businesses has a positive impact on output growth of a nation.

- R&D carried out by businesses…
  - has a **positive impact on GDP growth** of a nation.
  - is more **directed towards innovation and implementation** of new processes, in production leading to higher productivity.
- R&D carried out by federal government, national labs and public sources…
  - has very **limited commercial impact.**
  - may **not raise technology levels significantly** and may not result in productivity improvements in short run but **may generate basic knowledge with "technology spillovers."**

* OECD (2003) and Wall Street Journal (2015). Detailed sources mentioned in endnote 10a.

Research by BLS** indicates...

Commercial returns from government R&D investments are lower than that from business R&D.

- Majority of the research conducted by universities and government…
  - is aimed at **understanding science than generating direct commercial returns.**
  - has **little commercial value or generates near zero commercial returns.**
  - results in many advances that **have an indirect effect on output growth through "knowledge spillovers"** on consumers, other research institutions or other countries.
- On an average, **privately financed research** has generated 25 percent in commercial returns and 65 percent in social returns.
- Spillovers from innovations that happen at public and private firms help in generating **much larger social returns to R&D than commercial returns.**

** US Bureau of Labor Statistics (2007) and Wall Street Journal (2015). Detailed sources mentioned in endnote 10b.

Research conducted by OECD and BLS suggests...

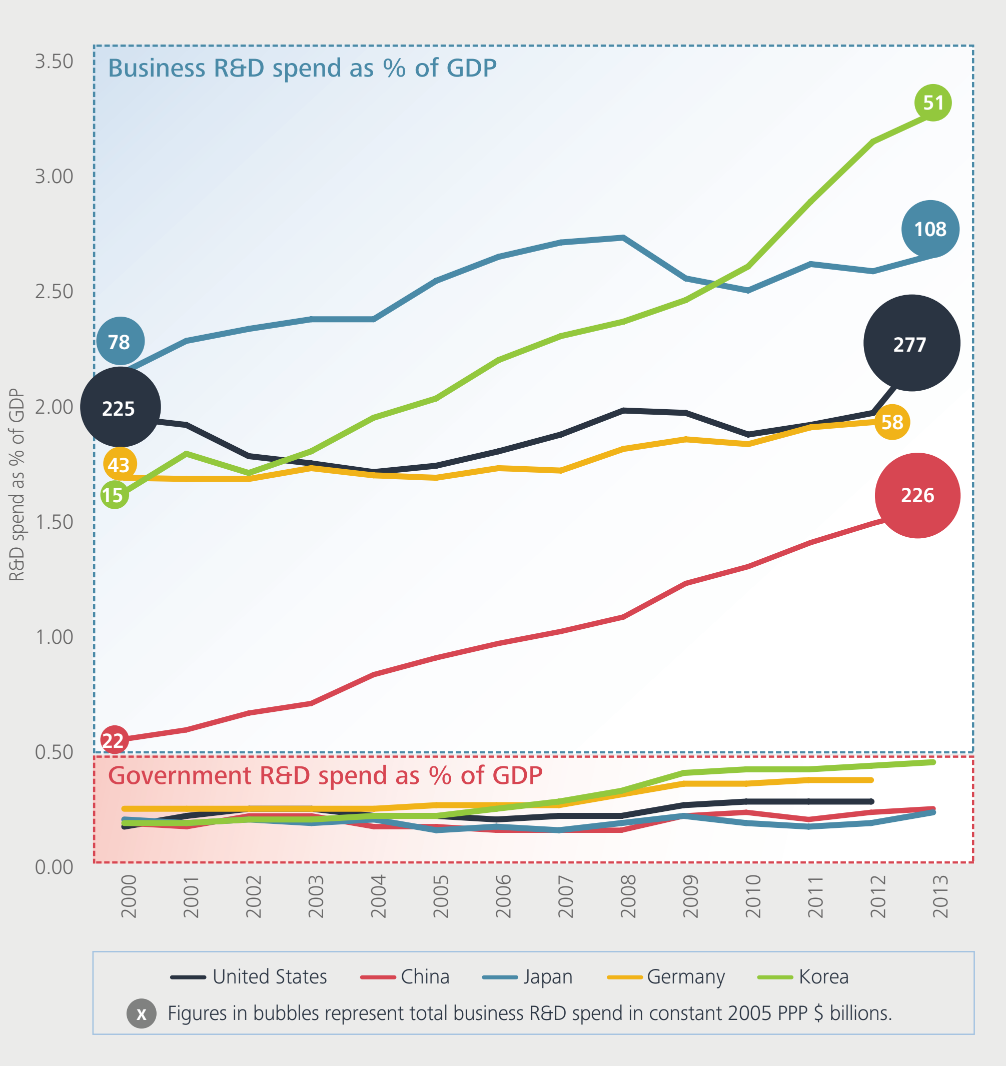
A **collaborative environment** between public and private enterprises **leads to knowledge spillovers and higher productivity,** translating to better research output, and higher GDP growth. This could be further achieved by **increasing the indirect support to private enterprises** through incentives, such as higher R&D tax credits.

R&D spending wars: Businesses account for lion's share of R&D spending, an accelerating trend across leading nations

Executives interviewed believe . . .

- **Businesses not only finance a majority of R&D activities, but also carry out most of the commercialization work.** That said, government plays an important role in supporting and improving a nation's long-term R&D prowess.
- **American businesses have invested heavily in R&D activities** to gain competitive advantage at the global level.
- **Businesses from emerging nations, especially China, have been aggressively pursuing advanced R&D activities**, and are narrowing the gap with developed economies, in terms of business R&D spending.

Business and government R&D spend as % of GDP, 2000–2013



Source: Deloitte analysis based on data from OECD.(xiv)

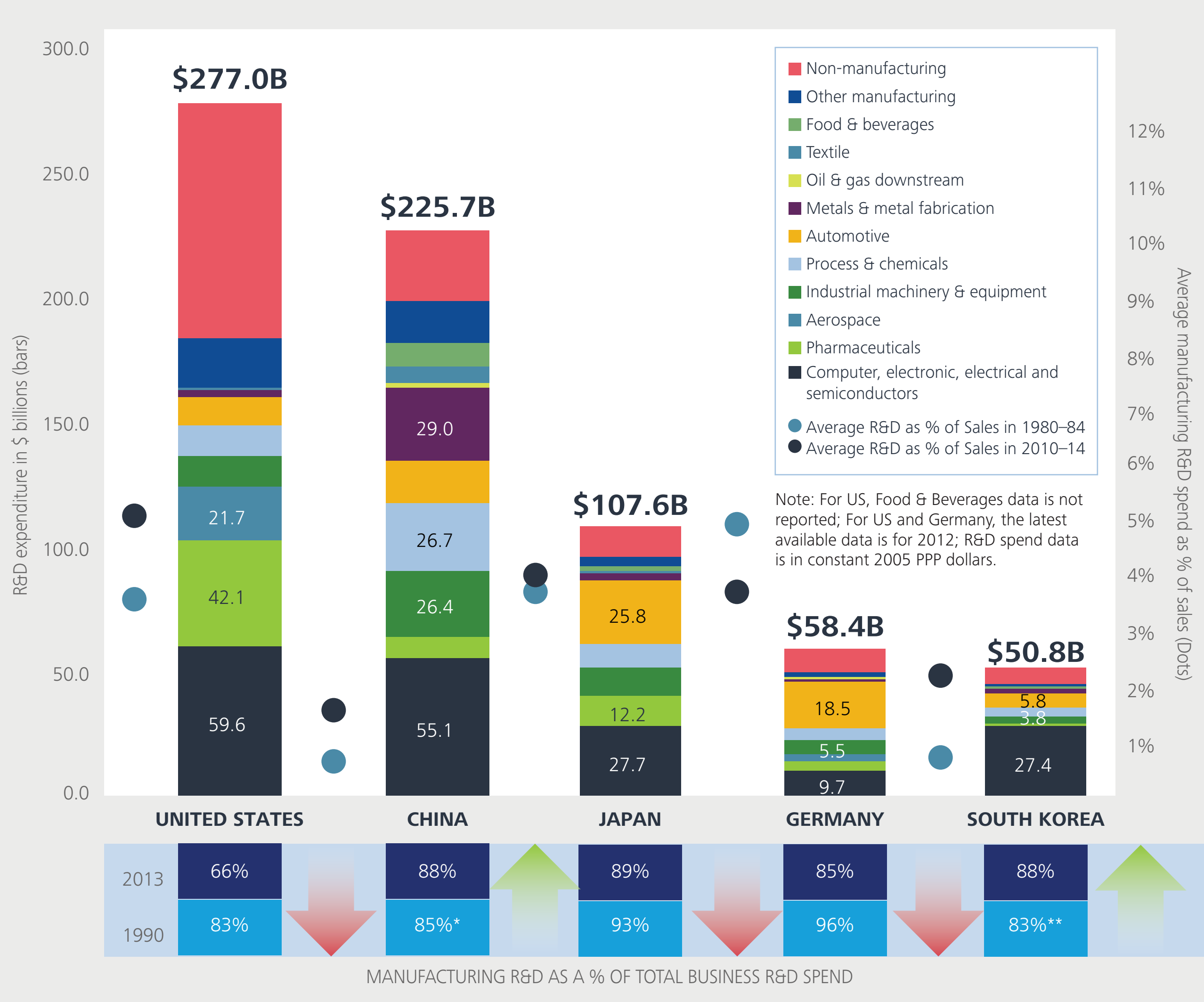
Note: For US and Germany, the latest available data is for 2012.

Nations have different research approaches: While the United States and China are placing large and diversified bets, Japan, Germany, and South Korea are taking a more focused approach

According to executives interviewed, emerging advanced technologies expected to transform the entire global technology landscape will likewise significantly impact and alter the manufacturing sector. However, these advanced technologies may affect different manufacturing sectors to varying degrees depending upon each particular nation's approach in developing these technologies.

- **Diversified approach:** Both the United States and China have spread their R&D expenses across many industries:
  - US companies' R&D manufacturing spend has been liberal, but predominant in computers and electronics, pharmaceuticals, and aerospace sectors.
  - Companies in China conduct R&D in sectors ranging from computers and electronics to process chemicals to industrial machinery and equipment.
- **Focused approach:** While both Japan and Germany focus their R&D efforts on the automotive and computers and electronics sectors, more than half of South Korea's manufacturing R&D expenditure is in the computer and electronics sector.

Playing the game differently: Distribution of business R&D expenditure among various industries, 2013



Source: Deloitte analysis based on data from OECD and National Science Foundation.[xv]
Note: See endnote 10 for detailed explanations of industries.

*Data is available from 2000. **Data is available from 1995.

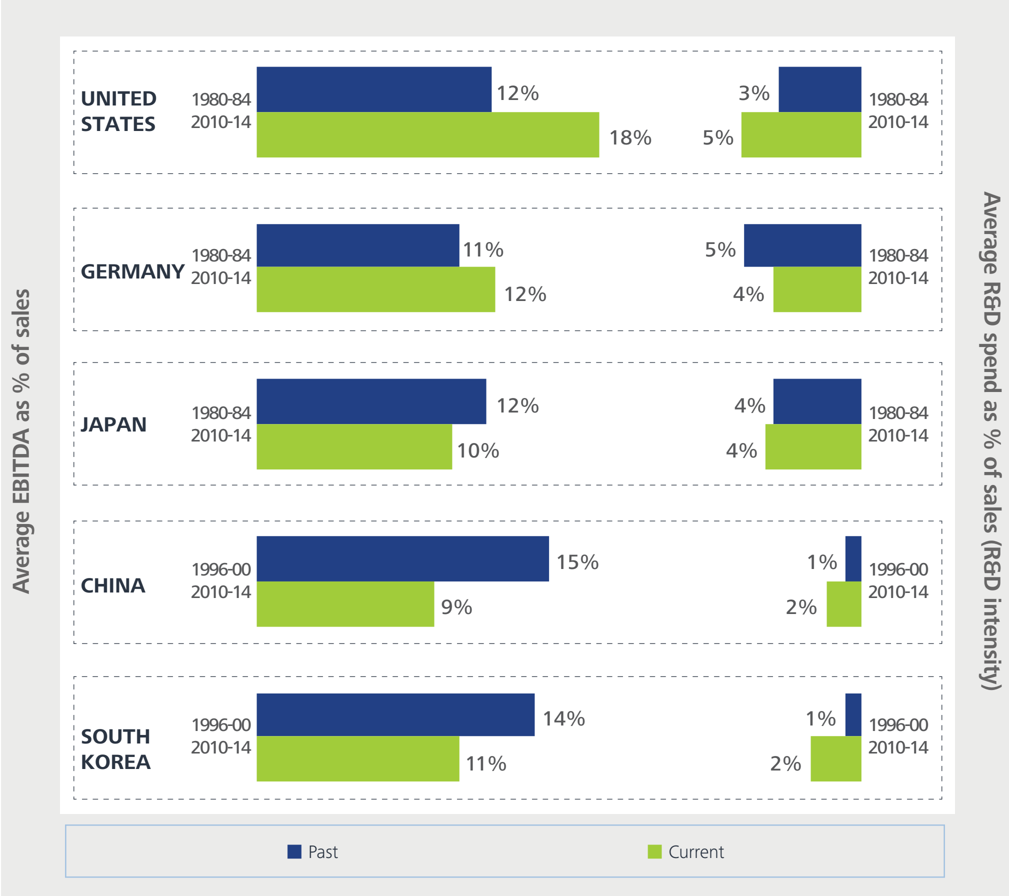
Manufacturing R&D as percentage of sales has increased for most nations, yet only a few have reaped the benefits

- **Rising R&D intensity in the United States:** Both R&D intensity and profitability in the US manufacturing industry have increased over the last 30 years.
- **Increasing German efficiency:** Despite a lower R&D spending as a percentage of sales, manufacturing companies in Germany posted higher profitability over the last three decades.
- **Japan's R&D intensity remains flat:** R&D intensity and profitability in Japan's manufacturing industry have remained almost flat in the last 30 years.
- **Jury is out for China and Korea:** Though manufacturing companies in China and South Korea increased their R&D intensity, profitability declined over the last two decades.

"Companies in China are gradually developing their R&D capabilities, but right now they are working on the lower technology products. Also, China is getting more expensive as it used to be 25 percent of America's labor costs, which now has increased to 40 percent."

— Executive interviewee

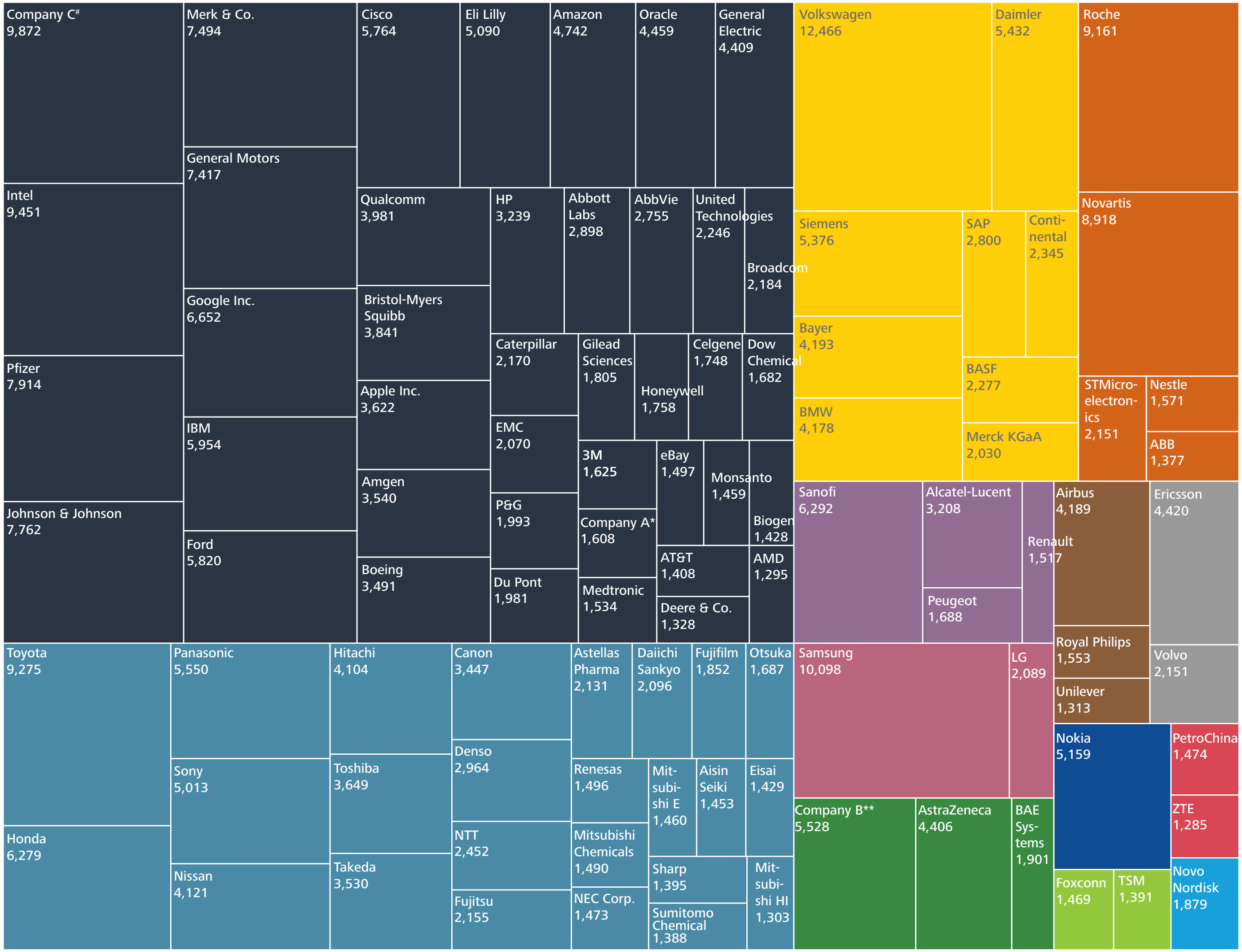
Profit margins and R&D intensity of manufacturing companies, 1980–84 and 2010–14



Note: For China and South Korea, past years data was available from 1996-2000 period instead of 1980-1984.
Source: Deloitte analysis based on FactSet data.[xvi]

US companies lead the global R&D spending landscape

Top 100 global R&D spending companies (based on five-year data) by country, 2010-2014



Out of top 100 global R&D companies, **41 are from the United States** and **86 belong to the manufacturing sector.**

Country:
- United States
- Japan
- Germany
- Switzerland
- France
- Korea (South)
- United Kingdom
- Netherlands
- Sweden
- Finland
- Taiwan
- China
- Denmark

A leading software provider.

* A leading semiconductor company.

** A leading pharmaceutical company.

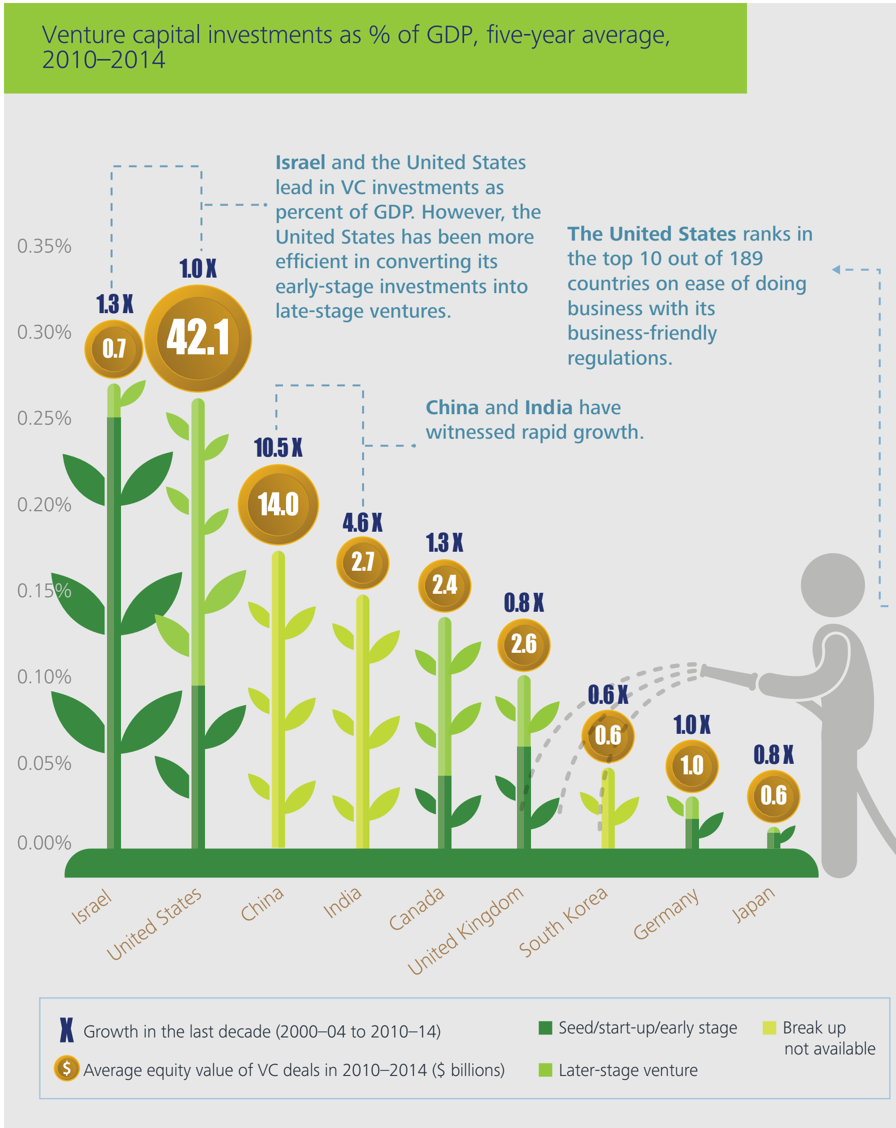
Note: Figures inside the boxes are "Average R&D spend over 2010–2014" in $ millions.

Source: FactSet.(xvii)

Strong Venture Capital (VC) investments feed national innovation pipelines

Executives interviewed expressed . . .

- The United States' **entrepreneurial spirit and substantial funding from venture capital firms** are huge competitive advantages and key differentiators for the country.
- The United States remains the **center for "disruptive innovation"** thanks to its research infrastructure and low barriers to entrepreneurs and start-ups.
- Disruptive innovation within the United States is fueled by active investments through a variety of mechanisms:
  - **Traditional VC firms and angel investors**, as well as joint funding by large and small VC firms.
  - A growing trend for industrial companies to develop **separate venture funding arms** to supplement traditional in-house R&D capabilities.
  - **Crowdsourcing and sharing of open platforms** to find new, innovative solutions at a lower cost than through traditional measures.
  - **Crowdfunding of new ideas** to develop seed funding and create new pathways to capital.



Ease of starting a business, 2015

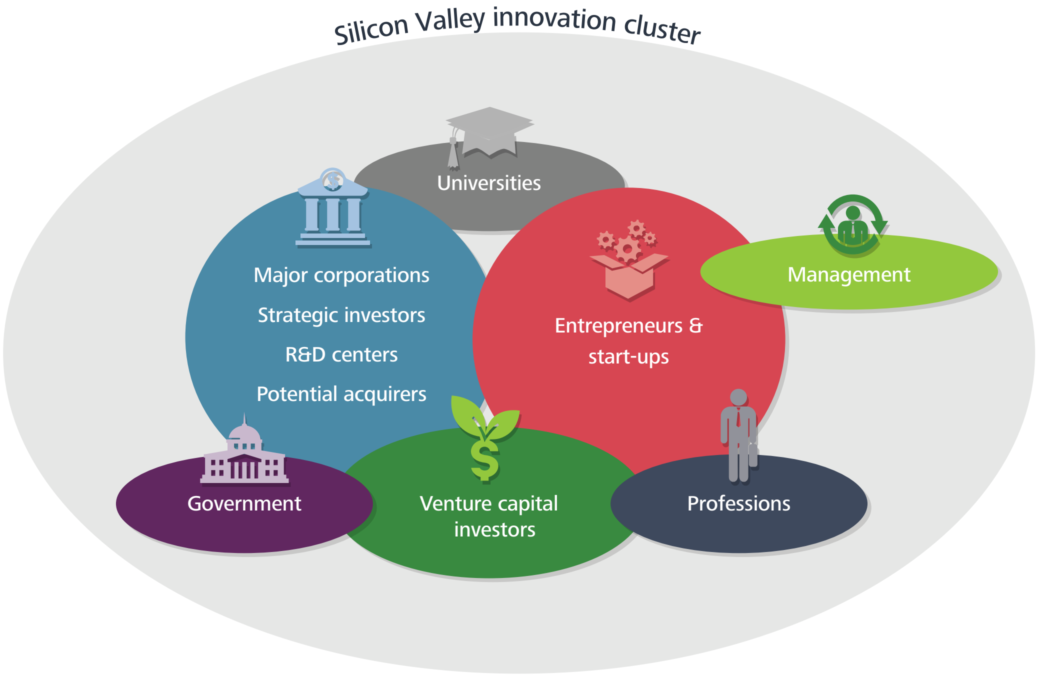
1. SINGAPORE
2. NEW ZEALAND
3. HONG KONG
4. DENMARK
5. SOUTH KOREA
6. NORWAY
7. **UNITED STATES**
8. UNITED KINGDOM
9. FINLAND
10. AUSTRALIA

"Venture capital backed companies generate more sales, pay more taxes, generate more exports, and invest more in research and development (R&D) than other public companies, when adjusting for size."
– National Venture Capital Association

Source: Deloitte analysis based on data sourced from Thomson Reuters, OECD and World Bank.[xviii]

The Silicon Valley innovation ecosystem exemplifies how the proximity to industry, start-ups, VCs, labs, and universities enhance an industry sector's competitiveness

- Executives interviewed said regional innovation clusters not only act as magnets for top students, researchers, scientists and VC funds, but also enable fruitful partnerships between research and educational institutions and corporations, that can lead to revolutionary research outcomes in key focus areas. Case in point is **Silicon Valley, a role model for other nations looking to replicate an innovation cluster that has been the main driving force for an entire country in terms of technology creation and commercialization.**
- Most importantly, the **US innovation ecosystem also provides a conducive environment for innovative entrepreneurship**, enabling small and medium-sized enterprises (SMEs), as well as start-ups, to more easily do business in the United States.
- In general, nations with developed innovation ecosystems are characterized by high levels of public spending on top-tier universities, business R&D spending, venture capital investments, Information and Communication Technology (ICT) investments, and tertiary education expenditure.
- All these factors and variables are correlated with actions taken by both government and businesses. Thus, the onus of creating a highly developed innovation ecosystem should be borne by both business and government.



Source: California Management Review.(xix)

- Other regional innovation cluster examples exist, such as Biotech in Boston, Pharma in New Jersey, Energy in the Carolinas, Automotive in Detroit, and Oil & Gas in Houston.

Can the United States sustain the necessary elements to continue to replicate and grow innovation ecosystem clusters to advance its competitiveness as a whole?

SECTION THREE

Most promising advanced manufacturing technologies - A deep dive look

A snapshot of ten of the most promising advanced technologies transforming the global manufacturing industry

21st century advanced manufacturing competitiveness has fully converged the digital & physical worlds where advanced hardware combined with advanced software, sensors, and massive amounts of data and analytics results in smarter products, processes, and more closely connected customers, suppliers, and manufacturers. Here's a deeper dive look at some of the most promising technologies:

Rank*	Manufacturing Technology
1	Predictive Analytics
2	Smart, Connected Products (IoT)
3	Advanced Materials
4	Smart Factories (IoT)
5	Digital Design, Simulation, and Integration
6	High Performance Computing
7	Advanced Robotics
8	Additive Manufacturing (3D Printing/Scanning)
9	Open-Source Design / Direct Customer Input
10	Augmented Reality

*US Ranking from 2016 Global Manufacturing Competitiveness Index

Technologies described in this section

Predictive analytics utilizes a variety of statistical and analytical techniques that are used to develop mathematical models which predict future events or behaviors based on past data.[12]

Internet-of-Things (IoT) refers to amalgamation of advanced software, cost-effective sensors, and network connectivity that allow objects and machines to interact digitally.[18]

Advanced Materials refers to discovering and making new materials such as **Lightweight**, **High-strength Metals and High Performance Alloys,**[22] **Advanced Ceramics and Composites,**[27] **Critical Materials**[32], and **Bio-based Polymers**.[36]

Digital design, simulation and integration is the conceptualization and digital construction of a virtual prototype or a process achieved through computer simulation of a physical product or a process.[43]

High Performance Computing refers to the practice of aggregating computing power in a way that delivers much higher performance, i.e. systems that typically function above a teraflop or 10^{12} floating-point operations per second, in order to solve large, highly complex problems in science, engineering, or business.[48]

Advanced robotics are machines or systems capable of accepting high-level mission-oriented commands, for example, navigating to a workplace, and performing complex tasks in a semi-structured environment with minimal human intervention using **Artificial Intelligence and Machine Learning**.[52,58]

3D printing is an additive process of building objects, layer upon layer, from 3D model data as opposed to subtractive manufacturing methodologies like machining. **3D scanning** is a fast and accurate method of transferring the physical measurements of an object to a computer as a digital file in an organized manner, resulting in what is called 3D scan data.[63,64]

Open-source design or open innovation refers to problem solving through soliciting ideas and opinions on products or services from both internal and external entities, thus helping in advancing innovation potential with a broader set of constituents.[69]

Augmented Reality (AR) technology (e.g., adding computer vision and object recognition) makes information interactive and manipulable by the user. By adding an overlay of relevant digital content and information, AR enhances the world around the user.[73]

Predictive Analytics

Global Market Size, Growth[11] and Description[12]

Predictive analytics utilizes a variety of statistical and analytical techniques that are used to develop mathematical models which predict future events or behaviors based on past data. The complexity of these predictive models differs, depending on the behavior or event that is being predicted.

Predictive analytics uses many tools and techniques such as data mining, machine learning and artificial intelligence. It helps organizations in becoming proactive and forward looking by uncovering hidden patterns, relationships, and greater insights by analyzing both structured and unstructured data.

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$2.4 billion	17.8% (2.7 X)	$6.5 billion

Current Applications Include:[13]

- Used to identify factors leading to quality and production issues, and optimize service delivery, supply chains and distribution.
- Used to improve effectiveness of new procedures, medical tests and medications as well as improve services or outcomes by providing safe and effective patient care.
- Used to assess consumer behavior and effectiveness of promotional campaigns.
- Provides manufacturers with a clearer view into their supply chain risks and market activity so they can foresee challenges and respond to them proactively, increasing both efficiency and profitability.

Aerospace | Automotive | Healthcare | Consumer Products | Other Industries

Leading National Lab Involvement[15]

Argonne National Lab

Lawrence Berkeley National Lab

Lawrence Livermore National Lab

Oak Ridge National Lab

Pacific Northwest National Lab

Sandia National Labs

Promising Future Application Examples[14]

- Use of predictive models for traffic navigation and collision avoidance systems, including semi or fully autonomous (self-driving) vehicles.
- Use in predicting future consumer behavior and optimizing product portfolio by linking data and insights from connected products to the design and development process.
- Wide variety of potential applications throughout the value chain as predictive analytics enables business intelligence, forecasting, and planning.

DID YOU KNOW

Predictive analytics can save many human lives in the future by analyzing their health conditions in real time.[16]

Internet-of-Things

Global Market Size, Growth[17] and Description[18]

Internet-of-Things (IoT) refers to amalgamation of advanced software, cost-effective sensors, and network connectivity that allow objects to interact digitally.

The IoT concept involves connecting machines, facilities, fleets, networks, and even people to sensors and controls; feeding sensor data into advanced analytics applications and predictive algorithms; automating and improving the maintenance and operation of machines and entire systems; and even enhancing human health.

Note: Market size of IoT is exceedingly large since IoT encompasses many of the emerging technologies that have applications across industries.

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$1,928 billion	19.6% (2.9 x)	$5,649 billion

Current Applications Include:[19]

- Services related to safety of the vehicle and passengers, navigation, location-based services, and infotainment.
- RFID technology - made possible through IoT — to predict retailer's inventory requirements in real-time.
- Developing a behavioral model that can predict disease outbreaks.
- Enabling smart city infrastructure, smart manufacturing, building and home automation, and smart farming (that ensures better crop yield, greater control of soil conditions, better irrigation management and real-time weather monitoring).

Aerospace | Automotive | Healthcare | Consumer Products | Other Industries

Leading National Lab Involvement[20]

- Argonne National Lab
- Oak Ridge National Lab
- Pacific Northwest National Lab
- Sandia National Labs

Promising Future Application Examples[19]

- Use in remote vehicle monitoring, control and diagnosis; enhanced human-machine interactions; enhanced and automated safety systems; smart parking and traffic management; vehicle-to-vehicle (V2V), vehicle-to-device (V2D) and vehicle-to-infrastructure (V2I) communications; autonomous or self-driving vehicles.
- Use in precision manufacturing; improved logistics/supply management.
- Remote Machine and Machine to Machine (M2M) communications will enable new levels of smart manufacturing automation across industries and value chains.

DID YOU KNOW

It is projected that 4.9 billion connected devices (enabled by IoT) will be in use by 2015 and will likely increase to 25 billion by 2025.[21]

Lightweight, High-strength Metals and High Performance Alloys

Global Market Size, Growth and Description[22]

Lightweight, high-strength metals (LHMs) have low density, allowing them to be used for lighter components. High performance alloys (HPAs) exhibit superior properties in corrosive media, high pressures and radiation and mainly include Nickel and Titanium alloys which are used in engine parts.

High production runs and lower cost (compared to composites or ceramics) are typical of these advanced metals and alloys. As with steel, advanced high strength steel (AHSS) and aluminum alloys have standardized grades which make prototyping less costly and choice selection easier for OEMs.

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$112.8 billion	3.4% (1.2 x)	$138.2 billion

Current Applications Include:[23]

LHMs are mainly used for reducing weight of aircraft and automobile components without compromising the structural integrity and safety.

HPAs (non-ferrous alloys, platinum group metal alloys, refractory metal alloys and super alloys) are mainly used in engines and industrial gas turbines.

Aerospace Automotive Healthcare

Leading National Lab Involvement[24]

Ames Lab

Argonne National Lab

Lawrence Berkeley National Lab

Oak Ridge National Lab

Pacific Northwest National Lab

Sandia National Labs

Promising Future Application Examples[23]

Future airframes and vehicle bodies will be manufactured using both aluminum alloys and composite materials while HPAs will penetrate deeper into aeroengines and gas turbines in power generation applications.

Greater use in surgical tools and medical equipment.

DID YOU KNOW

Scientists at Sandia National Labs have created a new shape-shifting alloy technology that could change air travel and how medical procedures are done. Also, friction stir scribe technology developed by Pacific Northwest National Lab enables welding of many metals otherwise considered unweldable.[25]

Advanced Ceramics and Composites

Global Market Size, Growth[26] and Description[27]

Advanced ceramics are reinforced ceramic compounds which have excellent thermal, magnetic, optical, and electrical properties. Advanced composites are matrices of polymers with embedded multi-oriented fibers with different ratios that exhibit excellent stiffness and strength properties.

They exhibit desirable physical and chemical properties that include light weight coupled with high stiffness and strength along the direction of the reinforcing fiber, dimensional stability, temperature and chemical resistance, flexible performance, and relatively easy processing.

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$26.0 billion	13.7% (2.2 x)	$56.1 billion

Current Applications Include:[28]

- Advanced composites are mainly used for making structural parts in aircrafts.
- Advanced ceramics are used in sensors for electronic controls; ceramic-metal composites are also used in light metal construction, high-temperature strength applications like automotive heat engines; Advanced composites are used in vehicle frame design and construction to reduce vehicle weight and size.
- Advanced ceramics are used in hip, knee and shoulder implants and joint replacements.
- Advanced composites are also used for making sporting goods such as golf club shafts and bicycle rods.

Aerospace   Automotive   Healthcare   Consumer Products

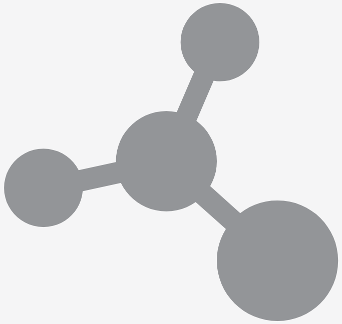
Leading National Lab Involvement[29]

Argonne National Lab

National Renewable Energy Lab

Oak Ridge National Lab

Sandia National Labs



Promising Future Application Examples[28]

- Replacement of plastics and metals in high performance applications.
- Manufacturing artificial organ implants in fields ranging from orthopedics to cardiovascular surgery.

DID YOU KNOW

The US government has recently launched the Institute for Advanced Composites Manufacturing Innovation (IACMI)—the fifth Institute in the National Network of Manufacturing Innovation (NNMI)—as a public-private partnership to increase domestic production capacity, grow manufacturing, and create jobs across the US composites industry.[30]

Critical Materials

Global Market Size, Growth[31] and Description

Many clean energy technologies—from wind turbines and energy-efficient lighting to electric vehicles and thin-film solar cells—use materials with magnetic, catalytic, structural and luminescent properties. These materials—classified as critical materials by the Energy Department—are essential to the clean energy economy (they are in high demand and have limited substitutes) and are at risk of supply disruption.[32]

Critical materials mainly include rare earth elements/metals such as Neodymium, Yttrium, Lanthanum and others such as Antimony, Indium, Lithium, Cobalt, Platinum, and Gallium.

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$6.9 billion	6.5% (1.5 x)	$10.1 billion

Current Applications Include:[32]

Used in permanent magnets in electric vehicle (EV) motors; used in automotive catalytic converters to filter toxic pollutants.

Used in light emitting diodes (LEDs) for solid-state lighting due to luminescent properties.

Used in permanent magnets in wind turbine generators, fluid catalytic cracking in oil & gas industry (an important part of petroleum refining), thin films for solar cells, semiconductors for power electronics, and as an alloying element in high strength steels.

Automotive | Consumer Products | Energy | Other Industries

Leading National Lab Involvement[33]

Ames Lab

Idaho National Lab

Lawrence Berkeley National Lab

Lawrence Livermore National Lab

Oak Ridge National Lab

Pacific Northwest National Lab

Promising Future Application Examples[32]

Use in future grid-storage technologies like vanadium redox batteries; use in electrolytes of stationary distributed power fuel cell systems.

Use in metal-organic frameworks for applications such as removal of greenhouse gases from the atmosphere, and safe storage of combustible gases.

DID YOU KNOW

More than 95% of rare earth elements (a key subset of critical materials) are currently produced in China.[34]

Bio-based Polymers

Global Market Size, Growth[35] and Description

Bio-based polymers are a green and sustainable form of plastics derived from renewable biomass sources. Examples include PLA (Poly-Lactic Acid), PHA (Poly-Hydroxy Alkanoate), bio-based PET (Poly-Ethylene Terephthalate) and bio-based PE (Poly-Ethylene).[36]

Bio-based polymers have the potential to replace petroleum-based plastics in applications including composites, coatings, manufactured parts and components, and packaging materials.[37]

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$1.2 billion	17.8% (2.7 x)	$3.3 billion

Current Applications Include:[38]

- Used in floor mats and spare parts for automotive.
- Used for drug carrier/drug release; used in bone fixation devices, plates, pins, screws, and wires, and other orthopedic applications.
- Used in food packaging, electrical appliances, mobile phone covers, floor mats; commodity applications, shampoo and cosmetic bottles, agricultural mulch films (to control the growing conditions of crops and enhance moisture conditions).

Automotive Healthcare Consumer Products

Leading National Lab Involvement[40]

National Renewable Energy Lab

Oak Ridge National Lab

Pacific Northwest National Lab

Promising Future Application Examples[39]

- Use in bioresorbable composites (which can be used in scaffolds for treating diseased arteries).
- Use in electronic devices and other engineering applications; use of bio-based carbon fiber precursor materials in composites applications.

DID YOU KNOW

The production capacity of bio-based polymers is slated to triple from 3.5 million tons in 2011 to nearly 12 million tons by 2020.[41]

Digital Design, Simulation, and Integration

Global Market Size, Growth[42] and Description[43]

Digital design, simulation and integration (DDSI) is the conceptualization and digital construction of a virtual prototype or a process achieved through computer simulation of a physical product or a process. Simulation models are developed through logic and symbolic relationships between entities to study the behavior of a system that evolves over time.

DDSI utilizes tools such as computer-aided design, computer-automated design, and computer-aided engineering software to design, iterate, optimize, validate, and visualize a product or process digitally throughout the development cycle.

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$21.8 billion	7.0% (1.5 x)	$32.7 billion

Current Applications Include:[44]

Used in designing and optimizing aircraft parts, tool/mold design, factory and cell design and simulation; Modeling of vehicle bodies and subassemblies, design and prototyping of vehicle components, creation of virtual production systems to validate and improve product manufacturing minimizing the amount of physical prototypes.

Used in making biomechanical models of human anatomies to plan and build walking assistance devices.

Design and prototyping of mobile and electronic devices, design and selection of chips to lower manufacturing costs.

Aerospace | Automotive | Healthcare | Consumer Products | Other Industries

Leading National Lab Involvement[45]

Argonne National Lab

Los Alamos National Lab

Oak Ridge National Lab

Pacific Northwest National Lab

Sandia National Lab

Savannah River National Lab

Promising Future Application Examples[44]

Use of hybrid or hardware-assisted simulation models due to the demand for more accurate prototypes and faster simulation. These hybrid solutions are combinations of virtual platforms, hardware components, and hardware emulation tools.

Wide variety of potential applications as DDSI linked throughout the value chain would enable faster, cheaper, and more complex systems to be developed through a highly coordinated closed loop virtual design process.

DID YOU KNOW

New digital design and simulation tools are integrating powerful visualization techniques with complex statistical algorithms.[46]

High Performance Computing

Global Market Size, Growth[47] and Description[48]

High Performance Computing (HPC) refers to the practice of aggregating computing power in a way that delivers much higher performance, i.e. systems that typically function above a teraflop or 10^{12} floating-point operations per second, in order to solve large highly complex problems in science, engineering, or business.

HPC is transforming the manufacturing industry because it enables firms to more easily model components and test assembled systems without the need to create physical prototypes. Superior simulation ability is helping to shorten the time to discovery in many manufacturing industries while accelerating the product development process.

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$30.4 billion	4.6% (1.3 x)	$39.9 billion

Current Applications Include:[49]

- Used in designing complex aircraft parts and systems, like engines, as well as improving aircraft fuel efficiency.
- Used in designing safe vehicles and enhancing fuel efficiency by developing better aerodynamics.
- Used in genomics research and drug development and impact analysis in computational biology
- Used for green energy solutions through improved engineering design, more efficient combustion, and plant optimization.

Aerospace Automotive Healthcare Energy

Leading National Lab Involvement[50]

- Argonne National Lab
- Lawrence Livermore National Lab
- Los Alamos National Lab
- Oak Ridge National Lab
- Pacific Northwest National Lab
- Sandia National Labs

Promising Future Application Examples[49]

- Real-time simulation of a full aircraft in flight to reduce passenger costs and enhance availability of aircrafts in extreme weather conditions.
- Developing new batteries and motors for alternative fuel engines.
- Tailoring of pharmaceutical products and drugs according to the requirement of individual consumer.

DID YOU KNOW

HPC provides the required computing power for high-scale simulations such as atmospheric re-entry of space vehicles and gas flow in rocket motors, and for processing of large-scale data streams received from satellite payloads.[49]

Advanced Robotics

Global Market Size, Growth[51] and Description

Advanced robotics are machines or systems capable of accepting high-level mission-oriented commands, for example, navigating to a workplace, and performing complex tasks in a semi-structured environment with minimal human intervention.[52]

Use of sensors in robotics plays a pivotal role in not only their movement but also in safety monitoring, quality control in work part inspection, and data collection of objects in the robot work cell.[53]

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$28.1 billion	5.2% (1.4 x)	$38.1 billion

Current Applications Include:[54]

- Used in arc welding, spot welding, fully automatic robotic welding systems; use in moving, storing, and retrieving products; use in materials handling, painting, automobile bodies, and assembly line work.
- Used in minimally invasive robotic surgery, robotic prosthetics, and exoskeletons.
- Mechanizing the production line to improve efficiency.

Automotive | Healthcare | Consumer Products | Other Industries

Leading National Lab Involvement[56]

Argonne National Lab

Idaho National Lab

Oak Ridge National Lab

Sandia National Labs

Promising Future Application Examples[55]

Human-machine interaction is the next big trend in robotics; robots that emulate human senses will be equipped with an array of sensors for vision recognition, sound, movement detection and even tactile and force resistance sensing.

DID YOU KNOW

Latest developments in sensors, artificial intelligence and machine learning have enabled the creation of a myriad of robotic forms: from fish-inspired bots that can swim under ships, to canine-like machines that can gallop up hills.[57]

Artificial Intelligence and Machine Learning

Global Market Size, Growth and Description[58]

Artificial intelligence and machine learning help optimize multiple processes in real time (i.e. control) and improve decision-making during manufacturing by automating the analysis of large, complex datasets through adaptive computing techniques.
Due to enhanced methods for rapidly capturing large volumes of data, exponential increases in computing capacity and availability of powerful computing techniques coupled with the development of smart algorithms, artificial intelligence and the domain of machine learning promise exponential growth and market opportunities.

Note: For "Artificial Intelligence & Machine Learning," only 2013 ($900M) and 2015 ($36B) market sizes are available which gives the short-term growth rate in excess of 500%.

Current Market Size, 2013	Future Market Size, 2015
$0.9 billion	$36.0 billion

Current Applications Include:[59]

Used in unmanned aerial vehicles, automobiles with computer vision and speech recognition capabilities, advanced prototyping and stress testing of the products, simulation of actual service conditions of the products, monitoring conditions in real time, providing system status, and monitoring atmospheric conditions.

Used in "cobots" that share jobs with humans on the factory floor, solving complex optimization problems to properly allocate resources for manufacturing processes: speech recognition, face recognition, data mining, bioinformatics, character recognition, machine vision, machine tool production, and computer chip production.

Aerospace | Automotive | Healthcare | Other Industries

Leading National Lab Involvement[60]

Lawrence Berkeley National Lab

Lawrence Livermore National Lab

Oak Ridge National Lab

Pacific Northwest National Lab

Sandia National Labs

Promising Future Application Examples[59]

Advanced expert system applications in health care used to improve patient care and allocation of financial, social, and other resources.

Advanced speech recognition platforms to enhance customized production; machines and products that learn and anticipate user needs, and that replicate cognitive capacities of the human mind.

DID YOU KNOW?

Startups are now launching products that use cognitive technologies, including machine learning for varied tasks,from helping couples plan pregnancies, to controlling home appliances via voice commands.[61]

3D Printing and Scanning

Global Market Size, Growth[62] and Description

3D printing is an additive process of building objects, layer upon layer, from 3D model data as opposed to subtractive manufacturing methodologies like machining. 3D scanning is a fast and accurate method of transferring the physical measurements of an object to a computer as a digital file in an organized manner, resulting in what is called 3D scan data.[63]

3D printing helps in creating intricate designs which are difficult to make through traditional methods, saves enormous amounts of time during product design and development stages, and eliminates scrap.[64]

Current Market Size, 2013	CAGR (2013-2019)	Future Market Size, 2019
$5.1 billion	25.9% (4.0 x)	$20.4 billion

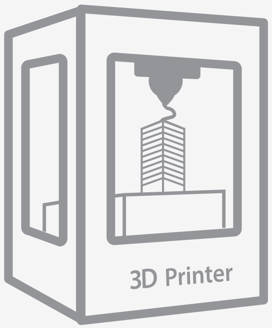
Current Applications Include:[65]

- Concept modeling and prototyping, printing structural and nonstructural production parts and printing low volume replacement parts.
- Printing prostheses and implants, medical instruments and models, hearing aids and dental implants; 3D scanned images are used to replicate organic matter into perfectly fitting prosthetics.
- Rapid prototyping, creating and testing design iterations, and printing customized jewelry and watches.

Aerospace Automotive Healthcare Consumer Products

Leading National Lab Involvement[66]

- Ames Lab
- Lawrence Livermore National Lab
- Los Alamos National Lab
- Oak Ridge National Lab
- Pacific Northwest National Lab



Promising Future Application Examples[65]

- 3D printing electronics directly embedded into aircraft parts unlike today wherein electronics and electrical components are added later.
- Printing sophisticated auto components, cleaner, lighter and safer products with shorter lead times and lower costs.
- Bio-printing organs for transplant, and developing human tissues for regenerative therapies.
- Co-designing and co-creating with customers, and customized living spaces.

DID YOU KNOW

New 3D printing techniques will fabricate materials which have combinations of density, strength and thermal expansion properties that do not exist in nature.[67]

Open-Source Design/Open Innovation

Global Market Size, Growth[68] and Description[69]

Open-source design or open innovation refers to problem solving through soliciting ideas and opinions on products or services from both internal and external entities, thus helping in advancing innovation potential with a broader set of constituents.

Companies may use intermediaries or service providers for open-source design or open innovation that have expertise in crowdsourcing, the lead user method, netnography, ideation contests, technology scouting and broadcast search.

Current Market Size, 2013	CAGR (2013-2015)	Future Market Size, 2015
$3.7 billion	28.4% (1.6 x)	$6.1 billion

Current Applications Include:[70]

- Used in collective problem solving for designing and manufacturing new aircraft or automotive parts.
- Used to help deliver up-to-date content adapted to local markets; and support clinical trials.
- Used in market research, improving social media communications, content production and verification.
- Used in user-generated content translation, metadata production, and creating visual reviews, mainly in service sectors.

Aerospace | Automotive | Healthcare | Consumer Products | Other Industries

Leading National Lab Involvement[71]

Lawrence Livermore National Lab

National Renewable Energy Lab

Oak Ridge National Lab

Pacific Northwest National Lab

Promising Future Application Examples[70]

- Highly customized products & solutions through direct customer inputs.
- Decentralization of R&D across industries, as ideas and innovations blur lines between individuals and organizations.
- Greater proliferation of inter-organizational alliances to develop highly innovative products and technologies not only to cut developmental costs but also create higher value.

DID YOU KNOW

By using a combination of crowdfunding and crowdsourced materials, a 3D printing start-up has managed to create a 3D-printed car.[68]

Augmented Reality

Global Market Size, Growth[72] and Description[73]

Augmented Reality (AR) technology (e.g. adding computer vision and object recognition) makes the information interactive and manipulable by the user. By adding an overlay of relevant digital content and information, AR enhances the world around the user.

AR utilizes devices such as mobiles or smartphones, wearables, head mounted displays (HMD), and video spatial displays to enhance the real-world experience for the user.

Current Market Size, 2013	Future Market Size, 2019
$0.3 to $0.5 billion	$1.2 to $3.6 billion

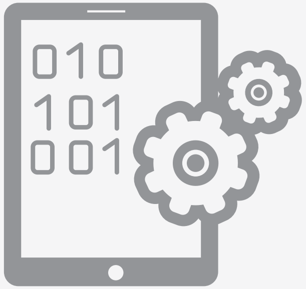
Current Applications Include:[74]

- Used in virtual production systems to validate and improve product manufacturing; used for simulations for training purposes; used in enhanced GPS systems in making travelling easier for the user.
- Used by medical students to practice surgery in a controlled environment.
- Teaching and implementing manufacturing procedures; creation of visualizations that turn data into interactive statistics; Used in understanding complex procedural repairs and training technicians.

Aerospace Automotive Healthcare Consumer Products Other Industries

Leading National Lab Involvement[75]

- Argonne National Lab
- Los Alamos National Lab
- Lawrence Livermore National Lab
- Pacific Northwest National Lab
- Sandia National Labs



Promising Future Application Examples[74]

- Use in retail to enhance interactive consumer experiences.
- Greater use in facilitating education and training.
- More prevalent use of AR apps and tools to learn the intricacies of a machine or a manufacturing process (e.g. 3D visual tour); availability of real-time information of manufacturing operations on a smartphone device.

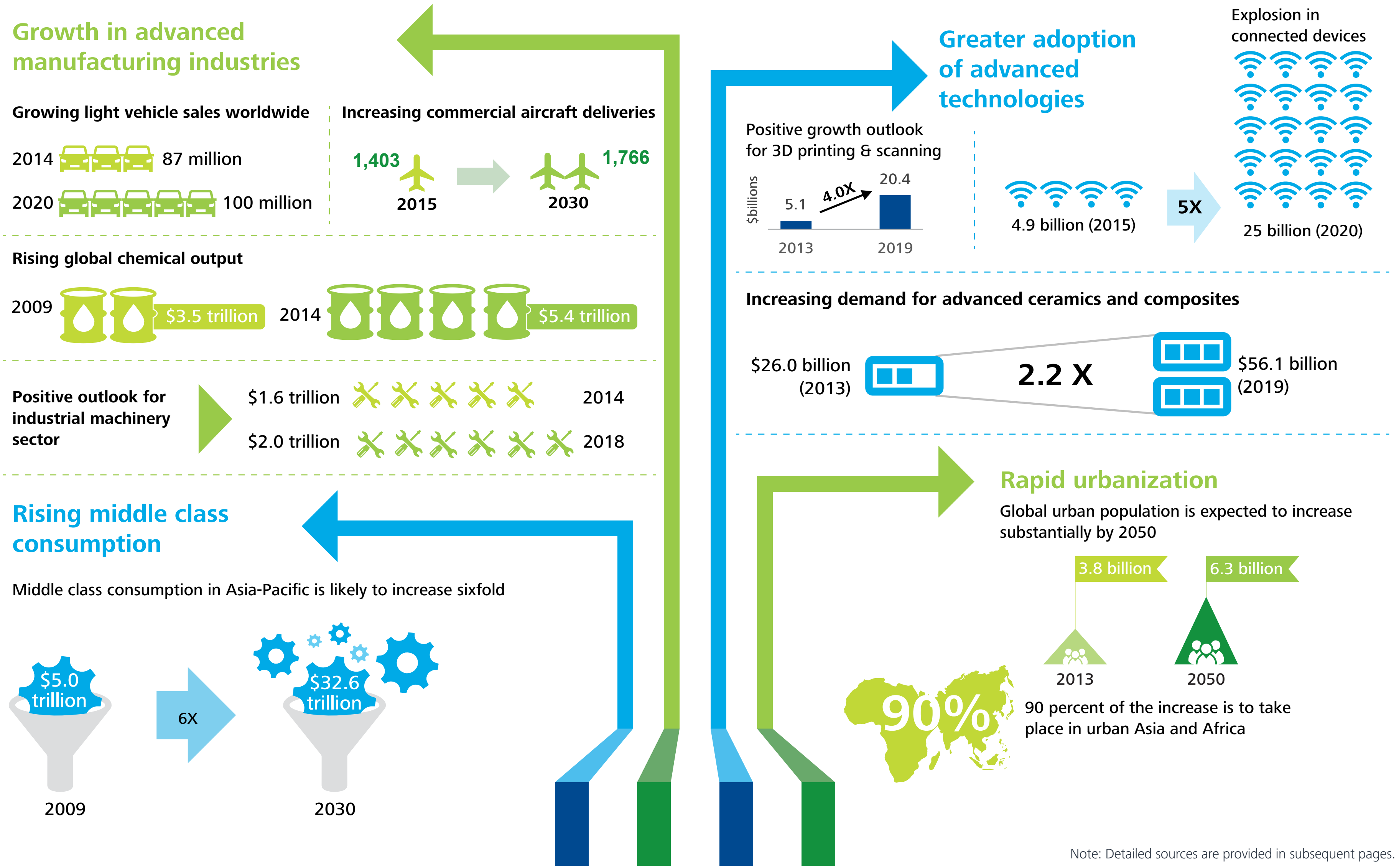
DID YOU KNOW

Global shipments of smart AR glasses are expected to increase from 114,000 units in 2015 to nearly 5.4 million annually by 2020.[76]

SECTION FOUR

Opportunities and challenges faced by US businesses

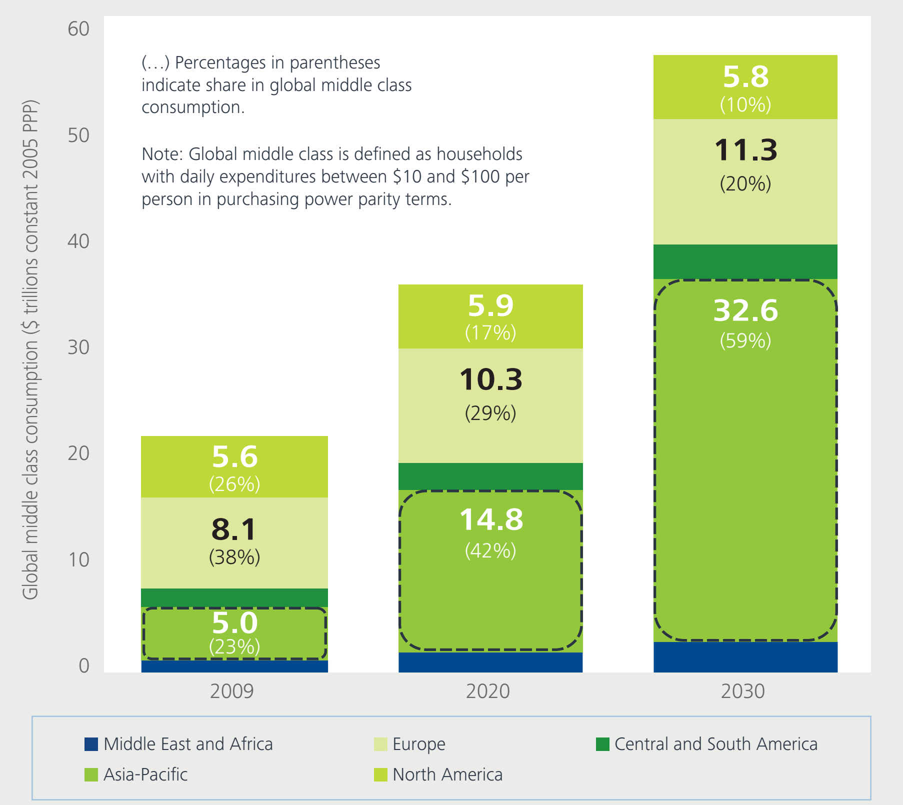
A host of promising global opportunities will spur growth for companies



Note: Detailed sources are provided in subsequent pages.

An expanding middle class and rapid urbanization, especially in Asia, presents sizable opportunities for US multinationals

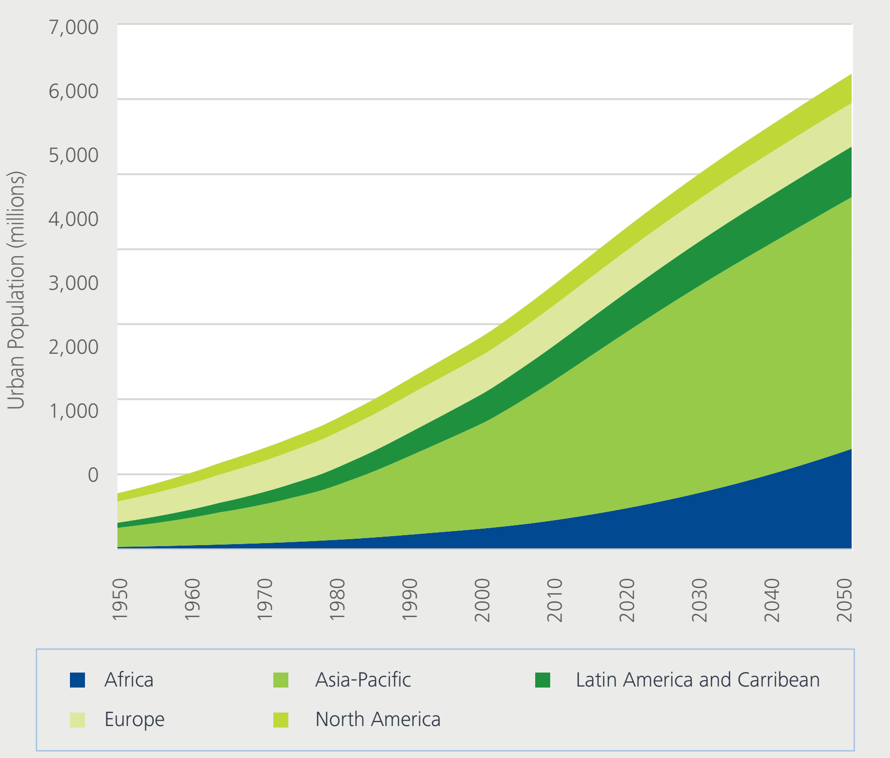
Global middle class consumption ($trillions), 2009–2030



Source: Deloitte analysis based on data from OECD.[xx]

- Larger share of Asia-Pacific's middle class population in global middle class consumption indicates the **vast market potential the region offers to US companies**.
- **US businesses will need to recalibrate their business models** to accommodate the varying needs of this aspiring middle class in emerging markets.

Urban population of the world,1950-2050



Source: Deloitte analysis based on data from United Nations Population Division.[xxi]

- The urban population of the world is expected to increase by **more than two thirds by 2050,** with nearly **90 percent of the increase to take place in the urban areas of Asia and Africa.**
- A dramatic surge in the size and growth of urban populations, especially in emerging economies of Asia and Africa, will present substantial opportunities for US multinationals to tap into these markets, and develop and deploy new products and technologies to manage and meet the expectations and needs of the rising urban class.

Multinationals catering to commercial aerospace and automotive sectors are likely to witness growth

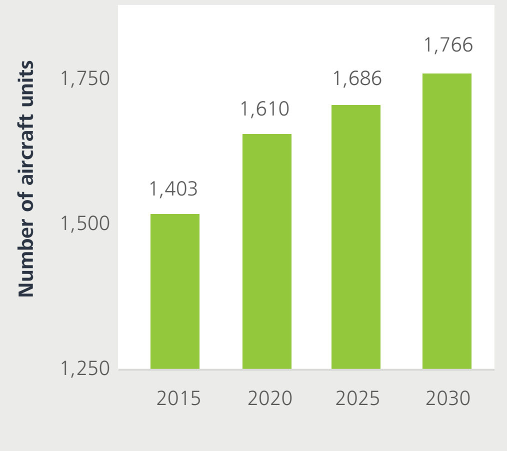
Demand for commercial aircraft to drive overall Aerospace and Defense growth[77]

- Over the next 15 years, commercial aircraft annual production levels (or aircraft annual deliveries) are likely to increase by more than 25 percent to meet growing passenger travel needs, particularly in Middle East and Asia-Pacific regions, and rising demand for more fuel-efficient aircrafts.
- Regions like Asia-Pacific and, Middle East and Africa are witnessing a surge in defense spending, while growth in Europe and North America is relatively flat.

Light vehicle sales to continue to grow[78]

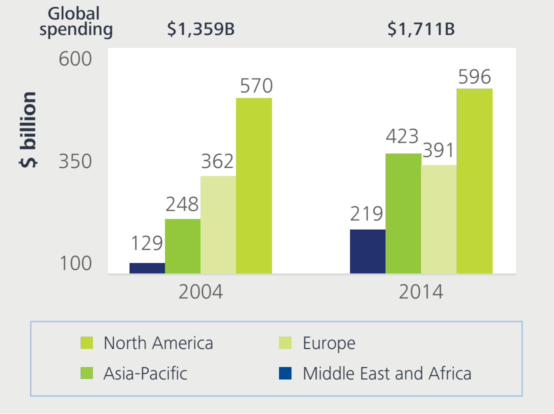
- IHS Automotive expects global auto sales to grow from 87 million in 2014 to 100 million in 2020, primarily driven by China and the United States.
- Despite slowing economic growth, light vehicle sales in China are likely to rise 7 percent in 2015 to 25 million units, spurred by increased auto financing, rapid expansion of dealerships, and the government's push to scrap aging vehicles to improve air quality.
- In the United States vehicle sales are expected to reach 17 million in 2015, aided by improving economic conditions. Though falling oil prices should bolster consumer demand to the benefit of the US auto sector, slowing economic growth in China, the world's largest auto market, will remain a matter of concern.
- With consumer attitudes increasingly in favor of vehicle sharing than vehicle ownership, and advent of "autonomous" or "self-driving" vehicles, automotive OEMs need to rethink not only about 'value creation' but also 'value capture' as rapid technological advancements pose significant change and enable new products in the automotive industry.

Aircraft delivery forecast worldwide, 2015-30



Source: 2015 Global aerospace and defense industry outlook, Deloitte Global.[xxii]

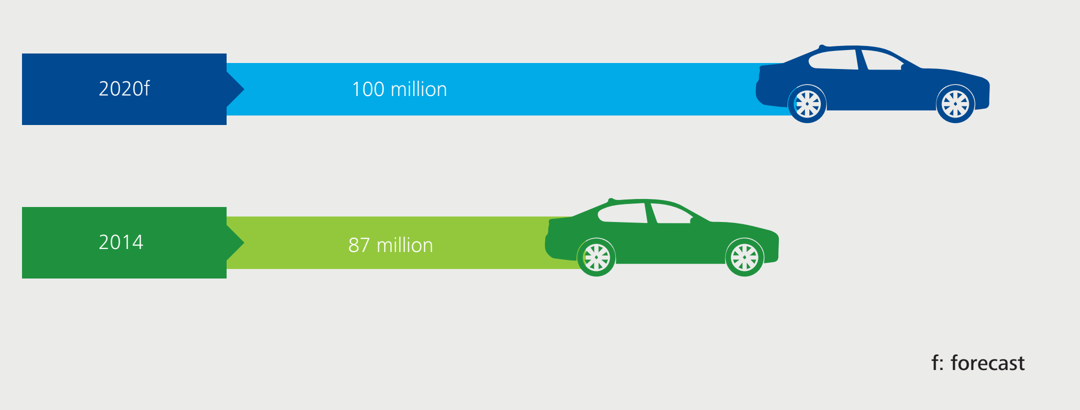
Global military spending 2004-14, ($billion in constant 2011 prices)



Note: Military spending for Central and South America not shown in graph due to its small size.

Source: Deloitte analysis based on data from Stockholm International Peace Research Institute.[xxiii]

Global light vehicle sales, 2014-20



Source: Deloitte analysis based on data from IHS Automotive.[xxiv]

US chemical companies are better positioned than their peers in other major chemical producing nations while prospects remain bright for US industrial machinery companies

Chemical output growth expected to be mixed across major nations[79]

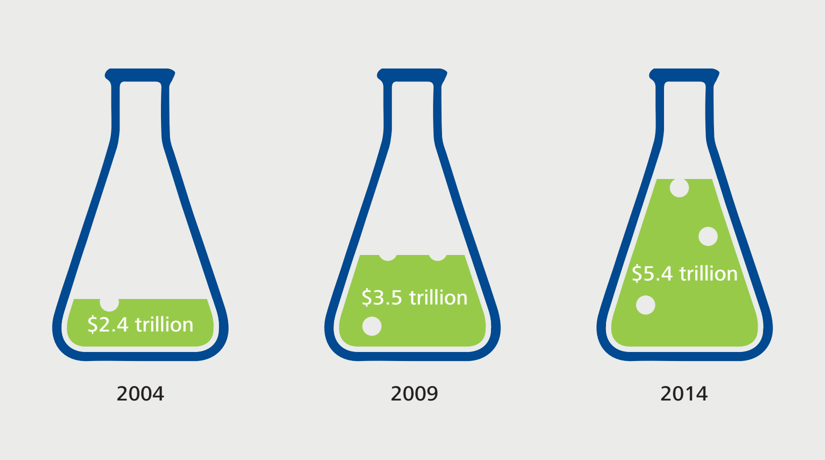
- China ($1,831 billion*), United States ($801 billion*), and Japan ($291 billion*) are the top three nations in chemical shipments, contributing more than half of global shipments in 2014.
- Chemical industry in China is likely to be under pressure in 2015 due to overcapacity and falling oil prices.
- On the other hand, US chemical output will likely grow by 4 percent, thanks to low-cost natural gas. In fact, more than 200 new chemical production projects, valued at over $135 billion, are likely to come online in the United States over the next few years to take advantage of low gas prices driven by the shale revolution.
- Near-term outlook for the chemical industry in Japan seems mixed, teetering between positive demand for chemicals used to make materials for the electronics industry and declining demand for basic chemicals due to weak economic growth.
- Germany, the fourth largest nation in chemical shipments ($245 billion*), will likely witness a modest 1.5 percent growth in chemical production in 2015.

Industrial machinery sector growth has slowed but outlook remains positive[80]

- Improving economic conditions are expected to push the worldwide market for industrial machinery to new heights, driven by demand in sectors such as agriculture, packaging, materials handling and machine tools.
- Industry forecasts indicate industrial machinery market will grow from $1.6 trillion in 2015 to $2.0 trillion by 2018, at an annual average growth rate of 6 percent.
- Asia-Pacific is expected to experience the most significant growth in its industrial machinery sector, followed by the Americas, though sector growth in both regions has slowed considerably. Meanwhile, sector prospects in Europe seem dim, with broad economic recovery still sluggish.

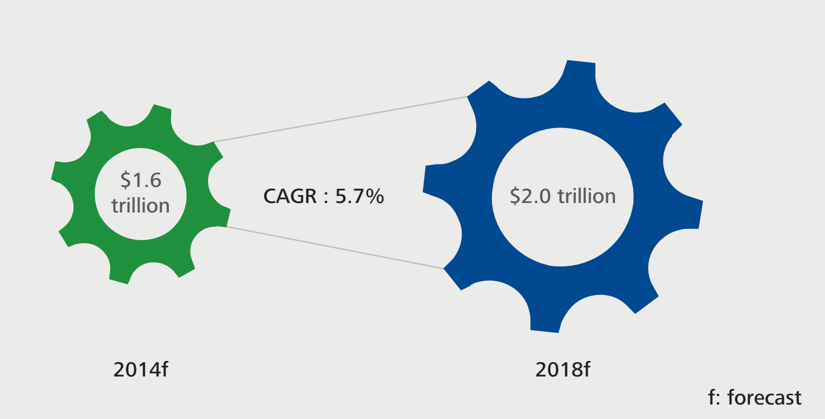
* Numbers mentioned in parentheses are total chemicals export trade for the country

Global chemical shipments, 2004-14 ($trillions)



Source: Deloitte analysis based on data from American Chemistry Council.

Global industrial machinery market, 2014 and 2018 ($trillions)



Source: Deloitte analysis based on data from IHS.

US companies are grappling with multiple challenges on both domestic and international fronts

Despite the market potential emerging nations promise, executives interviewed agreed US companies have to adapt to business environment in foreign markets by:

- **Competing for highly skilled talent:** US companies face significant challenges recruiting highly skilled workers in these markets when vying against local companies (in particular high-growth technology companies) aggressive in attracting top talent.
- **Coping with weak Intellectual Property (IP) regimes:** Emerging countries like China are not only lax in enforcement of IP laws (which lead to counterfeited and pirated products) but also figure prominently in cases related to IP theft.
- **Meeting unique local requirements:** Gaining market entry depends on adhering to country-specific design standards which are often developed by alliances between local government bodies and associations.
- **Dealing with cultural aspects and local needs and tastes:** Products to be marketed to consumers in emerging markets may need to be modified and tailored to satisfy specific, cultural requirements.

> "I am worried about aggressive countries that threaten Intellectual Property Rights (IPRs). There is a shared nervousness amongst CTOs from experiences of few countries stealing IPRs; this has led to things like masking the composition of products that you bring into these countries so they cannot be as easily reverse engineered or replicated."
>
> — Executive interviewee

Uphill battle: US companies face prominent domestic challenges that might impact their performance in the long run such as…

> "Higher competition from Asia is also leading US companies to spend most of the R&D budget on defending the core businesses rather than on new ones."
>
> — Executive interviewee

Talent shortage is a major hurdle to the sustainability and growth of US companies

The US skills gap is widening

Over the next decade, nearly **3.5 million** manufacturing jobs in the United States will likely need to be filled

2015 — **2 million** — 2025

are expected to go unfilled due to the skills gap.

The implications are significant

Every job in manufacturing creates another 4.6 new jobs throughout the entire economy.

For every $1 invested in manufacturing, another $1.37 in additional value is created in other sectors.

2.7 million
Baby Boomer retirements.

700K manufacturing jobs expected from economic expansion.

3.4 million
manufacturing jobs are likely to be needed over the next decade.

Only **1.4 million** jobs are likely to be filled.

An expected **2 million** manufacturing jobs will remain unfilled due to the skills gap.

By 2025 the skills gap is expected to grow to **2 million.** In 2011, **600K jobs** were unfilled due to the skills gap.

According to the skills gap study[xxvii]...

84% of executives agree there is a talent shortage in the US manufacturing industry.

6 out of 10 open positions among skilled workers are unfilled due to talent shortage.

Retiring Baby Boomers, strength of the economy and attractiveness of the industry are ranked among leading factors impacting the talent shortage.

80% of manufacturing companies are willing to pay more than prevailing market rates in workforce areas most impacted by talent crisis.

Additional sources concur ...

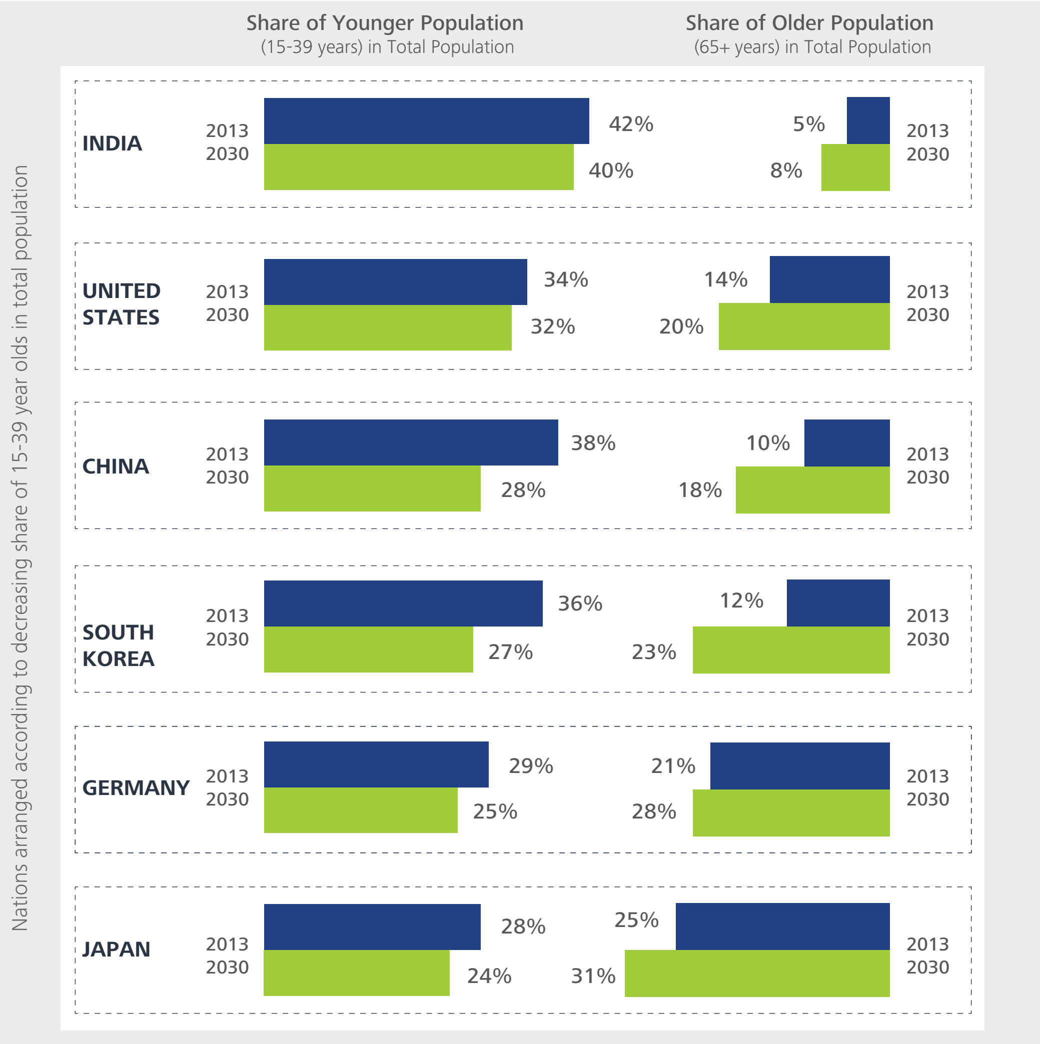
60% of all job postings in advanced industries are for STEM workers, compared with 34 percent outside of advanced industries.[81]

39% of US employers report difficulty in finding qualified talent,[82] and critical positions requiring advanced STEM skills take a longer time to fill.

86% of business executives cite leadership as one of their most important challenges.[83]

Source: 2014 Skills Gap Study, Deloitte and The Manufacturing Institute.[xxvii]

Other advanced nations such as Japan, Germany and South Korea face far more severe demographic challenges than that in the United States



Source: Deloitte analysis based on data from EIU.[xxviii]

India and the United States are well positioned to take advantage of their younger population segments

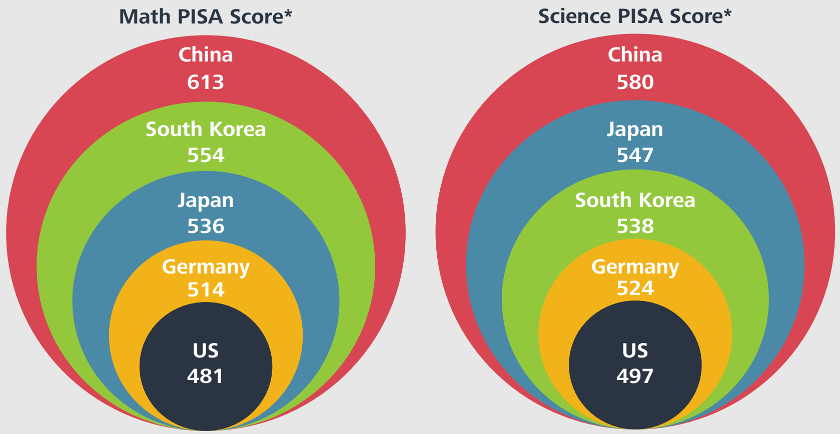
- Across all major nations, the younger population segment (15 to 39 years) as a share of total population is declining. This lower availability of younger workers is likely to have significant long-term economic consequences for many developed nations.
- However, by 2030, both India and the United States are expected to benefit from having younger population segments that comprise a higher share of their respective total populations than other emerging and developed nations.
- By 2030, other nations, like Japan, Germany and South Korea, will have higher proportion of aged population (65+ years) than that in the United States. However, the United States needs to proactively train and prepare its younger population to mobilize when baby boomers retire, to maintain economic vitality.

"Aging of engineering and manufacturing workforce, without appropriate knowledge transfer, is exacerbating skills shortage not only in the US but also in other developed and developing nations like China."

— Executive interviewee

Asian students outperform American students in international assessments, while China and India lead in the number of STEM graduates

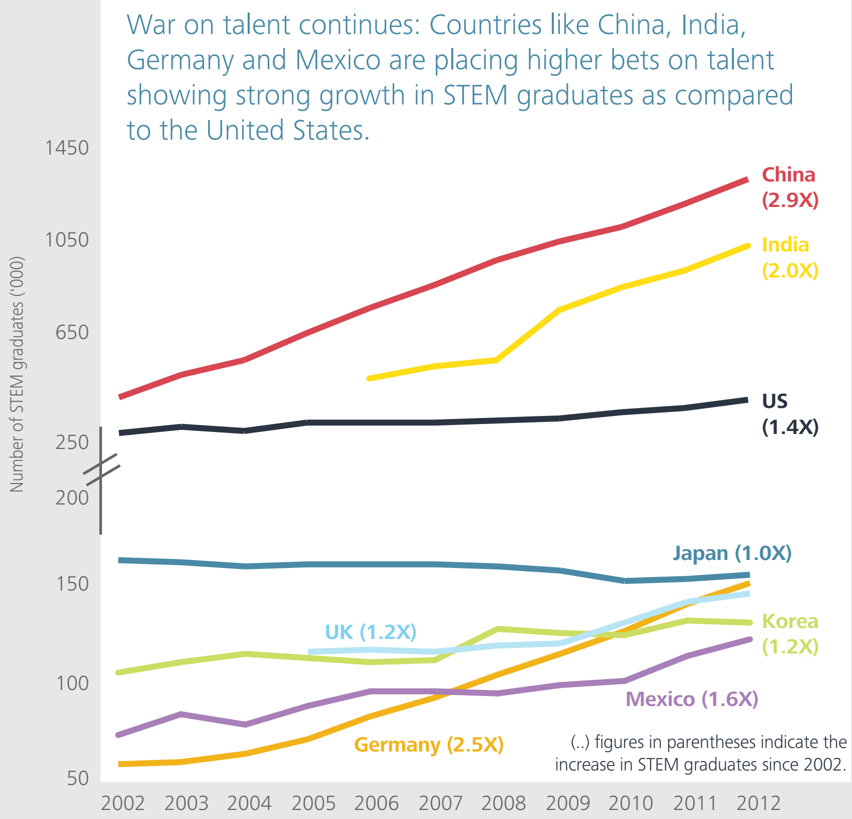
Latest math and science PISA# scores by country, 2012



Programme for International Student Assessments
* Out of a total of 1,000

Source: National Center for Education Statistics.[xxix]

Number of STEM Graduates ('000), 2002-2012



*STEM graduates refer to science and engineering graduates who have attained at least a Bachelor's degree.

According to the executives interviewed, the United States is gradually losing its ability to hire and retain talent as there is a waning interest in STEM fields. While the government has been establishing new initiatives to boost STEM education, more needs to be done to increase student interest, and instill an awareness of its benefits to its younger population.

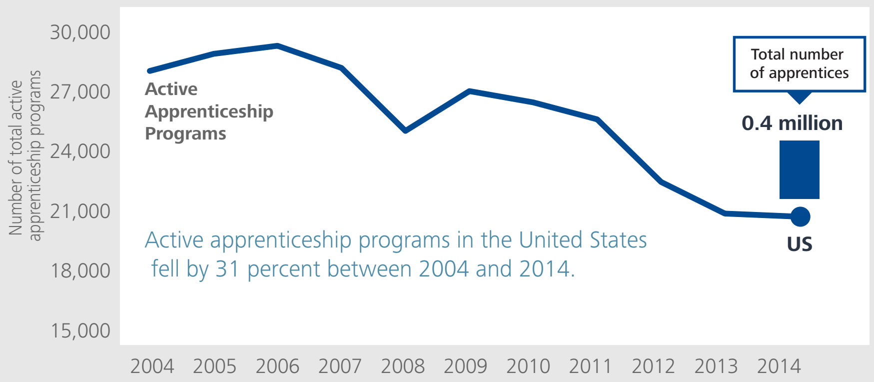
Source: Deloitte analysis based on data from OECD, National Bureau of Statistics of China and University Grants Commission, India.[xxx]

Higher demand for skilled workers in advanced manufacturing industries, as well as the decline in apprenticeship programs, are aggravating the US skills gap

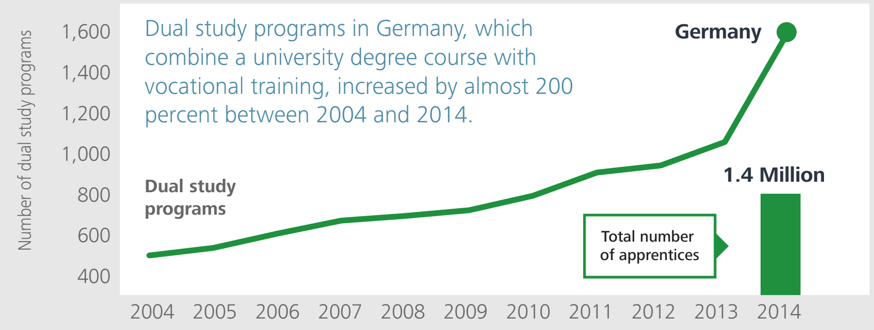
- **Focus has shifted to acute demand for high-skilled workers:** Demand for tertiary-educated or highly-skilled workers is likely to increase in the next five years in industries requiring personnel competent to work in technologically advanced facilities. **By 2020, 35 percent of jobs will require a bachelor's degree or higher, as compared to 22 percent, currently.**[84]

- **Too few skills-based training programs are a cause for concern:** According to executives interviewed, formal programs that combine on-the-job learning in tandem with mentorships and classroom education, fell significantly in the United States, while countries, such as Germany, have increased and designed apprenticeship programs that better prepare their young students to enter the manufacturing workforce.

Trends in active apprenticeship programs in United States and dual study programs in Germany, 2004–2014



Note: Vertical bar size indicates the total number of apprentices in 2014.



Source: US Department of labor, Federal Institute for Vocational Training (Germany) and Federal Statistical Office, Germany.[xxx]

> "Nations like Germany have set up excellent research institutions (like Fraunhofer), established apprenticeship programs to make manufacturing and R&D talent job-ready and linked them to a nation-wide network of universities and industries, thereby establishing a highly developed national innovation ecosystem."
>
> — Executive interviewee

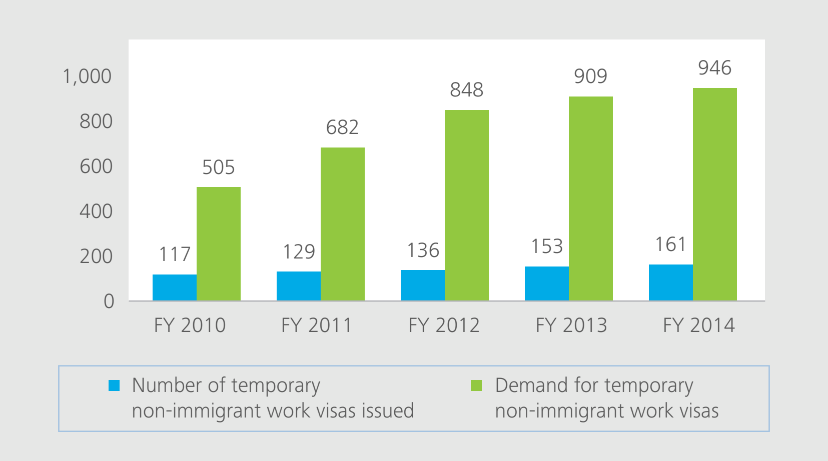
Stringent immigration policies are creating a brain drain in the United States

Executives interviewed indicated current immigration policies are making it difficult to recruit and retain top global talent. Many noted a few particular but crucial issues that need to be addressed, including:

- **Tremendous pent-up demand for temporary work visas:** From 2010 to 2014, demand for temporary non-immigrant visas almost doubled to nearly one million. However, only one out of six visa requests were approved. Demand for these visas is so high that it took just 7 days in FY2015 to reach the 65,000 annual cap, compared to 300 days in FY2011.[85]
- **Abnormally long waiting period for green cards:** A study by the Migration Policy Institute calculated that it would take 19 years to clear existing backlogs filed under family-based petitions for green cards. Excessive delays may cause skilled foreign workers to abandon efforts to remain in the US and return to their respective home countries.[86]
- **International students' work visa woes results in brain drain:** Research by Harvard and other schools shows that 85 percent of Indian and Chinese students are worried and are uncertain about securing work visas.[87] Such uncertainties may encourage them to return to their respective home countries to establish new business or find employment, deploying the skills and knowledge they acquired in US universities, resulting in a brain drain of the US economy.

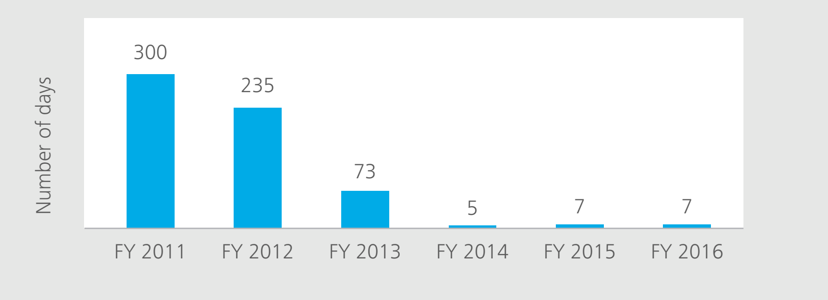
> "The United States is gradually losing its ability to acquire and retain talent because of multiple difficulties talented immigrants face in getting work visas and aggressive competition from emerging countries. Foreign-born students and graduates are not getting the necessary clearances and work visas."
>
> — Executive interviewee

Number of temporary non-immigrant work visas (H1-B) issued and their demand ('000), 2010-14



Source: Deloitte analysis based on US Department of Labor and US Department of State data.[xxxii]

Number of days it took for H1-B visa applications to reach the annual US cap of 65,000



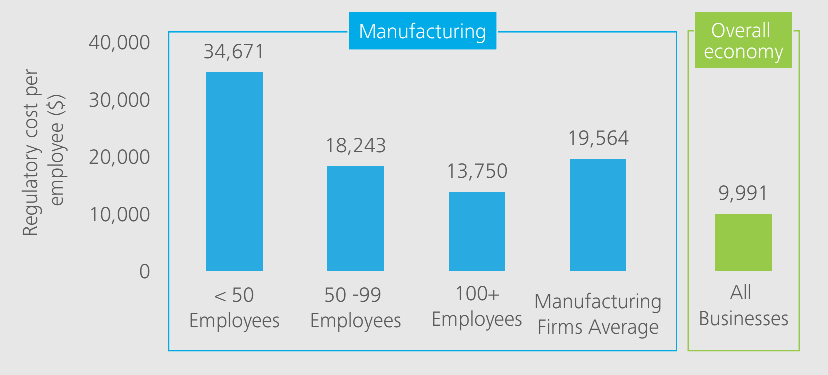
Source: Wall Street Journal and US Department of Homeland Security.[xxxiii]

US companies are concerned about the high costs and complexity of regulatory compliance...

- **Compliance costs stifling US investments:** Many of the manufacturing executives interviewed said if the cost of regulatory compliance could be reduced, they would divert (upward of two-thirds) of saving towards investments, such as building or expanding manufacturing capacity, and/or R&D expenditures. They also indicated excessive regulation disproportionately hurts smaller manufacturing firms, hampering their ability to invest in R&D, hampering their profitability, and causing some companies to move their operations abroad.
  - **Regulatory costs and complexity continue to increase:** More than 2,000 manufacturing-related regulations have been enacted since 1981 - at an average rate of more than 70 per year – according to Aspen Institute research. Further, the research indicates a dramatic increase in the number of regulations has resulted in higher compliance costs, which have grown at a sharper rate than inflation-adjusted GDP and manufacturing output.[88] A study by the World Economic Forum ranks the United States 82nd out of 144 countries on regulatory burden.
  - **High federal regulatory burden on manufacturing:** The National Association of Manufacturers estimated federal regulations cost the US economy $10,000 per employee, more than $2 trillion in aggregate in 2012 (in 2014 dollars). Costs for manufacturing firms were $20,000 per employee ($215 billion, in aggregate), more than double the cost as compared to the overall economy.[89]

> "The current regulatory environment places too big a burden on companies, and government regulatory systems are not up to date with reality. For example, the chemical industry is as highly regulated as the pharmaceutical industry—that makes it very difficult and expensive to bring innovations in chemicals to the market."
>
> — Executive interviewee

Regulatory costs per employee in US manufacturing sector vs. overall economy by firm size ($), 2012



Source: National Association of Manufacturers.[xxxiv]

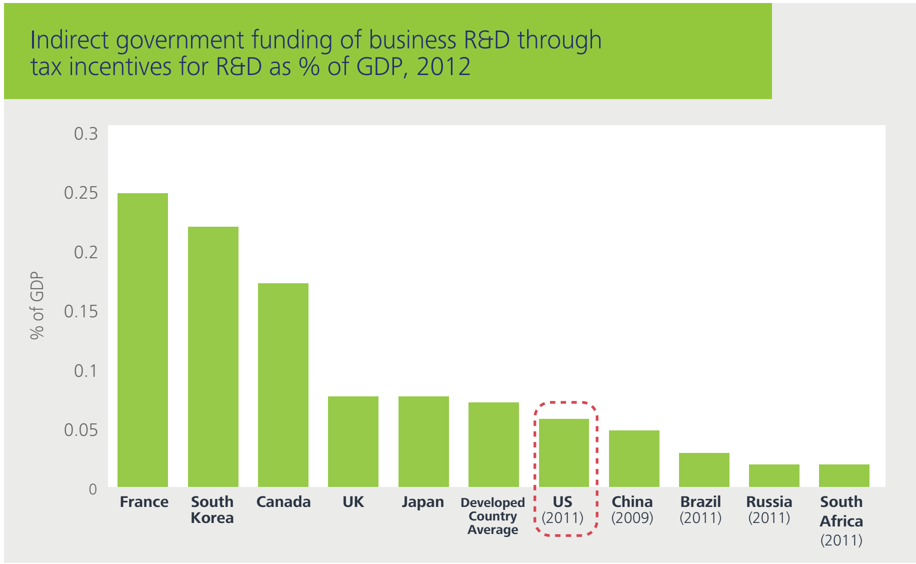
Ranking on "Burden of government regulation," 2014-15
(out of 144 countries, #144 having the highest regulatory burden)

Source: World Economic Forum.[xxxv]

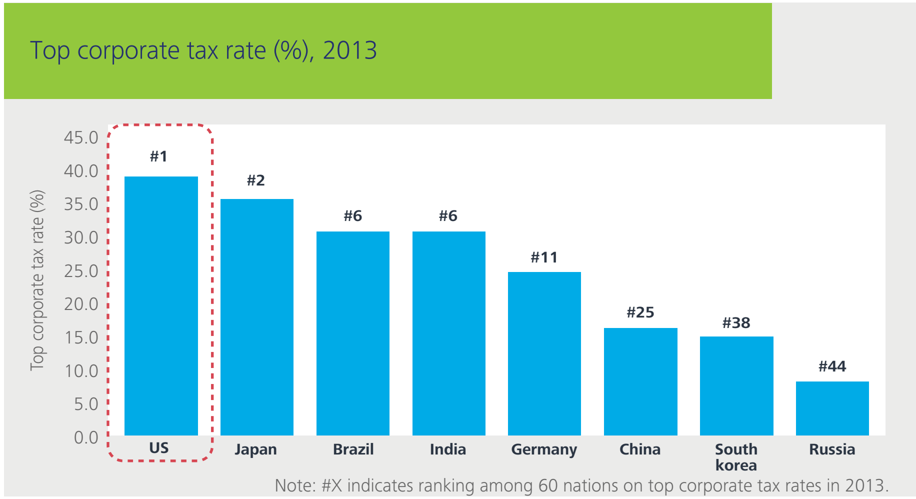
….and uncertainty in the current regulatory environment

Executives interviewed made the following recommendations:

- **Reduce regulatory and tax credit uncertainties:** According to executives interviewed, the US regulatory environment needs to be more predictable. For example, the federal R&D Tax Credit is currently bundled with a group of temporary tax extenders which expire in 2015. Making the R&D Tax Credit permanent would remove uncertainty which now tends to discourage businesses from making large scale R&D investments, and actively participate in the US innovation ecosystem.
- **Provide higher R&D tax credit rates and reduce complex claiming procedures:** US R&D tax credit rates are lower, on average, in comparison with developed countries. Oppressive and costly administrative procedures, required to establish and claim credit, have resulted in contentious disputes between businesses and the Internal Revenue Service (IRS), which may drive some US companies to migrate research activities and investments abroad.
- **Make corporate tax rate competitive:** US corporate tax rates are the highest in the developed world, which further discourages investments from multinationals and foreign sources. According to Milken Institute research, reducing the current US corporate tax rate to 22 percent could boost GDP by $375 billion, while increasing the R&D Tax Credit by 25 percent could add $206 billion to the US economy, and create more than 300,000 new manufacturing jobs.[90]
- **Regulatory mechanisms need to be updated:** Additionally, some of the executives interviewed expressed a belief the US regulatory environment is overly burdensome, and current regulatory mechanisms should be updated on a regular basis to account for dynamic market realities.



Source: Deloitte analysis based on OECD data.[xxxvi]



Source: Deloitte analysis based on EIU data.[xxxvii]

Summary and Conclusions

Advanced industries are essential for a nation's prosperity

Advanced industries play a pivotal role in contributing to a nation's GDP by producing higher worker earnings, high-value exports, greater employment opportunities and higher productivity

Investments in advanced manufacturing capabilities enhance a nation's competitiveness resulting in economic prosperity

Investments in R&D lead to advanced manufacturing capabilities – that lead to more complex and exclusive products ready for exports. These high-tech, value-added exports make the nation more competitive

Prominent technologies transforming the global manufacturing industry

- Predictive Analytics
- Smart, Connected Products (IoT)
- Advanced Materials
- Smart Factories (IoT)
- Digital Design, Simulation, and Integration
- High Performance Computing
- Advanced Robotics
- Additive Manufacturing (3D Printing/Scanning)
- Open-Source Design / Direct Customer Input
- Augmented Reality

UNITED STATES

The US is a global leader in research and development

- Excellent research talent and infrastructure
- Top-notch tech firms
- Dedicated industrial clusters
- Strong VC investments

The United States contributes to 32 percent of total global R&D spend#
- The highest among all nations

Slowdown in economic growth, especially in developed nations, and short term focus have put downward pressure on R&D budgets

China contributes 23 percent of total global R&D spending#, and is expected to overtake the US by 2019

CHINA

But the gap is closing, especially with countries like China

- High growth in overall R&D spending
- Robust growth and volume of STEM graduates
- Strong focus on commercialization of technologies
- High growth in VC investments

#in 2013

The US Innovation ecosystem will continue to determine America's success as an innovation powerhouse

Government
Government is the second largest sponsor of R&D activities including critical, long-term basic and applied R&D work

National Labs
National labs perform basic and applied R&D in the United States

Universities
Both private and public universities perform basic and applied research financed by either government or business

Venture Capital
VC and PE funds invest in tech start-ups

Start-ups
Mostly funded by VCs, they are instrumental in bringing new technologies to market

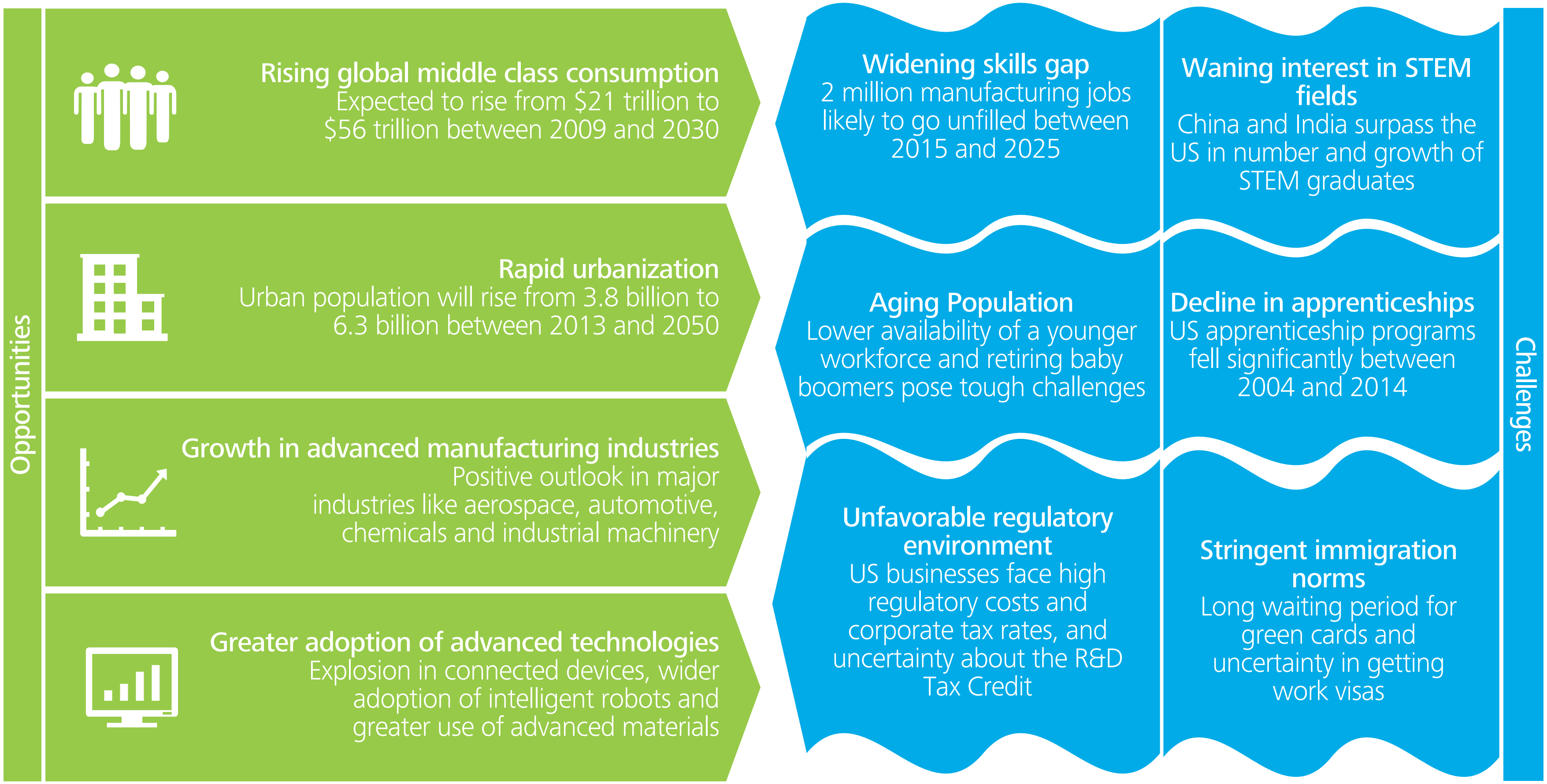
Businesses
They not only finance a majority of R&D activities but also carry out most of the commercialization work

The seamless coordination between its various entities will fuel America's innovation engine

Note: Break up in the above chart represents distribution of overall R&D funds by sponsor in the United States in 2012.

Source: Advanced Technologies Initiative: Manufacturing and innovation, Deloitte Global and US Council on Competitiveness, 2015.

Opportunities and challenges US businesses face in advancing their R&D capabilities



Source: Advanced Technologies Initiative: Manufacturing and innovation, Deloitte Global and US Council on Competitiveness, 2015.

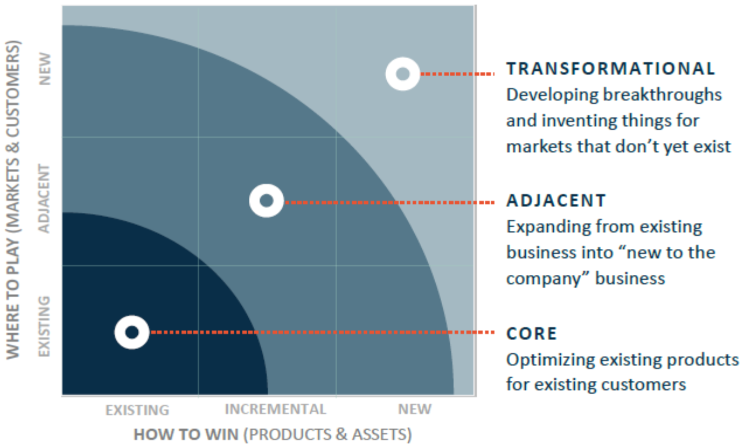
Putting it to work: Advanced Technologies—The Industry Innovation Playbook

Clearly, a strong focus on innovation is essential to the health of not only individual companies, but also the overall US economy. In order for advanced manufacturers to grow and succeed in the highly competitive global market, there are a number of key insights to guide solid business strategy development and include in their "Innovation Playbook" going forward.

Think like a venture capitalist
In today's highly dynamic and interconnected world, highly innovative companies are adopting calculated risk-taking strategies and leveraging best practices from more agile start-ups.

Take a portfolio approach
Companies not only need to invest in short-term innovations for immediate benefits with existing products but should also place emphasis on long-term R&D investments that result in transformational gains.

Operate outside of traditional walls
Innovative companies are exploring various mechanisms of collaboration outside of their walls and with the broader innovation ecosystem (e.g. VC arm, joint ventures with cross-industry companies/organizations, university and/or national lab innovation partnerships, crowd sourced solutions).



Source: Deloitte Monitor Innovation Matrix.(xxxviii)

There is no singular solution
Many advanced technologies hold great promise but the most significant transformational shifts occur when multiple technologies are combined synergistically to achieve innovative solutions. There is no singular solution where the path to success is forged in synergistic solutions and perseverance.

Have strategic focus
Successful companies are explicit about aligning their activities and resources across different innovation ambition levels and ensure the approach, organization configuration, competencies, and incentives consistently reinforce their strategic goals.

Be risk tolerant
Truly transformative innovations, like basic research breakthroughs, are saddled with high risks of failure.[91] But, if successful, transformative innovations can create new business opportunities which result in significant market share gains and profits.

Perseverance pays
Firms which fear failure or which fear to bounce back when met with failure will remain as followers to innovative firms which have a greater appetite to risk, innovate consistently and have gained experience from their failures.

Be explicit about innovation ambitions
Then organize and execute accordingly.

Look beyond product innovation
To transform other elements of your business system.

Diagnose your capabilities
And build up your innovation management system along with your ecosystems partnerships.

Source: Advanced Technologies Initiative: Manufacturing and innovation, Deloitte Global and US Council on Competitiveness, 2015.

Endnotes

Endnotes (for main text)

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   b. “Science and technology historical timeline”, Bridge, http://www.bridge-online.cz/aitom/upload/maturita/temata/38_science_and_technology.pdf, 2006.

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   d. Jena McGregor, “A history of big ideas”, http://www.bloomberg.com/ss/09/03/0312_game_changing_timeline/index.htm, September 2012.

   e. Richard C. Atkinsona and William A. Blanpied, “Research universities: Core of the US science and technology system”, Technology in Society, http://rca.ucsd.edu/speeches/TIS_ResearchUniversitiesCoreoftheUSscienceandtechnologysystem1.pdf, Pages 34-41, 2008.

7. Sources of R&D funds are explained as follows:

   a. Business or Business Enterprises - covers R&D expenses funded by private and public enterprises and institutes serving such enterprises.

   b. Government - covers R&D expenses funded by federal or central government only.

   c. Higher education – covers R&D expenses funded by institutes of higher education like universities.

   d. Private non-profit - covers R&D expenses funded by non-profit organizations like research institutes, professional associations, hospitals, schools that receive donations from private entities.

   e. Foreign – covers R&D expenses funded by foreign affiliates of multinational companies mainly.

8. Types of research are explained as follows:

   a. Basic research - Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.

   b. Applied research - Original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.

   c. Commercialization (Experimental Development) - Systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices; installing new processes, systems and services, or to improving substantially those already produced or installed. R&D covers both formal R&D in R&D units and informal or occasional R&D in other units.

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    a. Other Manufacturing includes: Building of ships and boats, manufacture of railway locomotives and rolling stock, military fighting vehicles, transport equipment, furniture, medical and dental instruments and supplies.

    b. Food & beverages includes: Manufacture of food products, beverages and tobacco products

    c. Textiles includes: Manufacture of textiles, wearing apparel, leather and related products.

    d. Oil & gas downstream includes: Manufacture of coke and refined petroleum products.

    e. Metals & metal fabrication includes: Manufacture of basic metals, fabricated metal products, except machinery and equipment and weapons and ammunition.

    f. Automotive includes: Manufacture of motor vehicles and parts.

    g. Process & chemicals includes: Manufacture of chemicals and chemical products, rubber and plastic products, wood, paper, printing and reproduction.

    h. Industrial machinery & equipment includes: Manufacture of general-purpose machinery and special-purpose machinery.

    i. Aerospace includes: Manufacture of air and spacecraft and related machinery.

    j. Pharmaceuticals includes: Manufacture of basic pharmaceutical products and pharmaceutical preparations.

    k. Computer, Electronic, Electrical and Optical includes: Manufacture of electronic components and boards, computers and peripheral equipment, communication equipment, consumer electronics, instruments and appliances for measuring, testing and navigation; watches and clocks, irradiation, electromedical and electrotherapeutic equipment, optical instruments and photographic equipment, magnetic and optical media, and electrical equipment like motors, generators, transformers, batteries, domestic appliances, electric lighting etc.

11. Includes software solutions going into customer intelligence, decision support systems, data mining and management, performance management, fraud and security intelligence, risk management, financial intelligence, operations and campaign management. "Predictive analytics market to reach USD 6,546.4 million by 2019", Transparency Market Research, http://www.prnewswire.com/news-releases/predictive-analytics-market-to-reach-usd-65464-million-by-2019-globally-transparency-market-research-233725001.html, November 2013.

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Acknowledgements

The authors would like to acknowledge the guidance and continued support of the following persons: Dan Haynes (US Manufacturing Leader, Deloitte Consulting LLP), Timothy Hanley (Deloitte Global Industry Leader, Consumer and Industrial Products, DTTL), Duane Dickson (Deloitte Global Sector Leader, Chemicals and Specialty Materials, DTTL), Douglas Gish (Principal, Manufacturing, Deloitte Consulting LLP), Trina Huelsman (Vice Chairman and US Process & Industrial Products Leader, Deloitte & Touche LLP), Tom Captain (Deloitte Global Sector Leader, Aerospace & Defense, DTTL), John Coykendall (US Aerospace & Defense Leader, Deloitte Consulting LLP), Gina Pingitore (Director, C&IP Center, Deloitte Services LP), Rene Stranghoner (Sector Marketing Leader, Industrial Products, Deloitte Services LP), Robert Libbey (Manager, Deloitte Services LP), Joanie Pearson (Manager, Graphic Design, Deloitte University Press), Surendra Dakoju (Senior Graphic Designer, National Creative Services, Deloitte Services LP) and Ashwin Ganapathi Balaji (Graphic Designer, National Creative Services, Deloitte Services LP).

The authors would also like to thank Jud Virden (Associate Director, Energy and Environment Directorate, Pacific Northwest National Laboratory) and Michael Rinker (Manager, Energy Efficiency and Renewable Energy market sector, Pacific Northwest National Laboratory) for their invaluable suggestions.

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