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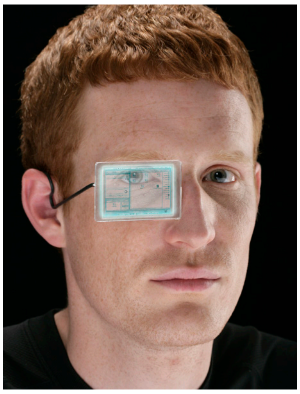


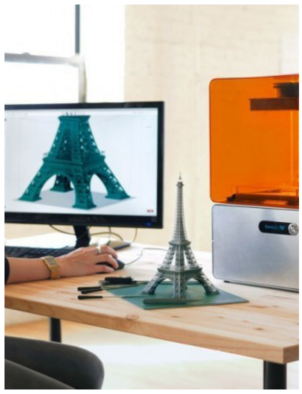

May 2013

Disruptive technologies: Advances that will transform life, business, and the global economy

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Disruptive technologies: Advances that will transform life, business, and the global economy

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Connecting rate of improvement and reach today …

$5 million vs. $400

Price of the fastest supercomputer in 1975[1] and an iPhone 4 with equal performance

230+ million

Knowledge workers in 2012

$2.7 billion, 13 years

Cost and duration of the Human Genome Project, completed in 2003

300,000

Miles driven by Google's autonomous cars with only one accident (human error)

3x

Increase in efficiency of North American gas wells between 2007 and 2011

85%

Drop in cost per watt of a solar photovoltaic cell since 2000

1 For CDC-7600, considered the world's fastest computer from 1969 to 1975; equivalent to $32 million in 2013 at an average inflation rate of 4.3 percent per year since launch in 1969.

… *with economic potential in 2025*

2–3 billion

More people with access to the Internet in 2025

$5–7 trillion

Potential economic impact by 2025 of automation of knowledge work

$100, 1 hour

Cost and time to sequence a human genome in the next decade[2]

1.5 million

Driver-caused deaths from car accidents in 2025, potentially addressable by autonomous vehicles

100–200%

Potential increase in North American oil production by 2025, driven by hydraulic fracturing and horizontal drilling

16%

Potential share of solar and wind in global electricity generation by 2025[3]

2 Derek Thompson, "IBM's killer idea: The $100 DNA-sequencing machine," *The Atlantic*, November 16, 2011.

3 Assuming continued cost declines in solar and wind technology and policy support for meeting the global environmental target of CO_2 concentration lower than 450 ppm by 2050.

Executive summary

The parade of new technologies and scientific breakthroughs is relentless and is unfolding on many fronts. Almost any advance is billed as a breakthrough, and the list of "next big things" grows ever longer. Yet some technologies do in fact have the potential to disrupt the status quo, alter the way people live and work, rearrange value pools, and lead to entirely new products and services. Business leaders can't wait until evolving technologies are having these effects to determine which developments are truly big things. They need to understand how the competitive advantages on which they have based strategy might erode or be enhanced a decade from now by emerging technologies—how technologies might bring them new customers or force them to defend their existing bases or inspire them to invent new strategies.

Policy makers and societies need to prepare for future technology, too. To do this well, they will need a clear understanding of how technology might shape the global economy and society over the coming decade. They will need to decide how to invest in new forms of education and infrastructure, and figure out how disruptive economic change will affect comparative advantages. Governments will need to create an environment in which citizens can continue to prosper, even as emerging technologies disrupt their lives. Lawmakers and regulators will be challenged to learn how to manage new biological capabilities and protect the rights and privacy of citizens.

Many forces can bring about large-scale changes in economies and societies—demographic shifts, labor force expansion, urbanization, or new patterns in capital formation, for example. But since the Industrial Revolution of the late 18th and early 19th centuries, technology has had a unique role in powering growth and transforming economies. Technology represents new ways of doing things, and, once mastered, creates lasting change, which businesses and cultures do not "unlearn." Adopted technology becomes embodied in capital, whether physical or human, and it allows economies to create more value with less input. At the same time, technology often disrupts, supplanting older ways of doing things and rendering old skills and organizational approaches irrelevant. These economically disruptive technologies are the focus of our report.[1]

We view technology both in terms of potential economic impact and capacity to disrupt, because we believe these effects go hand-in-hand and because both are of critical importance to leaders. As the early 20th-century economist Joseph Schumpeter observed, the most significant advances in economies are often accompanied by a process of "creative destruction," which shifts profit pools, rearranges industry structures, and replaces incumbent businesses. This process is often driven by technological innovation in the hands of entrepreneurs. Schumpeter describes how the Illinois Central railroad's high-speed freight

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1 Recent reports by the McKinsey Global Institute have analyzed how changes in labor forces, global financial markets, and infrastructure investment will shape economies and influence growth in coming years. See, for example, *The world at work: Jobs, pay, and skills for 3.5 billion people*, McKinsey Global Institute, June 2012.

service enabled the growth of cities yet disrupted established agricultural businesses. In the recent past, chemical-based photography—a technology that dominated for more than a century and continued to evolve—was routed by digital technology in less than 20 years. Today the print media industry is in a life-and-death struggle to remain relevant in a world of instant, online news and entertainment.

Some economists question whether technology can still deliver the kind of wide-ranging, profound impact that the introduction of the automobile or the semiconductor chip had, and point to data showing slowing productivity growth in the United States and the United Kingdom—often early adopters of new technology—as evidence. While we agree that significant challenges lie ahead, we also see considerable reason for optimism about the potential for new and emerging technologies to raise productivity and provide widespread benefits across economies. Achieving the full potential of promising technologies while addressing their challenges and risks will require effective leadership, but the potential is vast. As technology continues to transform our world, business leaders, policy makers, and citizens must look ahead and plan.

Today, we see many rapidly evolving, potentially transformative technologies on the horizon—spanning information technologies, biological sciences, material science, energy, and other fields. The McKinsey Global Institute set out to identify which of these technologies could have massive, economically disruptive impact between now and 2025. We also sought to understand how these technologies could change our world and how leaders of businesses and other institutions should respond. Our goal is not to predict the future, but rather to use a structured analysis to sort through the technologies with the potential to transform and disrupt in the next decade or two, and to assess potential impact based on what we can know today, and put these promising technologies in a useful perspective. We offer this work as a guide for leaders to anticipate the coming opportunities and changes.

IDENTIFYING THE TECHNOLOGIES THAT MATTER

The noise about the next big thing can make it difficult to identify which technologies truly matter. Here we attempt to sort through the many claims to identify the technologies that have the greatest potential to drive substantial economic impact and disruption by 2025 and to identify which potential impacts leaders should know about. Important technologies can come in any field or emerge from any scientific discipline, but they share four characteristics: high rate of technology change, broad potential scope of impact, large economic value that could be affected, and substantial potential for disruptive economic impact. Many technologies have the potential to meet these criteria eventually, but leaders need to focus on technologies with potential impact that is near enough at hand to be meaningfully anticipated and prepared for. Therefore, we focused on technologies that we believe have significant potential to drive economic impact and disruption by 2025.

- **The technology is rapidly advancing or experiencing breakthroughs.** Disruptive technologies typically demonstrate a rapid rate of change in capabilities in terms of price/performance relative to substitutes and alternative approaches, or they experience breakthroughs that drive accelerated rates of change or discontinuous capability improvements. Gene-sequencing technology, for example, is advancing at a rate even faster than computer processing power and could soon make possible inexpensive desktop sequencing machines. Advanced materials technology is experiencing significant breakthroughs, from the first artificial production of graphene (a nanomaterial with extraordinary properties including strength and conductivity) in 2004, to IBM's creation of the first graphene-based integrated circuit in 2011.[2]

- **The potential scope of impact is broad.** To be economically disruptive, a technology must have broad reach--touching companies and industries and affecting (or giving rise to) a wide range of machines, products, or services. The mobile Internet, for example, could affect how 5 billion people go about their lives, giving them tools to become potential innovators or entrepreneurs—making the mobile Internet one our most impactful technologies. And the Internet of Things technology could connect and embed intelligence in billions of objects and devices all around the world, affecting the health, safety, and productivity of billions of people.

- **Significant economic value could be affected.** An economically disruptive technology must have the potential to create massive economic impact. The value at stake must be large in terms of profit pools that might be disrupted, additions to GDP that might result, and capital investments that might be rendered obsolete. Advanced robotics, for example, has the potential to affect $6.3 trillion in labor costs globally. Cloud has the potential to improve productivity across $3 trillion in global enterprise IT spending, as well as enabling the creation of new online products and services for billions of consumers and millions of businesses alike.

- **Economic impact is potentially disruptive.** Technologies that matter have the potential to dramatically change the status quo. They can transform how people live and work, create new opportunities or shift surplus for businesses, and drive growth or change comparative advantage for nations. Next-generation genomics has the potential to transform how doctors diagnose and treat cancer and other diseases, potentially extending lives. Energy storage technology could change how, where, and when we use energy. Advanced oil and gas exploration and recovery could fuel economic growth and shift value across energy markets and regions.

To reach our final list of a dozen economically disruptive technologies we started with more than 100 possible candidates drawn from academic journals, the business and technology press, analysis of published venture capital portfolios, and hundreds of interviews with relevant experts and thought leaders. We assessed each candidate according to our four criteria, eliminating some that were too narrow and others that seem unlikely to start having significant economic impact within our time period. We believe that the technologies we identify have potential to affect billions of consumers, hundreds of millions of workers, and trillions of dollars of economic activity across industries. The 12 potentially economically disruptive technologies are listed in Exhibit E1.

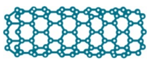
In Exhibit E2, we show representative metrics of how each technology fulfills our criteria for speed, range of impact, and potential scale of economic value that could be affected. The values in this chart serve to characterize the broad

2 Yu-Ming Lin et al., "Wafer-scale graphene integrated circuit," *Science*, volume 332, number 6035, June 2011.

potential of these technologies to drive economic impact and disruption and do not represent our estimates of the potential economic impact by 2025, which we describe in Exhibit E3 below. These numbers are not exhaustive; they are indicative and do not represent all possible applications or potential impacts for each technology.

Exhibit E1

Twelve potentially economically disruptive technologies

	**Mobile Internet**	Increasingly inexpensive and capable mobile computing devices and Internet connectivity
	**Automation of knowledge work**	Intelligent software systems that can perform knowledge work tasks involving unstructured commands and subtle judgments
	**Internet of Things**	Networks of low-cost sensors and actuators for data collection, monitoring, decision making, and process optimization
	**Cloud technology**	Use of computer hardware and software resources delivered over a network or the Internet, often as a service
	**Advanced robotics**	Increasingly capable robots with enhanced senses, dexterity, and intelligence used to automate tasks or augment humans
	**Autonomous and near-autonomous vehicles**	Vehicles that can navigate and operate with reduced or no human intervention
	**Next-generation genomics**	Fast, low-cost gene sequencing, advanced big data analytics, and synthetic biology ("writing" DNA)
	**Energy storage**	Devices or systems that store energy for later use, including batteries
	**3D printing**	Additive manufacturing techniques to create objects by printing layers of material based on digital models
	**Advanced materials**	Materials designed to have superior characteristics (e.g., strength, weight, conductivity) or functionality
	**Advanced oil and gas exploration and recovery**	Exploration and recovery techniques that make extraction of unconventional oil and gas economical
	**Renewable energy**	Generation of electricity from renewable sources with reduced harmful climate impact

SOURCE: McKinsey Global Institute analysis

Exhibit E2

Speed, scope, and economic value at stake of 12 potentially economically disruptive technologies

	Illustrative rates of technology improvement and diffusion	Illustrative groups, products, and resources that could be impacted[1]	Illustrative pools of economic value that could be impacted[1]
Mobile Internet	**$5 million vs. $400[2]** Price of the fastest supercomputer in 1975 vs. that of an iPhone 4 today, equal in performance (MFLOPS) **6x** Growth in sales of smartphones and tablets since launch of iPhone in 2007	**4.3 billion** People remaining to be connected to the Internet, potentially through mobile Internet **1 billion** Transaction and interaction workers, nearly 40% of global workforce	**$1.7 trillion** GDP related to the Internet **$25 trillion** Interaction and transaction worker employment costs, 70% of global employment costs
Automation of knowledge work	**100x** Increase in computing power from IBM's Deep Blue (chess champion in 1997) to Watson (Jeopardy winner in 2011) **400+ million** Increase in number of users of intelligent digital assistants like Siri and Google Now in last 5 years	**230+ million** Knowledge workers, 9% of global workforce **1.1 billion** Smartphone users, with potential to use automated digital assistance apps	**$9+ trillion** Knowledge worker employment costs, 27% of global employment costs
Internet of Things	**300%** Increase in connected machine-to-machine devices over past 5 years **80–90%** Price decline in MEMS (microelectromechanical systems) sensors in last 5 years	**1 trillion** Things that could be connected to the Internet across industries such as manufacturing, health care, and mining **40 million** Annual deaths from chronic diseases like Type 2 diabetes and cardiovascular disease	**$36 trillion** Operating costs of key affected industries (manufacturing, health care, and mining) **$4 trillion** Global health care spend on chronic diseases
Cloud technology	**18 months** Time to double server performance per dollar **3x** Monthly cost of owning a server vs. renting in the cloud	**2.7 billion** Internet users **50 million** Servers in the world	**$1.7 trillion** GDP related to the Internet **$3 trillion** Enterprise IT spend
Advanced robotics	**75–85%** Lower price for Baxter[3] than a typical industrial robot **170%** Growth in sales of industrial robots, 2009–11	**320 million** Manufacturing workers, 12% of global workforce **250 million** Annual major surgeries	**$6 trillion** Manufacturing worker employment costs, 19% of global employment costs **$2–3 trillion** Cost of major surgeries
Autonomous and near-autonomous vehicles	**7** Miles driven by top-performing driverless car in 2004 DARPA Grand Challenge along a 150-mile route **1,540** Miles cumulatively driven by cars competing in 2005 Grand Challenge **300,000+** Miles driven by Google's autonomous cars with only 1 accident (which was human-caused)	**1 billion** Cars and trucks globally **450,000** Civilian, military, and general aviation aircraft in the world	**$4 trillion** Automobile industry revenues **$155 billion** Revenue from sales of civilian, military, and general aviation aircraft
Next-generation genomics	**10 months** Time to double sequencing speed per dollar **100x** Increase in acreage of genetically modified crops, 1996–2012	**26 million** Annual deaths from cancer, cardio-vascular disease, or Type 2 diabetes **2.5 billion** People employed in agriculture	**$6.5 trillion** Global health-care costs **$1.1 trillion** Global value of wheat, rice, maize, soy, and barley
Energy storage	**40%** Price decline for a lithium-ion battery pack in an electric vehicle since 2009	**1 billion** Cars and trucks globally **1.2 billion** People without access to electricity	**$2.5 trillion** Revenue from global consumption of gasoline and diesel **$100 billion** Estimated value of electricity for households currently without access
3D printing	**90%** Lower price for a home 3D printer vs. 4 years ago **4x** Increase in additive manufacturing revenues in past 10 years	**320 million** Manufacturing workers, 12% of global workforce **8 billion** Annual number of toys manufactured globally	**$11 trillion** Global manufacturing GDP **$85 billion** Revenue from global toy sales
Advanced materials	**$1,000 vs. $50** Difference in price of 1 gram of nanotubes over 10 years **115x** Strength-to-weight ratio of carbon nanotubes vs. steel	**7.6 million tons** Annual global silicon consumption **45,000 metric tons** Annual global carbon fiber consumption	**$1.2 trillion** Revenue from global semiconductor sales **$4 billion** Revenue from global carbon fiber sales
Advanced oil and gas exploration and recovery	**3x** Increase in efficiency of US gas wells between 2007 and 2011 **2x** Increase in efficiency of US oil wells between 2007 and 2011	**22 billion** Barrels of oil equivalent in natural gas produced globally **30 billion** Barrels of crude oil produced globally	**$800 billion** Revenue from global sales of natural gas **$3.4 trillion** Revenue from global sales of crude oil
Renewable energy	**85%** Lower price for a solar photovoltaic cell per watt since 2000 **19x** Growth in solar photovoltaic and wind generation capacity since 2000	**21,000 TWh** Annual global electricity consumption **13 billion tons** Annual CO_2 emissions from electricity generation, more than from all cars, trucks, and planes	**$3.5 trillion** Value of global electricity consumption **$80 billion** Value of global carbon market transactions

1 Not comprehensive; indicative groups, products, and resources only.
2 For CDC-7600, considered the world's fastest computer from 1969 to 1975; equivalent to $32 million in 2013 at an average inflation rate of 4.3% per year since launch in 1969.
3 Baxter is a general-purpose basic manufacturing robot developed by startup Rethink Robotics.
SOURCE: McKinsey Global Institute analysis

Mobile Internet

In just a few years, Internet-enabled portable devices have gone from a luxury for a few to a way of life for more than 1 billion people who own smartphones and tablets. In the United States, an estimated 30 percent of Web browsing and 40 percent of social media use is done on mobile devices; by 2015, wireless Web use is expected to exceed wired use. Ubiquitous connectivity and an explosive proliferation of apps are enabling users to go about their daily routines with new ways of knowing, perceiving, and even interacting with the physical world. The technology of the mobile Internet is evolving rapidly, with intuitive interfaces and new formats, including wearable devices. The mobile Internet also has applications across businesses and the public sector, enabling more efficient delivery of many services and creating opportunities to increase workforce productivity. In developing economies, the mobile Internet could bring billions of people into the connected world.

Automation of knowledge work

Advances in artificial intelligence, machine learning, and natural user interfaces (e.g., voice recognition) are making it possible to automate many knowledge worker tasks that have long been regarded as impossible or impractical for machines to perform. For instance, some computers can answer "unstructured" questions (i.e., those posed in ordinary language, rather than precisely written as software queries), so employees or customers without specialized training can get information on their own. This opens up possibilities for sweeping change in how knowledge work is organized and performed. Sophisticated analytics tools can be used to augment the talents of highly skilled employees, and as more knowledge worker tasks can be done by machine, it is also possible that some types of jobs could become fully automated.

Internet of Things

The Internet of Things—embedding sensors and actuators in machines and other physical objects to bring them into the connected world—is spreading rapidly. From monitoring the flow of products through a factory to measuring the moisture in a field of crops to tracking the flow of water through utility pipes, the Internet of Things allows businesses and public-sector organizations to manage assets, optimize performance, and create new business models. With remote monitoring, the Internet of Things also has great potential to improve the health of patients with chronic illnesses and attack a major cause of rising health-care costs.

Cloud

With cloud technology, any computer application or service can be delivered over a network or the Internet, with minimal or no local software or processing power required. In order to do this, IT resources (such as computation and storage) are made available on an as-needed basis—when extra capacity is needed it is seamlessly added, without requiring up-front investment in new hardware or programming. The cloud is enabling the explosive growth of Internet-based services, from search to streaming media to offline storage of personal data (photos, books, music), as well as the background processing capabilities that enable mobile Internet devices to do things like respond to spoken commands to ask for directions. The cloud can also improve the economics of IT for companies and governments, as well as provide greater flexibility and responsiveness. Finally, the cloud can enable entirely new business models, including all kinds of pay-as-you-go service models.

Advanced robotics

For the past several decades, industrial robots have taken on physically difficult, dangerous, or dirty jobs, such as welding and spray painting. These robots have been expensive, bulky, and inflexible—bolted to the floor and fenced off to protect workers. Now, more advanced robots are gaining enhanced senses, dexterity, and intelligence, thanks to accelerating advancements in machine vision, artificial intelligence, machine-to-machine communication, sensors, and actuators. These robots can be easier for workers to program and interact with. They can be more compact and adaptable, making it possible to deploy them safely alongside workers. These advances could make it practical to substitute robots for human labor in more manufacturing tasks, as well as in a growing number of service jobs, such as cleaning and maintenance. This technology could also enable new types of surgical robots, robotic prosthetics, and "exoskeleton" braces that can help people with limited mobility to function more normally, helping to improve and extend lives.

Next-generation genomics

Next-generation genomics marries advances in the science of sequencing and modifying genetic material with the latest big data analytics capabilities. Today, a human genome can be sequenced in a few hours and for a few thousand dollars, a task that took 13 years and $2.7 billion to accomplish during the Human Genome Project. With rapid sequencing and advanced computing power, scientists can systematically test how genetic variations can bring about specific traits and diseases, rather than using trial and error. Relatively low-cost desktop sequencing machines could be used in routine diagnostics, potentially significantly improving treatments by matching treatments to patients. The next step is synthetic biology—the ability to precisely customize organisms by "writing" DNA. These advances in the power and availability of genetic science could have profound impact on medicine, agriculture, and even the production of high-value substances such as biofuels—as well as speed up the process of drug discovery.

Autonomous and near-autonomous vehicles

It is now possible to create cars, trucks, aircraft, and boats that are completely or partly autonomous. From drone aircraft on the battlefield to Google's self-driving car, the technologies of machine vision, artificial intelligence, sensors, and actuators that make these machines possible is rapidly improving. Over the coming decade, low-cost, commercially available drones and submersibles could be used for a range of applications. Autonomous cars and trucks could enable a revolution in ground transportation—regulations and public acceptance permitting. Short of that, there is also substantial value in systems that assist drivers in steering, braking, and collision avoidance. The potential benefits of autonomous cars and trucks include increased safety, reduced CO_2 emissions, more leisure or work time for motorists (with hands-off driving), and increased productivity in the trucking industry.

Energy storage

Energy storage technology includes batteries and other systems that store energy for later use. Lithium-ion batteries and fuel cells are already powering electric and hybrid vehicles, along with billions of portable consumer electronics devices. Li-ion batteries in particular have seen consistent increases in performance and reductions in price, with cost per unit of storage capacity declining dramatically over the past decade. Over the next decade, advances in energy storage technology could make electric vehicles (hybrids, plug-in hybrids, and all-electrics) cost competitive with vehicles based on internal-combustion engines. On the power grid, advanced battery storage systems can help with the integration of solar and wind power, improve quality by controlling frequency variations, handle peak loads, and reduce costs by enabling utilities to postpone infrastructure expansion. In developing economies, battery/solar systems have the potential to bring reliable power to places it has never reached.

3D printing

Until now, 3D printing has largely been used by product designers and hobbyists and for a few select manufacturing applications. However, the performance of additive manufacturing machinery is improving, the range of materials is expanding, and prices (for both printers and materials) are declining rapidly—bringing 3D printing to a point where it could see rapid adoption by consumers and even for more manufacturing uses. With 3D printing, an idea can go directly from a 3D design file to a finished part or product, potentially skipping many traditional manufacturing steps. Importantly, 3D printing enables on-demand production, which has interesting implications for supply chains and for stocking spare parts—a major cost for manufacturers. 3D printing can also reduce the amount of material wasted in manufacturing and create objects that are difficult or impossible to produce with traditional techniques. Scientists have even “bioprinted” organs, using an inkjet printing technique to layer human stem cells along with supporting scaffolding.

Advanced materials

Over the past few decades, scientists have discovered ways to produce materials with incredible attributes—smart materials that are self-healing or self-cleaning; memory metals that can revert to their original shapes; piezoelectric ceramics and crystals that turn pressure into energy; and nanomaterials. Nanomaterials in particular stand out in terms of their high rate of improvement, broad potential applicability, and long-term potential to drive massive economic impact. At nanoscale (less than 100 nanometers), ordinary substances take on new properties—greater reactivity, unusual electrical properties, enormous strength per unit of weight—that can enable new types of medicine, super-slick coatings, stronger composites, and other improvements. Advanced nanomaterials such as graphene and carbon nanotubes could drive particularly significant impact. For example, graphene and carbon nanotubes could help create new types of displays and super-efficient batteries and solar cells. Finally, pharmaceutical companies are already progressing in research to use nanoparticles for targeted drug treatments for diseases such as cancer.

Advanced oil and gas exploration and recovery

The ability to extract so-called unconventional oil and gas reserves from shale rock formations is a technology revolution that has been gathering force for nearly four decades. The combination of horizontal drilling and hydraulic fracturing makes it possible to reach oil and gas deposits that were known to exist in the United States and other places but that were not economically accessible by conventional drilling methods. The potential impact of this technology has received enormous attention. With continued improvements, this technology could significantly increase the availability of fossil fuels for decades and produce an immediate boon for energy-intensive industries such as petrochemicals manufacturing. Eventually, improving technology for oil and gas exploration and recovery could even unlock new types of reserves, including coalbed methane, tight sandstones, and methane clathrates (also known as methane hydrates), potentially ushering in another energy "revolution."

Renewable energy

Renewable energy sources such as solar, wind, hydro-electric, and ocean wave hold the promise of an endless source of power without stripping resources, contributing to climate change, or worrying about competition for fossil fuels. Solar cell technology is progressing particularly rapidly. In the past two decades, the cost of power produced by solar cells has dropped from nearly $8 per watt of capacity to one tenth of that amount. Meanwhile, wind power constitutes a rapidly growing proportion of renewable electricity generation. Renewable energy sources such as solar and wind are increasingly being adopted at scale in advanced economies like the United States and the European Union. Even more importantly, China, India, and other emerging economies have aggressive plans for solar and wind adoption that could enable further rapid economic growth while mitigating growing concerns about pollution.

The 12 technologies in our final list do not represent all potentially economically disruptive technologies in 2025. Many of the other advancing technologies that we reviewed are also worth following and thinking about. In our view they do not have the same potential for economic impact and disruption by 2025, but we cannot rule out sudden breakthroughs or other factors, such as new public policies, that might change that (see Box 1, "Other technologies on the radar").

Box 1. Other technologies on the radar

Some of the technologies that we reviewed, but which did not make our final list, are nonetheless interesting and worthy of consideration. Here we note two groups of these technologies.

Five technologies that nearly made our final list:

- **Next-generation nuclear (fission)** has potential to disrupt the global energy mix but seems unlikely to create significant impact by 2025 given the time frames of current experiments and pilots.
- **Fusion power** also has massive potential, but it is even more speculative than next-generation nuclear fission in terms of both technological maturity and time frame.
- **Carbon sequestration** could have great impact on reducing CO_2 concentration in the atmosphere, but despite sustained R&D investment it may not become cost-effective and deployed at scale by 2025.
- **Advanced water purification** could benefit millions of people facing water shortages, but approaches with substantially better economics than currently known approaches may not be operating at scale by 2025.
- **Quantum computing** represents a potentially transformative alternative to digital computers, but the breadth of its applicability and impact remain unclear and the time frame for commercialization is uncertain.

A sampling of other interesting and often hyped candidates that were not close in the final running:

- **Private space flight** is likely to be limited to space tourism and private satellite launches through 2025, though after that, applications such as asteroid mining could drive greater economic impact.
- **OLED / LED lighting** has potential for extensive reach in terms of people affected but seems unlikely to disrupt pools of economic value beyond narrow industries by 2025.
- **Wireless charging** is promising for some applications but overall offers limited impact at high cost. Simple versions exist, but it is not clear that the technology serves an important need versus substitutes such as improved energy storage technology.
- **Flexible displays** have long been in development and could offer exciting new possibilities for for mobile the designs of mobile devices and TVs, but on their own seem unlikely to have broad-based disruptive impact by 2025.
- **3D and volumetric displays** have received a lot of attention, but it is not clear that these technologies will drive broad economic impact by 2025.

ESTIMATED POTENTIAL ECONOMIC IMPACT IN 2025 ACROSS SIZED APPLICATIONS

Exhibit E3 shows our estimates of the potential economic impact that select applications of each technology could create in 2025 (see Box 2, "Approach to estimating potential economic impact in 2025"). While these estimates are incomplete by definition, the analysis suggests significant potential impact from even a few possible applications. It is important to note, however, that this economic potential should not be equated with market sizes for these technologies. The economic potential will be captured as consumer surplus as well as in new revenue and GDP growth as companies commercialize these technologies. For company leaders, it is worth noting the great extent to which Internet-based technologies have tended to shift value to consumers; in our work we see that as much as two-thirds of the value created by new Internet offerings has been captured as consumer surplus. [3]

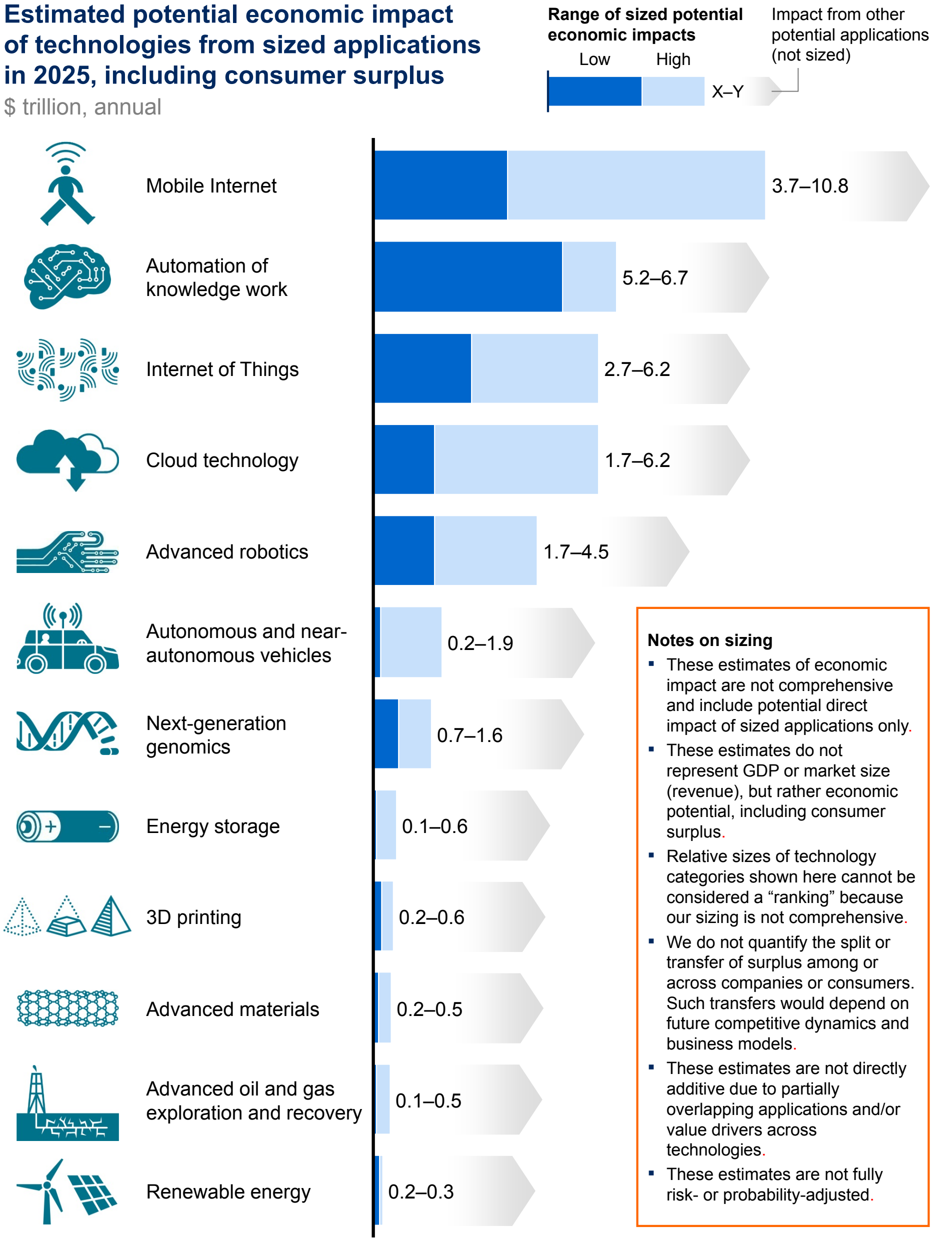
Moreover, our sizing is not comprehensive: we have estimated the potential economic impact in 2025 of applications that we can anticipate today and which appear capable of affecting large amounts of value. But it is impossible to predict all the ways in which technologies will be applied; the value created in 2025 could be far larger than what we estimate here. Based on our analysis, however, we are convinced that collectively the potential for our sized technologies and applications is huge: taken together and netting out potential overlaps, we find that they have the potential to drive direct economic impact on the order of $14 trillion to $33 trillion per year in 2025.

3 *Internet matters: The Net's sweeping impact on growth, jobs, and prosperity*, McKinsey Global Institute, May 2011.

Exhibit E3

Estimated potential economic impact of technologies from sized applications in 2025, including consumer surplus

$ trillion, annual



Notes on sizing

- These estimates of economic impact are not comprehensive and include potential direct impact of sized applications only.
- These estimates do not represent GDP or market size (revenue), but rather economic potential, including consumer surplus.
- Relative sizes of technology categories shown here cannot be considered a "ranking" because our sizing is not comprehensive.
- We do not quantify the split or transfer of surplus among or across companies or consumers. Such transfers would depend on future competitive dynamics and business models.
- These estimates are not directly additive due to partially overlapping applications and/or value drivers across technologies.
- These estimates are not fully risk- or probability-adjusted.

SOURCE: McKinsey Global Institute analysis

Box 2. Approach to estimating potential economic impact in 2025

We focus on estimating the potential economic impact of 12 technologies across a set of promising applications, based on feasible scenarios for technology advancement, reach, and resulting productivity or value gains that could be achieved by 2025. We focus on estimating the potential (rather than realized) value in 2025 by assuming that addressable barriers to technology adoption and value creation (such as the need for supporting regulations) can be overcome and that reasonable, necessary investments can be made.

Our estimates represent annual value, including consumer surplus, that could be realized in 2025 across sized applications. These estimates are not potential revenue, market size, or GDP impact. We do not attempt to size all of the many possible indirect and follow-on effects. We also do not size possible surplus shifts among companies and industries, or between companies and consumers. Finally, our estimates are not adjusted for risk or probability.

To estimate the potential direct economic impact of technologies by 2025, we first identify applications and drivers of value for each technology. We then define a scope of potential impact for each application (for example, the operating cost base of an industry where the introduction of a technology might alter costs) which we project forward to 2025 to create a hypothetical base case in which the technology under examination is effectively "frozen" or held constant with no technology progress, diffusion, or additional use. We next consider potential rates of technology diffusion and adoption across the estimated scope of impact for the application, taking into account price/performance improvement. Finally, we estimate potential productivity or value gains from each application that could be achieved across our defined scope of impact by 2025 to determine the potential direct economic impact of the use of the technology for this application. In some cases, we use prior McKinsey research to estimate a portion of the additional surplus that could be created by use of technologies such as the Internet. In the case of advanced oil and gas exploration and recovery and renewable energy, we focus on estimating the value of additional output that could be cost-effectively produced using improved technology.

In many cases there could be a lag between the introduction of new technology and its economic impact, owing in part to the need to reconfigure processes to fully capture benefits. We account for this lag by factoring in structural constraints such as the need for supporting infrastructure, up-front investments (for example, the cost of advanced robots), and prevailing industry investment cycles. We do not take into account less tangible barriers such as cultural resistance or political opposition, as these barriers could potentially be overcome by 2025.

We have focused on quantifying the total value from use of each technology because we believe this is a better measure than GDP or other growth accounting metrics for evaluating the potential of a technology to drive transformative impact on people and the economy. GDP, for example, does not include consumer surplus, which is an important portion of the value created from new technology.

SOME OBSERVATIONS

While we evaluated each technology separately and sized their potential economic impacts independently, we did observe some interesting patterns in the results. These observations reflect common traits among economically disruptive technologies. Here we examine a set of overarching implications for stakeholders to consider as they plan for the coming decade of economically disruptive technology.

Information technology is pervasive. Most of the technologies on our list are directly enabled, or enhanced, by information technology. Continuing progress in artificial intelligence and machine learning are essential to the development of advanced robots, autonomous vehicles, and in knowledge work automation tools. The next generation of gene sequencing depends highly on improvements in computational power and big data analytics, as does the process of exploring and tapping new sources of oil and natural gas. 3D printing uses computer generated models and benefits from an online design sharing ecosystem. The mobile Internet, Internet of Things, and cloud are themselves information and communications technologies. Information technologies tend to advance very rapidly, often following exponential trajectories of improvement in cost/performance. Also, information technologies are often characterized by strong network effects, meaning that the value to any user increases as the number of users multiplies. Just as IT creates network effects for users of social media and the mobile Internet, IT-enabled platforms and ecosystems could bring additional value to users of 3D printing or to researchers experimenting with next-generation genomics technology. In a separate report, also released in May 2013, we take a look at how advances in IT are shaping important business trends in the next few years (see Box 3: Ten IT-enabled business trends for the decade ahead).

Box 3. IT-enabled business trends

We have revisited and updated previous perspectives on IT-enabled business trends that appeared in the McKinsey Quarterly in 2007 and 2010. These trends are powerful ways in which businesses, organizations, and governments can use information technologies to implement strategy, manage people and assets, alter organizational structures, and build new business models.

These IT-enabled business trends are already driving pervasive impact across thousands of companies and across sectors. These trends include some of the technologies in this report, such as automation of knowledge work. Some technologies in this report, such as cloud computing, underpin IT-enabled business trends.

The report can be downloaded at www.mckinsey.com/mgi.

- **Combinations of technologies could multiply impact.** We see that certain emerging technologies could be used in combination, reinforcing each other and potentially driving far greater impact. For example, the combination of next-generation genomics with advances in nanotechnology has the potential to bring about new forms of targeted cancer drugs. It is possible that the first commercially available nano-electromechanical machines (NEMS), molecule-sized machines, could be used to create very advanced sensors for wearable mobile Internet devices or Internet of Things applications. And automated knowledge work capabilities could help drive dramatic advances across many areas, including next-generation genomics. Another example of symbiotic development exists between advances in energy storage and renewable energy sources; the ability to store electricity created by solar or wind helps to integrate renewables into the power grid. The advances in energy storage that make this possible could benefit, in turn, from advances in nanomaterials for batteries. Similarly, the mobile Internet might never live up to its enormous potential without important advances in cloud computing to enable applications—including tools for automating knowledge work—on mobile devices.

- **Consumers could win big, particularly in the long run.** Many of the technologies on our list have the potential to deliver the lion's share of their value to consumers, even while providing producers with sufficient profits to encourage technology adoption and production. Technologies like next-generation genomics and advanced robotics could deliver major health benefits, not all of which may be usable by health-care payers and providers, many of whom face growing pressure to help improve patient outcomes while also reducing health-care costs. Many technologies will also play out in fiercely competitive consumer markets—particularly on the Internet, where earlier McKinsey research has shown consumers capture the majority of the economic surplus created.[4] Mobile Internet, cloud, and the Internet of Things are prime examples. Also, as technologies are commercialized and come into widespread use, competition tends to shift value to consumers.

- **The nature of work will change, and millions of people will require new skills.** It is not surprising that new technologies make certain forms of human labor unnecessary or economically uncompetitive and create demand for new skills. This has been a repeated phenomenon since the Industrial Revolution: the mechanical loom marginalized home weaving while creating jobs for mill workers. However, the extent to which today's emerging technologies could affect the nature of work is striking. Automated knowledge work tools will almost certainly extend the powers of many types of workers and help drive top-line improvements with innovations and better decision making, but they could also automate some jobs entirely. Advanced robotics could make more manual tasks subject to automation, including in services where automation has had less impact until now. Business leaders and policy makers will need to find ways to realize the benefits of these technologies while creating new, innovative ways of working and providing new skills to the workforce.

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4 *Internet matters: The Net's sweeping impact on growth, jobs, and prosperity*, McKinsey Global Institute, May 2011.

- **The future for innovators and entrepreneurs looks bright.** A new wave of unprecedented innovation and entrepreneurship could be in the offing as a result of falling costs and rapid dissemination of technologies. Many of the technologies discussed in this report will be readily available and may require little or no capital investment. 3D printing, for example, could help “democratize” the design, production, and distribution of products and services. Cloud-based services and mobile Internet devices could help level the playing field, putting IT capabilities and other resources within reach of small enterprises, including in developing nations. Finally, the opportunities and innovation unleashed by a new wave of entrepreneurship could provide new sources of employment.

- **Technology impact differs between advanced and developing economies.** There are many examples: in advanced economies and in the fastest-growing developing economies, the chief value of energy storage could be to make electric vehicles competitive with cars that rely solely on internal-combustion engines. But in the poorest developing economies, advanced batteries can provide millions of people with access to electricity, enabling them to connect to the digital world and join the global economy (Exhibit E4). Advanced robots could be a boon to manufacturing, but could reduce global demand for the low-cost labor that developing economies offer the world and which drives their development. Mobile Internet devices could deliver remarkable new capabilities to many people in advanced economies, but could connect two billion to three billion more people to the digital economy in the developing world. Also, with less legacy infrastructure and fewer investments in old technology, developing economies could leapfrog to more efficient and capable technologies (e.g., adopting the mobile Internet before telephone or cable-TV wiring has been installed, or possibly even adopting solar power plus energy storage solutions before being connected to the power grid).

- **Benefits of technologies may not be evenly distributed.** While each of the technologies on our list has potential to create significant value, in some cases this value may not be evenly distributed, and could even contribute to widening income inequality. As MIT economist Erik Brynjolfsson has observed, it is possible that advancing technology, such as automation of knowledge work or advanced robotics, could create disproportionate opportunities for some highly skilled workers and owners of capital while replacing the labor of some less skilled workers with machines. This places an even greater importance on training and education to refresh and upgrade worker skills and could increase the urgency of addressing questions on how best to deal with rising income inequality.

- **The link between hype and potential is not clear.** Emerging technologies often receive a great deal of notice. News media know that the public is fascinated with gadgets and eager for information about how the future might unfold. The history of technology is littered with breathless stories of breakthroughs that never quite materialized. The hype machine can be equally misleading in what it chooses to ignore. As Exhibit E5 shows, with the exception of the mobile Internet, there is no clear relationship between the amount of talk a technology generates and its potential to create value. The lesson for leaders is to make sure that they and their advisers have the knowledge to make their own assessments based on a structured analysis involving multiple scenarios of technology advancement and potential impact.

Exhibit E4

Estimated distribution of potential economic impact between developed and developing economies for sized applications

% of potential economic impact for sized applications

Impact on
- Developed economies
- Developing economies

Technology	Developed economies (%)	Developing economies (%)	Developed	Developing
Mobile Internet	50	50	High-value applications, e.g., increasing worker productivity	Bulk of new mobile users
Automation of knowledge work	80	20	Higher impact of increasing labor productivity	Large number of knowledge workers
Internet of Things	70	30	Major applications enabled by advanced technology infrastructure, e.g., advanced supply chain systems	Large applicable spend base, lower initial adoption
Cloud technology	30	70	Higher surplus per user	Majority of new adoption
Advanced robotics	80	20	Greater ability to pay for surgical robots and prosthetics; high savings from automation	Many manufacturing workers but lower savings from automation
Autonomous and near-autonomous vehicles	80	20	Early adoption in high-end vehicles	Many vehicles but smaller percentage of high-end vehicles and low cost of hiring drivers
Next-generation genomics	80	20	Greater early adoption of genomic technologies and treatments	Lower initial adoption, particularly for new treatments
Energy storage	60	40	Many new vehicles with potentially higher adoption of electric and hybrid models	Many vehicles but potentially smaller percentage of new electric and hybrid models
3D printing	60	40	Potential for earlier adoption in manufacturing and by consumers	Large manufacturing base and many consumers, but lower initial adoption
Advanced materials	90	10	Greater early adoption of new nano-based treatments due to more advanced healthcare systems	Lower initial adoption for new nano-based treatments and substances
Advanced oil and gas exploration and recovery	80	20	North America leads in shale gas and light tight oil production	Significant investments being made but could require years to catch up
Renewable energy	20	80	Larger existing renewables base (especially wind) with moderate growth	Large renewables capacity development, e.g., in China

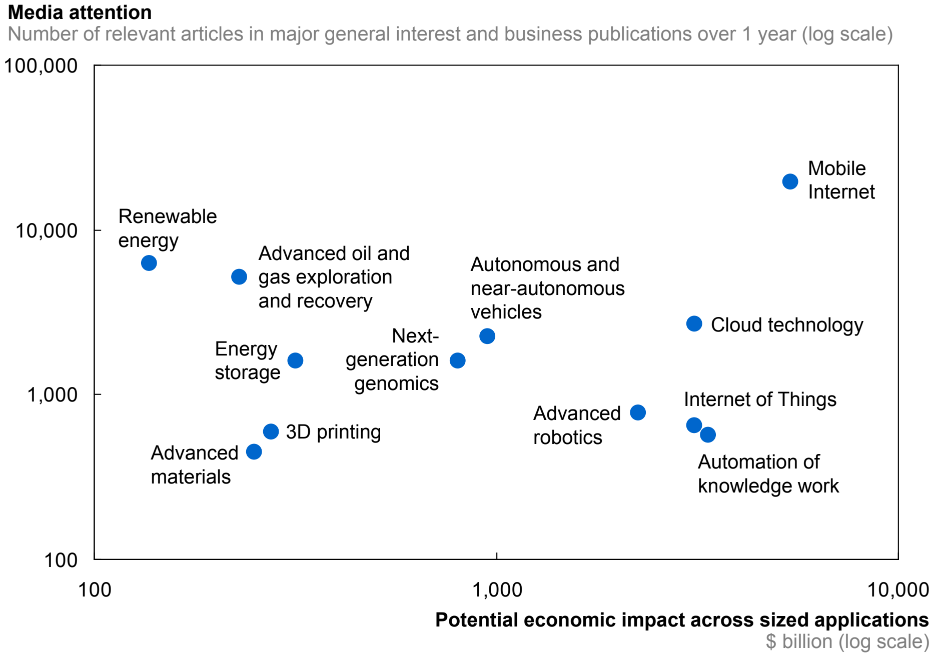
Notes on sizing

- These economic impact estimates are not comprehensive and include potential direct impact of sized applications only.
- These estimates do not represent GDP or market size (revenue), but rather economic potential, including consumer surplus.
- Relative sizes of technology categories shown here cannot be considered a "ranking" because our sizing is not comprehensive.
- We do not quantify the split or transfer of surplus among or across companies or consumers, as this would depend on emerging competitive dynamics and business models.
- These estimates are not directly additive due to partially overlapping applications and/or value drivers across technologies.
- These estimates are not fully risk- or probability-adjusted.

SOURCE: McKinsey Global Institute analysis

Exhibit E5

The relationship between hype about a technology and its potential economic impact is not clear



NOTE: Estimates of potential economic impact are for only some applications and is not a comprehensive estimate of total potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact. We do not size possible surplus shifts among companies and industries, or between companies and consumers. These estimates are not risk- or probability-adjusted.

SOURCE: Factiva; McKinsey Global Institute analysis

- **Scientific discovery and innovation will surprise us.** We examined many technologies to evaluate their potential, but in doing so we were impressed by the reality that it is impossible to predict how new technologies will emerge and play out. Many of the technologies on our list likely will, at some point, be revolutionized by advancements in science. The technologies that define the 20th and 21st centuries, including modern medicine and electronics, were enabled by scientific breakthroughs like germ theory and Maxwell's laws of electromagnetism. Emerging technologies like genomics and nanotechnology are likewise being driven by unpredictable scientific breakthroughs, from the completion of the Human Genome Project in 2003 to the first artificial production of graphene in 2004. Harnessing the full potential of advanced nanomaterials like graphene will require major improvements or breakthroughs in cost-effective production techniques. Moreover, when breakthroughs in technologies like advanced materials or energy storage occur, they could drive impact across a host of applications and sectors, likely including some major direct impacts, but potentially also including a wide array of indirect and follow-on impacts.

- **There are some troubling challenges.** The technologies on our list have great potential to improve the lives of billions of people. Cloud computing and the mobile Internet, for example, could raise productivity and quality in education, health care, and public services. At the same time, some of these technologies could bring unwanted side effects. The benefits of the mobile Internet and cloud computing are accompanied by rising risks of security and privacy breaches. Objects and machines under the control of computers across the Web (the Internet of Things) can also be hacked, exposing factories, refineries, supply chains, power plants, and transportation networks to new risks. Next-generation genomics has the potential to grant new powers over biology, but these powers could be abused to disastrous effect. Low-cost desktop gene-sequencing machines will not only put the power of genomics in doctor offices, but also potentially in the hands of terrorists. Even well-intentioned experiments in garages using inexpensive sequencing and DNA synthesis equipment could result in the production and release of dangerous organisms. And nanomaterials offer great promise, but more research will be required to fully ascertain their potential impact on health. It will be up to business leaders, policy makers, and societies to weigh these risks and navigate a path that maximizes the value of these technologies while avoiding their dangers.

IMPLICATIONS

As we conducted our research and created estimates of the potential economic impact of disruptive technologies, we focused on identifying how each of these technologies could affect individuals, societies, organizations, economies, and governments in transformative and disruptive ways. Exhibit E6 lays out some major ways in which each technology on our list could drive transformative and disruptive impact by 2025.

In considering the disruptive potential of these technologies, we see that each could drive profound changes across many dimensions—in the lives of citizens, in business, and across the global economy. As noted, the future seems bright for entrepreneurs and innovators. 3D printing, the mobile Internet, cloud technology, and even next-generation genomics could provide the opportunities and the tools to allow small enterprises to compete on a meaningful scale and advance into new markets rapidly.

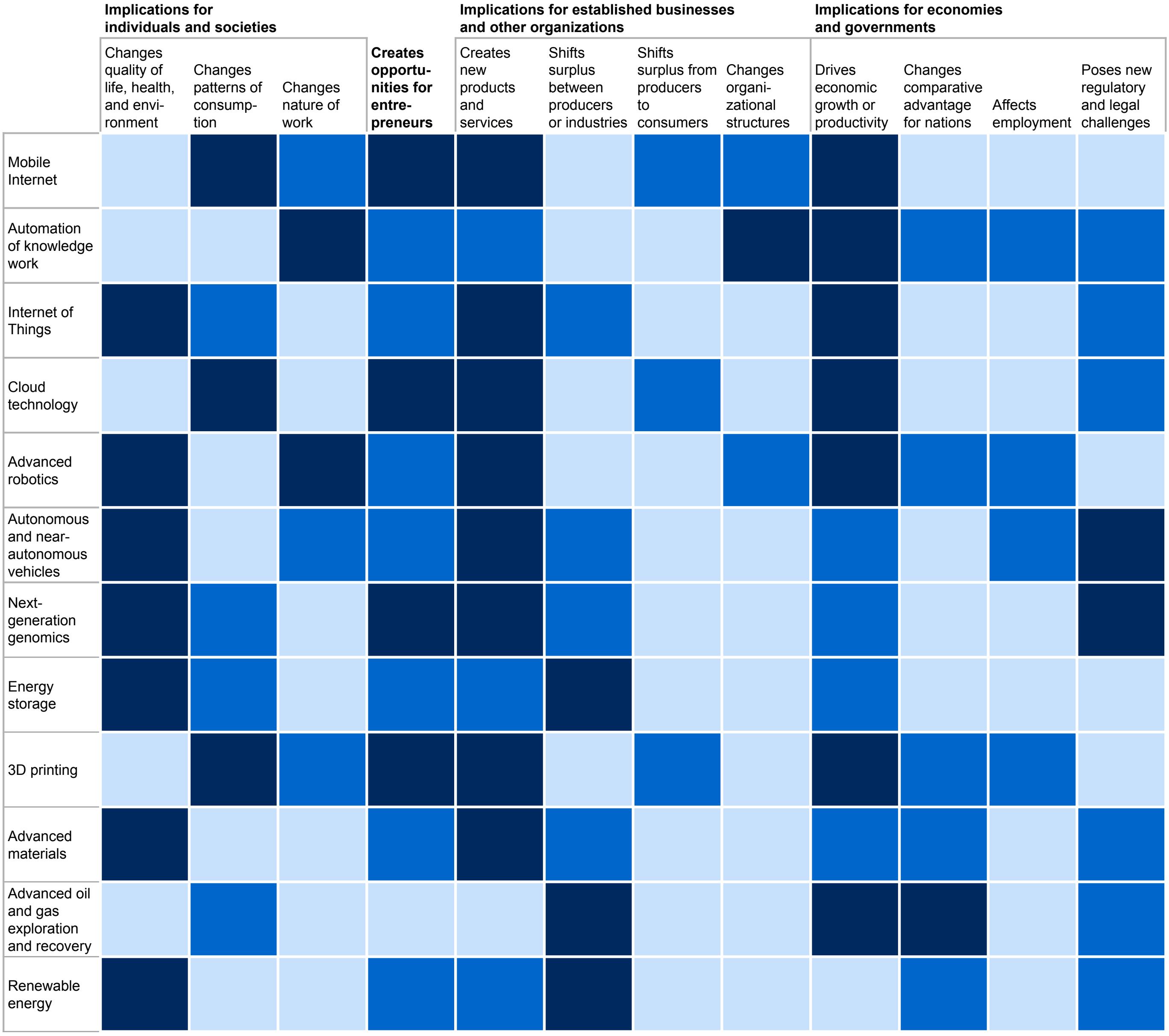
Many technologies, including advanced robotics, next-generation genomics, and renewable energy, have real potential to drive tangible improvements in quality of life, health, and the environment. For example, advanced robotic surgical systems and prosthetics could improve and extend many lives, while renewable energy sources could help clean up the environment and lessen the deleterious health effects of air pollution, a major and growing issue, particularly in developing economies. Many of these technologies could change how and what consumers buy, or alter overall consumption of certain resources such as energy and materials. Others could fundamentally change the nature of work for many employees around the world, both in manufacturing and knowledge work.

Almost every technology on our list could change the game for businesses, creating entirely new products and services, as well as shifting pools of value between producers or from producers to consumers. Some, like automation of knowledge work and the mobile Internet, could also change how companies and other organizations structure themselves, bringing new meaning to the anytime/anywhere work style. With automation of knowledge work tasks, organizations that can augment the powers of skilled workers stand to do well.

Exhibit E6

How disruptive technologies could affect society, businesses, and economies

Primary | Secondary | Other potential impact



SOURCE: McKinsey Global Institute analysis

Each of these technologies has significant potential to drive economic growth and even change the sources of comparative advantages among nations. Energy technologies such as unconventional oil and gas and energy storage could power overall economic growth, while technologies such as advanced robotics and 3D printing could foster increased productivity and growth in the manufacturing sector. These types of impacts could help nations develop and exploit their unique resources and capabilities in new ways, potentially shifting the global center of gravity across sectors and regions. Many of these technologies pose new regulatory and legal challenges. Some, such as autonomous vehicles, will require sensible regulatory regimes to help foster their growth and realize their benefits. Next-generation genomics and Internet of Things will need appropriate controls to help avoid accidents or misuse.

As these disruptive technologies continue to evolve and play out, it will be up to business leaders, entrepreneurs, policy makers, and citizens to maximize their opportunities while dealing with the challenges. Business leaders need to be on the winning side of these changes. They can do that by being the early adopters or innovators or by turning a disruptive threat into an opportunity. The first step is for leaders to invest in their own technology knowledge. Technology is no longer down the hall or simply a budget line; it is the enabler of virtually any strategy, whether by providing the big data analytics that reveal ways to reach new customer groups, or the Internet of Things connections that enable a whole new profit center in after-sale support. Top leaders need to know what technologies can do and how to bend it to their strategic goals. Leaders cannot wait until technologies are fully baked to think about how they will work for—or against—them. And sometimes companies will need to disrupt their own business models before a rival or a new competitor does it for them.

One clear message: the nature of work is changing. Technologies such as advanced robots and knowledge work automation tools move companies further to a future of leaner, more productive operations, but also far more technologically advanced operations. The need for high-level technical skills will only grow, even on the assembly line. Companies will need to find ways to get the workforce they need, by engaging with policy makers and their communities to shape secondary and tertiary education and by investing in talent development and training; the half-life of skills is shrinking, and companies may need to get back into the training business to keep their corporate skills fresh.

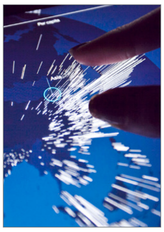
The scope of impact of the technologies in this report makes clear that policy makers could benefit from an informed and comprehensive view of how they can help their economies benefit from new technologies. Policy makers can find ways to turn the disruptions into positive change; they can encourage development of the technologies that are most relevant to their economies. In many cases, such as in next-generation genomics or autonomous vehicles, the proper regulatory frameworks will need to be in place before those technologies can blossom fully. In other cases governments may need to be the standards setters or the funders of the research that helps move ideas from science labs into the economy. In still others, they will need to draw the lines between progress and personal rights.

The challenge for policy makers—and for citizens—is enormous. It is a good time for policy makers to review how they address technology issues and develop a systematic approach; technology stops for no one, and governments cannot afford to be passive or reactive. The time may be right, for example, to rethink how governments measure the economic impact of technology—to look beyond GDP and employment and look for metrics that truly capture the value added (or put at risk) when new technologies take hold.

Disruptive technologies at a glance: Word cloud of report contents[5]

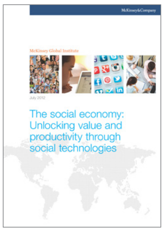
5 www.wordle.com; McKinsey Global Institute analysis.

Related McKinsey Global Institute research



Urban world tablet app for iPad and Android (May 2013)

An unprecedented wave of urbanization is driving the most significant economic transformation in history, as the center of economic gravity shifts decisively east. MGI's new tablet app, now available for Android as well as iPad, offers an intuitive sense of this new urban world, showcasing GDP, population, and income levels for over 2,600 cities worldwide in 2010 and 2025. The app is available from the Apple App Store and Google Play.



The social economy: Unlocking value and productivity through social technologies (July 2012)

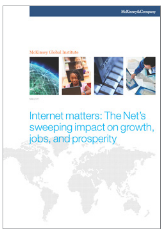
MGI analyzes the potential impact of social technologies. Based on in-depth analyses of how social technology can be used in five economic sectors (four commercial sectors, plus the social sector), the report identifies a series of value levers that can be applied across the value chain and within and across enterprises.

Online and upcoming: The Internet's impact on aspiring countries (January 2012)

This report explains how the Internet today connects about two billion people worldwide. Half of these are in the "aspiring" world—countries as varied as Algeria, South Africa, China, Iran, and Mexico that are climbing the developmental ladder quickly, with diverse populations and inarguable economic potentialities. It examines the impact of the Internet in populous and fast-growing aspiring countries, where it offers even greater potential than in the developed world.

Big data: The next frontier for innovation, competition, and productivity (May 2011)

Big data will become a key basis of competition, underpinning new waves of productivity growth, innovation, and consumer surplus—as long as the right policies and enablers are in place.



Internet matters: The Net's sweeping impact on growth, jobs, and prosperity (May 2011)

The Internet is a vast mosaic of economic activity, ranging from millions of daily online transactions and communications to smartphone downloads of TV shows. But little is known about how the Web in its entirety contributes to global growth, productivity, and employment. McKinsey research into the Internet economies of the G-8 nations as well as Brazil, China, India, South Korea, and Sweden finds that the Web accounts for a significant and growing portion of global GDP.

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