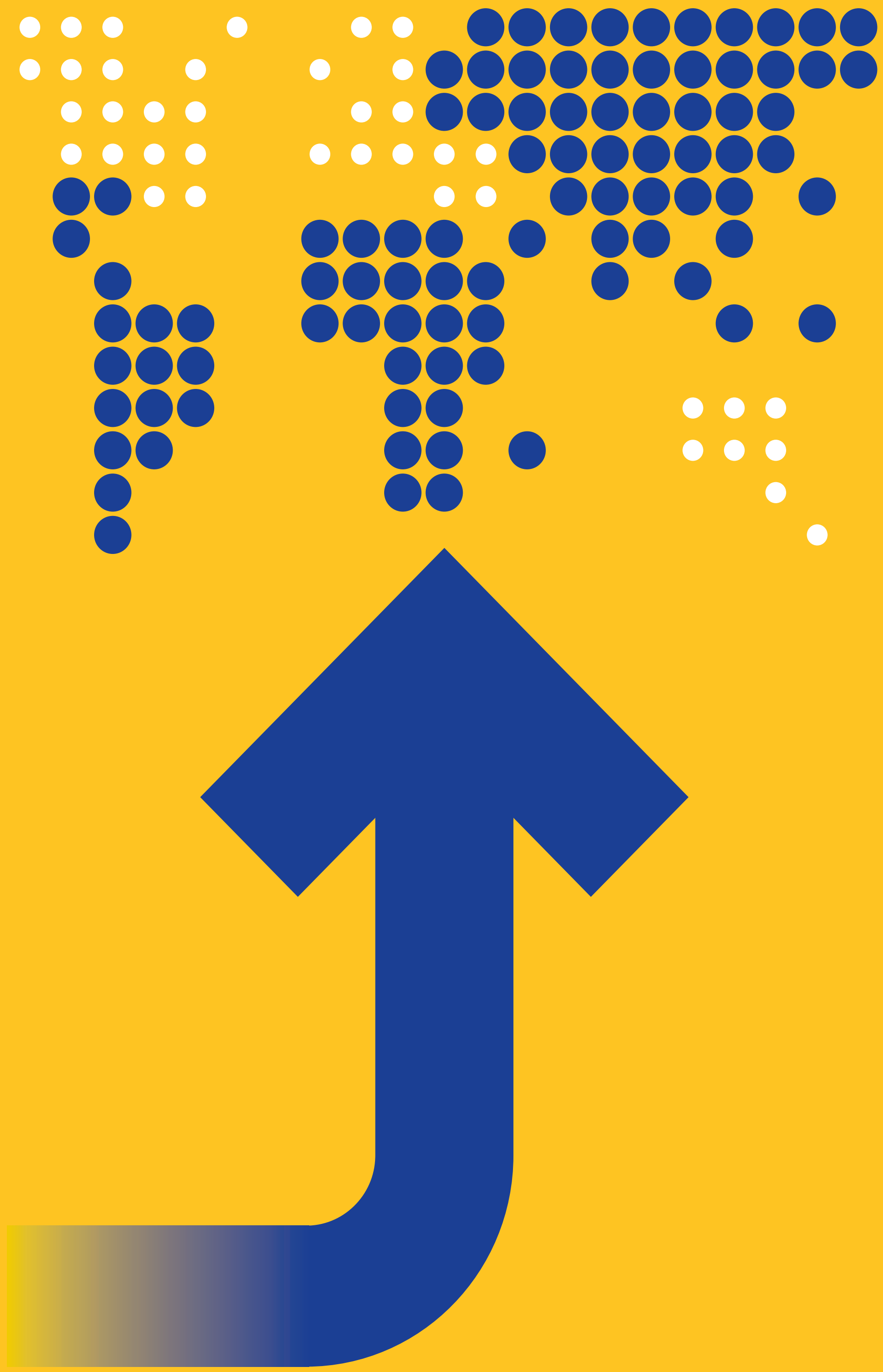

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Technology 2050: A potential landscape

R.A. Mashelkar, FRS

Background Paper

Emerging Markets Forum

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Technology 2050: A potential landscape

R.A. Mashelkar, FRS

Historical perspective

As someone has said, wise people may develop expectations for the future, but only foolish make the predictions. "A technology of the 20th century symposium" held in 1900, based on the level of knowledge that existed at the time, might not have mentioned airplane, radio, antibiotics, nuclear energy, electronics, computers or space exploration! Similarly, in the year 2000, no one would have mentioned iPhone, iPad, Facebook, and Twitter. One can imagine the hazards of predicting the scenario for Technology 2050, which is over three decades away.

Let us leave aside a prediction of 35 years here. Just look at the six-year horizon. The World Economic Forum held in Geneva in December 2014 discussed technology predictions for as early as 2020![1] Among these were the "humanized" internet, the end of the 19th century grid, cheaper, more widespread solar power, the Internet of Things being no longer about things, new cures from the bacteria that live in the human body, data-driven healthcare, printable organs, the "internet of everywhere," and so on!

Predicting the future

The future will be driven by paradigm shifts, whose origin may fundamentally lie in the technological breakthroughs that took place in the recent or the distant past. As we shall later explain, it was the breakthrough in hydraulic fracturing and horizontal drilling technology, in which the US started investing almost five decades ago, that has led to the shale gas revolution, an energy independence for the US and the dramatic shift in its geopolitical strategies.[2]

Advances in science will define the future technology. For example, modern medicine and electronics owe much to the scientific breakthroughs like germ theory and Maxwell's laws of electromagnetism. Quantum theory has given us the transistor, the laser and the digital revolution. Unpredictable scientific breakthroughs led to unpredictable technological changes. The completion of the Human Genome Project in 2003 is an example. The discovery of graphene in 2004 is yet another example. However, we are a long way from exploiting the full consequence of these breakthroughs. But when such breakthroughs occur, they have potential for huge impact.

There are a number of thought provoking and visionary contributions on the future of science[3,4,5] and how it will impact our future.

Many attempts have been made to predict the future of technology and technology in our future. Some of the prominent contributions[6,7,8,9,10] are worth highlighting.

Here are some typical (not exhaustive) efforts during the past five years. In the Harvard University Report[11], the leaders in the field have given their insights on the future progress of specific disciplines such as biology, engineering science, etc.

The book[12] titled "Physics of the Future" by Dr. Michio Kaku gives an interesting (and also sometimes romantic) view of how science will shape human destiny and our lives by the year 2100.

An effort was made by Mashelkar & Goel in 2011, when they brought out a report "Asia 2050: Technology Landscape"[13] which was a more Asia-specific study.

1. "14 Tech predictions for our world in 2020," https://agenda.weforum.org/08/14-technology%20predictions-2020
2. "The US Shale Revolution and the Arab Gulf State" SWP www.swp-berlin.org/filadmin/contents/.../2014-RP11_wep_ovs_sbg.pdf

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8. Cornish, Edward, ed. Futuring: The Exploration of the Future. Bethesda, MD: World Future Society, 2004.
9. Denning, Peter J., ed. The Invisible Future: The Seamless Integration of Technology into Everyday Life. New York: McGraw Hill, 2002.
10. Sheffield, Charles, Marcelo Alonso, and Morton A. Kaplan, eds. The World of 2044: Technological Development and the Future of Society. St. Paul, MN: Paragon House, 1994.
11. The Progress of the Disciplines, Harvard Magazine (September-October 2011), pp 72.
12. "Physics of the Future," Michio Kaku, Doubleday, (Random House, Inc.), NY, 2011.
13. Asia 2050: Technology Landscape', R.A. Mashelkar and V.K. Goel, in

Spectacular digital transformation of our lives, the way we live, work, think, act, and so on is already for us to see.

A very significant recent report[14] is that by the McKinsey Global Institute on the role of disruptive technologies in our future and the way these new technologies will transform our life, work, business and their overall impact on the global economy, which was released in May 2013. This insightful and powerful report has led to a wide ranging discussions in board rooms, amongst policy planners, the global research and innovation community and so on.

Another report,[15] again by McKinsey Global Institute (2014), pertains to the role such disruptive technologies are likely to play in an emerging economy like India. Citi GPS: Global Perspectives and Solutions has brought out reports[16,17] that identify ten disruptive innovations that will have a significant influence on our future.

Thomson Reuters' IP and Science Group has an interesting method for crystal gazing, i.e. making predictions based on data analysis. In order to forecast as to which emerging technologies[18] could be dominant by 2025, they looked at recently published scientific research papers and patents. They singled out the most frequently cited papers and patents, which represent the concentration of activity.

There are other reports[19, 20, 21] also that attempt to predict the future.

Our current report on Technology 2050 draws on some of these and similar studies. Extensive discussions were also held with several thought leaders from around the world about their perceptions on Technology 2050 and Society 2050.

This Report is divided into four subsections. The first sub-section is about the digital transformation of our lives and work due to the advent of mobile internet, automation of knowledge work and cloud technology. The second deals with the emergence of smart physical world due to the advances in the Internet of Things, intelligent transportation and distribution, nanomaterials and nanotechnology and additive manufacturing. The third sub-section concerns the future energy technologies covering unconventional energy, renewable energy and energy storage. The fourth sub-section concerns the future health technologies including next-gen genomics and regenerative medicine. We then consider the issues (societal, legal, moral, political, policy level) that will either aid or hamper the progress of Technology 2050. Finally, we deal with the dramatic shifts that are likely to take place in our life and work due to Technology 2050.

The digital transformation of life and work

Spectacular digital transformation of our lives, the way we live, work, think, act, and so on is already for us to see. The possibilities of the creation of a new digital world by 2050 are truly bewildering, since the changes are so rapid.

Take the case of information technology. The performance of microprocessors has improved by 25,000 times since their invention. Every 18 months, technology doubles the speed of microprocessors. The computer of 2050 is expected to be as powerful as all computers in Silicon Valley today put together. The buzz words in the computer world are: smaller, faster, cheaper, pipelined, superscalar and parallel. Several laboratories around the world are busy exploring novel technologies that may one day herald the arrival of a new generation of computers and microelectronic devices. Some are exploring the possibility of developing quantum techniques, which would capitalize on the non-classical behavior of the devices. Others are taking non-silicon routes by developing data storage systems that can potentially use photonically activated

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Asia 2050: Realizing the Asian Century, 2011, Saga Publication

14. "Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy," McKinsey Global Institute, May 2013, www.mckinsey.com

15. "India Technology Opportunity: Transforming Work, Empowering People," McKinsey Global Institute, December 2014, www.McKinsey.com

16. Citi Disruptive Innovation: Ten Things to Stop and Think about, April 2013, www.academia.edu

17. Disruptive Innovations II: Ten more things to stop and think about, May 2014, www.academia.edu

18. "The World in 2025: Ten Predications of Innovation," Science Watch Science Watch – World 2025

19. "Future Technology Predictions and Scenarios," http://www.futureforall.org/future-technology-predictions.html

20. "2050 and the Future of Infrastructure," http://www.futuristspeaker.com/2014/08/2050-and-the-future-of-infrastructure/

21. "10 Futurist Predictions in the World of Technology," http://electroncis.howstuffworks.com/future-tech/

By 2050, practically all Internet connections could be through mobile devices, and a majority of new Internet users could be using mobile devices as their primary or sole means of connecting to the internet.

bio-molecules. Yet others are exploring nano-mechanical logic gaps.

Computing power continues to grow exponentially, approximately doubling every two years on a price/performance basis. Today a $400 iPhone 4 (in millions of floating point operations per second or MFLOPS) is equal to the CDC 7600 supercomputer in performance, which was the fastest supercomputer in 1975 and cost $5 million at the time. These advances in computational power have been accompanied by significant strides in data storage systems, big data (the ability to process and analyze huge amounts of data, such as real-time location feeds from millions of cellphones), and cloud computing (which makes the computational power needed for knowledge work automation accessible to even individuals and small businesses via internet-enabled devices).

The three technologies, which are going to be the cornerstones for the new digital world, are mobile internet, automation of knowledge work and the cloud technology. Let us discuss each of these.

Mobile internet

Nielsen reported that 91% of US consumers have their mobile phones within reach 24x7. By 2050, practically all Internet connections could be through mobile devices, and a majority of new Internet users could be using mobile devices as their primary or sole means of connecting to the internet. The mobile world will be omnipresent in 2050.

Mobile internet is truly transformative. Mobile computing devices, high-speed wireless connectivity, and applications are combining in a powerful way already. But by 2050, Mobile internet devices would be smaller, faster, more intuitive, more interactive, wearable, and enhanced by sensors from accelerometers to location sensors - infrared sensors to sensors that detect screen proximity. Voice and gesture recognition will make them even more powerful.

By 2050, device makers would be packing more computing power, sharper displays, multiple sensors, and powerful antennas into ever-smaller mobile devices. Advanced nanomaterials such as graphene would have been successfully used.

Today, mobile devices connect to the internet via cellular networks (3G and 4G/LTE networks) or Wi-Fi networks. Newer network advances could include 5G cellular networks and satellite services with new innovative approaches to dynamically sharing the spectrum.

Billions of consumers would have joined the digital economy by 2050, both widening and equalizing the playing field. Indeed, the maximum growth of mobile internet use would be in currently developing economies, which are already beginning to compete globally in online commerce.

Wearable devices[22,23] are making rapid progress. Google Glass, for instance, today delivers many 'augmented reality' applications that let the wearer step into virtual spaces, just as virtual reality goggles do. A wearable mobile device would be programmed to help Alzheimer's patients recognize people and remind them of what various objects around the home are. Instant translation apps on wearable devices would be routinely used to read signs and menus, making travel to foreign lands far easier. Mobile internet devices would have become intelligent personal assistants, capable of managing our schedules, answering questions and even alerting us to important information.

The use of mobile internet in health care will be most promising. It is predicted[24] that in management of chronic diseases alone, this technology potentially could cut more than $2 trillion a year in the projected cost of care by 2025. Today, treating chronic diseases accounts for about 60 percent of global health-care spending, and it could be more than $15 trillion globally by 2025. Patients with diabetes would be monitored through ingestible or attached sensors, which can transmit readings and alert the patient, nurses, and physicians when vital signs indicate an

22. Wearable Technologies, bi-snu.ac.kr/Courses/4ai14s/140522.pdf
23. Wearable Computing, www.cs.Virgina.edu/-yoya/wearable.ppt
24. "Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy," McKinsey Global Institute, May 2013, www.mckinsey.com

The economic impact of mobile internet usage is potentially massive, and its effects could be highly disruptive across a wide range of sectors.

impending problem, thus avoiding crises and the costs of emergency room visits or hospitalization.

In education, mobile computing would have raised the productivity and improved learning both inside and outside classrooms. Hybrid online/offline internet based teaching models using tablets would be routine by 2050.

Mobile payments can be segregated into three types, namely remote mobile payment, proximity mobile payment and peer-to-peer payment. The rise of mobile payments[25] would have had material and widespread financial and social consequences. Today, 90 percent of the more than three trillion transactions made every year globally are still cash transactions. But mobile payments have expanded at a fast pace in the last few years, driven by the global uptake of mobile phones, replacing physical wallets. Players like PayPal and Amazon have been early entrants in the m-commerce space following their success in e-commerce. According to a study[26] across[27] key markets by Citi's Mobile Analytics Team, global m-payment volumes are expected to total $447 billion by 2016, growing at a CAGR of 86% between 2013 and 2016 led by increasing consumer acceptance.

By 2050, mobile payment systems would have fully matured, reaping the full benefits of huge savings in processing costs and creating unparalleled productivity benefits.

Today's emerging markets would have leapfrogged from a cash-based society to mobile payments - not very different from the communications industry, where we went from post offices to mobile phones without stopping for the wire-line infrastructure to be laid out. Already M-PESA in Kenya[27] is generally considered as one of the most successful mobile payment ecosystems in the world with clients representing 60% of Kenya's population. The ubiquity of mobile phones would have helped governments, businesses and individuals overcome a set of pressing and persistent issues, i.e., the lack of access to financial services, computers and internet connectivity. In-country remittance is likely to be the 'killer app' in many emerging markets.

Regardless of the specific technology, several milestones must likely be passed on both the consumer and merchant side on the road to widespread mobile payments adoption.

Digital currency is a form of virtual currency or medium of exchange that is electronically created and stored. At present, there are more than 200 digital currencies (30 with market capitalization above $1 million and 12 above $5 million) with more being created.

Bitcoin, the most prominent digital currency[28], has additional attributes, which include advanced cryptographic methods to secure transactions and ownership, pseudonymous transactions, payments that are verified and recorded in a decentralized ledger and maintained by 'miners' who are allocated newly created Bitcoins as an incentive.

The economic impact of mobile internet usage is potentially massive, and its effects could be highly disruptive across a wide range of sectors. Consumers, business leaders, and policy makers all have a stake in seeing mobile internet usage spread and take on greater capabilities. And all of these stakeholders will also have to grapple with challenges that could limit the realization of this full potential, a subject which has been covered in the section entitled "Making technology 2050 work for global good."

Automation of knowledge work

Computers will be able to perform tasks typically considered "human"—such as complex analyses, subtle judgments, and creative problem solving. We will be able to interact with a machine in the way that one would with a coworker. Instant access to information and substantial enhancement in the quality and pace of decision making, and consequently, the performance, will be the benefit.

25. www.mobile payments today.com
26. Disruptive Innovations II: Ten more things to stop and think about, May 2014, www.academia.edu
27. "Mobile Banking: The Impact of M-PESA in Kenya," www.nber.org/papers/w17129.pdf
28. Bitcoin: Open Source P2P money, https://bitcoin.org

By using the cloud technology from a computer or mobile internet device, one can get an access to a shared pool of computing resources such as servers, storage, and applications.

Indeed, thinking machines with processing powers that far exceed those of the human brain will become a distinct possibility by 2050.

Advances in software are already giving computers the ability to draw conclusions from patterns they discern within huge data sets. Computers with machine learning capabilities are no longer relying only on fixed algorithms and rules. They are modifying and adjusting their own algorithms based on analyses of data, enabling them to "see" relationships or links that a human mind might overlook. Moreover, these machines are 'learning' more and getting smarter day by day.

Advances in user interfaces, such as speech and gesture recognition technology, are giving computers the ability to respond directly to human commands and requests. For instance, Apple's Siri and Google now use such natural user interfaces to recognize spoken words, interpret their meanings and act on those meanings.

The McKinsey report[29] estimates that today total global employment costs are $33 trillion a year and, on current trend, could reach $41 trillion by 2025. The report shows that a subset of knowledge worker occupations will have employment costs that could reach $14 trillion by 2025. These workers – professionals, managers, engineers, scientists, teachers, analysts, and administrative support staff – represent some of the most expensive forms of labor and perform the most valuable work in many organizations.

By 2050, knowledge work automation would have affected education and health care profoundly. It will have replaced lectures with 'adaptive' learning programs—dynamic instruction systems that alter the pace of teaching to match the student's progress and suggest additional exercises based on student responses. In health care, oncologists at Memorial Sloan-Kettering Cancer Center in New York are already using IBM's Watson supercomputer to provide chronic care and cancer treatment diagnostics. Knowledge work automation in medical diagnostics would have had significant impact on the global healthcare system by 2050.

Advanced systems such as the Watson supercomputers, next-generation assistants similar to Apple's Siri, as well as special-purpose tools for analytics, search functions, or a host of other potential applications would be in regular use. Knowledge work automation tools would be delivered in many ways, including via enterprise solutions, apps or web services. By 2050, as a routine, they would be delivered via the cloud and on mobile internet devices.

Cloud technology

By using the cloud technology[30] from a computer or mobile internet device, one can get an access to a shared pool of computing resources such as servers, storage, and applications. Here a complex system of servers and storage systems allocates computing resources to serve multiple customers simultaneously and keep track of what each user needs. When thousands of users suddenly demand the same content, streaming services seamlessly tap more processing power, and then release the excess capacity when demand falls below the peak.

Cloud deployment represents a significant shift in IT management practices, from in-house work to lower-cost, outsourced solutions. In enterprise IT, cloud technology provides on-demand self-service, with a usage based pricing, anytime and anywhere. One of the chief advantages of the cloud model is elasticity—users can expand or shrink capacity as needed. Cloud technology can be implemented as a third-party service or by companies that pool their computing resources on their own private clouds. By centralizing computers, storage, and applications on the cloud, companies raise IT productivity by increasing utilization (which is currently limited by the fact that many computers are used at peak capacity for only 30 to 40 days a year) and reducing the number of employees needed

29. "Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy," McKinsey Global Institute, May 2013, www.mckinsey.com

30. "NIST Definition of Cloud Technology" http://winthrop.edu/domanm/csci411/Handout/NIST.pdf

The new world is going to be smart, interconnected, intelligent and responsive.

to maintain systems and develop software. With public clouds, companies can move to an 'asset-light' model by turning a large capital investment (IT infrastructure) into an operating cost. Cloud set ups are more reliable (since they are capable of shifting processing from one machine to another if one becomes overloaded or fails), eliminating productivity-draining outages.

The world population of internet users is estimated at about 2.5 billion today, and the McKinsey report[31] predicts that it will swell to more than 5 billion by 2025 thanks to the rapid proliferation of smartphones. Not only will there be more internet users in the near future, but these users will also rely more on off-device processing, storage, and applications. The biggest driver of cloud technology demand in the coming decade could be the rapid proliferation of services and applications for internet 'clients'— the computers and mobile devices that are used to access online services and resources. The total potential economic impact for cloud technology across sized applications is expected to exceed $6 trillion by 2025 already.

Small and medium sized enterprises (SMEs) are getting more benefit from cloud services than large corporations. Small companies often find it difficult to build and manage extensive IT infrastructure and plan for future needs. Like larger enterprises, they also often struggle with a poor rate of return on IT systems due to rapid obsolescence of technology. Cloud computing lets SMEs avoid tying up capital in IT and frees them from IT infrastructure management and demand planning, giving them the ability to compete more effectively with big companies. The utility of the cloud extends to software and applications (so-called software as a service). For example, Microsoft Office 365 and Google Apps offer suites of applications available over the internet (instead of via traditional software packages that must be purchased and installed).

31. "Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy," McKinsey Global Institute, May 2013, www.mckinsey.com

The cost of implementing cloud setups has rapidly fallen, while performance has improved. For example, renting a server in the cloud is now about one-third as expensive as buying and maintaining similar equipment. According to the Cisco Global Cloud Index[32], global cloud traffic could increase by a factor of six in the next five years, and according to the McKinsey report[33]; by 2019, more than two-thirds of the global traffic through data centers could be cloud-based—double of what it is today. One can only imagine the scenario of cloud omnipresence by 2050.

Technology-led transformation of physical world

The new world is going to be smart, interconnected, intelligent and responsive. The technological advances that will achieve this transformation will be led by the advent of the Internet of Things, intelligent transportation and distribution systems, additive manufacturing (based on 3D printing) and advanced materials, especially nanomaterials and nanotechnology. We will deal with each one of these in what follows.

Internet of things

By 2050, the physical and the digital world would have been merged in a currently unimaginable way. Sensors, actuators, and data communications technology built into physical objects—from roadways to pacemakers—will enable those objects to be tracked, coordinated, or controlled across a data network or the internet[34]. Internet of Things (IoT) technology ranges from simple identification tags to complex sensors. Sophisticated multi-sensor devices and actuators that communicate data regarding location, performance, environment, and condition would have become very common by 2050.

More than nine billion devices around the world are currently already connected to the internet, including

32. "Cisco Global Cloud Index: Forecast & Methodology" www.intercomms.net/issue-21/pdfs/articles/cisco.pdf
33. "Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy," McKinsey Global Institute, May 2013, www.mckinsey.com
34. To 50 Internet of Things Applications, www.libelium.com

In the new world that will be smart, intelligent and interconnected, intelligent transportation and distributions will lead, and autonomous vehicles will be a major driver.

computers and smartphones. That number is expected to increase dramatically within the next decade, with estimates ranging from quintupling to 50 billion devices to one trillion. One can imagine the possible multi trillion connected devices and the potential impact by 2050.

The portfolio of applications is expanding rapidly in IOT, improving resource productivity and infrastructure management. Smart grids for electricity, water, and transportation networks are typical examples.

By 2050, the greatest benefits in health care would have been achieved by using IOT, and it will be through improved efficiency in treating patients with chronic conditions. Using sensors that read the vital signs of patients at home, nurses and doctors would be routinely alerted to emerging problems, such as a dangerous drop in the glucose levels of a diabetic patient. Treatment costs for chronic diseases constitute approximately 60 percent of total health-care spending, and the annual cost of these diseases in 2025 could be as high as $15.5 trillion globally as per estimates in the McKinsey report[35]. It is estimated that remote monitoring could reduce this cost by 10 to 20 percent, although the realized value might be reduced by factors such as adoption rates and patient acceptance (or resistance).

In manufacturing, IOT would be routinely used for improving operational efficiency in a variety of ways, like tracking machinery, providing real- time updates on equipment status, decreasing downtime, supply chain tracking and management, monitoring flow of inventory around factory floors between different workstations, reducing work-in-progress inventory levels, decreasing wait times, etc.

IOT would have been commonplace in the management of urban infrastructure, systems, and services, including traffic, waste and water systems, and public safety. Cities would be using IOT technology to streamline garbage collection and improve water management.

The McKinsey report[26] estimates that the total operating cost of global manufacturing is currently about $25 trillion per year, and could reach more than $47 trillion by 2025. With reducing cost of sensors, very high adoption rates will be achieved, perhaps covering 100 percent of manufacturing. The potential economic impact of $900 billion to 2.3 trillion per year by the year 2025 itself is expected.

Intelligent transportation & distribution

During the past century, automobiles enabled economic development and higher living standards around the world. The automobile was a breakthrough general-purpose technology. It provided the means for getting workers to their jobs and consumers and goods to markets. However, automobiles have also caused pollution, soaring demand for fossil fuels, congestion and related productivity losses, as well as death and injury.

In the new world that will be smart, intelligent and interconnected, intelligent transportation and distributions will lead, and autonomous vehicles[36] will be a major driver. In autonomous vehicles, input signals from machine vision and sensors are integrated with stored spatial data by artificial-intelligence software to decide how the vehicle should operate based on traffic rules (for example, obeying speed limits and yields signs) and knowledge of exceptions (such as stopping when the light is green if a pedestrian is in the intersection). Control engineering software does the ’driving,’ giving instructions to the actuators that perform the task needed for the desired action, such as accelerating, braking, or turning. Autonomous vehicles that can thus maneuver with reduced or no human intervention will have the greatest impact by 2050.

Autonomous driving will comprise new kinds of vehicles. These will include driverless passenger vehicles (which would not require a driver to sit behind the wheel)

35. “Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy,” McKinsey Global Institute, May 2013, www.mckinsey.com

36. “Autonomous Vehicles,” www.technology review.com/tagged/autonomous-vehicles/

By 2050, autonomous vehicles would have improved the economics of trucking significantly.

that could be configured to maximize work space or even provide beds for passengers; new concepts involving car sharing, in which a car could arrive or leave and park wherever and whenever needed; or new public transportation vehicles that would allow for greater flexibility and personalization.

In addition to providing vehicles with the input devices and onboard intelligence to maneuver independently, companies may find new business models that capitalize on the free time of drivers-turned-passengers (entertainment services or worker productivity tools designed for use in cars, for example).

But will the promise of current technology show up in performance? Today's self-driving technology is expensive. But the cost of these systems will drop substantially in future. For example, researchers at Oxford University are aiming to develop an autonomous system that would cost as little as $150. Major automakers are moving ahead with development. General Motors, Toyota, Mercedes-Benz, Audi, BMW, and Volvo are already testing their own autonomous systems.

Japan's New Energy and Industrial Technology Development Organization, a research organization, has successfully tested an autonomous trucking system[37] in which a single driver leads three other trucks that are equipped with roof-mounted radar systems, traveling at 50 miles per hour, spaced about four meters apart. On-site autonomous vehicles are also being tested by mining giant Rio Tinto. The company has used 150 partly autonomous trucks in Australian mining operations. The trucks follow a predefined route and load and unload material without an operator.

Based on evolving technology, it is possible that autonomous trucks could be spaced less than three feet apart while driving, reducing fuel consumption by 15 to 20 percent by sharply reducing air resistance. Combined with speed control optimized for fuel efficiency, we estimate that autonomous trucks can use 10 to 40 percent less fuel than non-autonomous trucks.

Although experimental vehicles are being rapidly developed, continuing work is required on vision, pattern recognition, and artificial-intelligence technologies to account for unexpected vagaries in infrastructure (for example, what to do when lane marker lines are obscured or traffic is rerouted around work crews).

By 2050, autonomous vehicles would have improved the economics of trucking significantly. Self-driving trucks that transport goods over long distances would have been easily integrated into intermodal transportation and logistics systems. Trucks moving in convoys would be transporting goods on major arteries, then transfer their cargos at regional distribution centers, from which other vehicles would take the cargo to its final destination.

Additive manufacturing

3D printing uses additive manufacturing, where objects are built layer-by-layer[38]. This is in contrast to machining, which is a subtractive technique, taking material out. 3D printing can create objects from a variety of materials, including plastic, metal, ceramics, glass, paper, and even living cells. These materials can come in the form of powders, filaments, liquids, or sheets.

With 3D printing, an idea can go directly from a file on a designer's computer to a finished product. This will eliminate many traditional manufacturing steps. That means no procurement of individual parts, no creation of parts using molds, no machining to carve parts from blocks of material, no welding metal parts together, and no assembly. 3D printing will reduce the amount of material wasted in manufacturing. It will create objects that are difficult or impossible to produce with traditional techniques.

The business of 3D printing for producing complex, low volume, and highly customizable products is already

37. Disruptive Innovations II: Ten more things to stop and think about, May 2014, www.academia.edu

38. "3D Printing Technology" nic su.ap.nic.in/Knowdesk/3D-Printnig-Technology.pdf

The potential of 4D printing for development in remote locations is an obvious game changer.

accelerating. For instance, Boeing currently prints 200 different parts for ten aircraft platforms. In health care, manufacturers have been offering printed custom hearing aid earpieces, selling millions of them already.

Improvements in speed and performance and falling costs is bound to accelerate the spread of 3D printing in the coming decade. The average industrial printer now sells for about $75,000, and some machines cost more than $1 million. On the consumer side, prices for basic 3D printers using fused deposition modeling technology have declined from $30,000 a few years ago to less than $1,000 for some models. By 2050, these costs would have declined rapidly as production volumes grow. Advances are also under way that could dramatically improve the output speed and quality of 3D printers. A combination of falling prices for hardware, easier to use software with more complex design capabilities and the internet, would have allowed 3D printing to be used widely by both individuals and industry.

The materials used in 3D printing are still costly (generally about 50 to 100 times greater than materials used for injection molding), but prices are declining rapidly. Some newer polymer types that can work in 3D printers offer flexibility, electrical conductivity, and even biocompatibility (e.g., for implants).

Larger manufacturing companies are looking to add elements of additive manufacturing into the production process. Specialty end markets such as medical, dental and jewelry are already printing end-use parts and goods for commercial use. General Electric is incorporating 3D printed components for its next generation LEAP engine due to the ability to create more complex and intricate geometries. Companies within the health vertical such as hearing aid maker Phonac and Invisalign braces manufacturer Align have already based their entire manufacturing process on the technology.

The recent "Maker" movement (putting power in the hands of the people to design, manufacture and market their own goods) has created a flood of consumer curiosity and interest, which we believe, will materialize into a significant new market segment[39].

The McKinsey report[40] estimates that consumer use of 3D printing could have a potential economic impact of $100 billion to $300 billion per year by 2025, based on the reduced cost (compared with buying items through retailers) and the value of customization.

The next evolution is that of 4D printing. It is all about the ability of manufactured goods to self-assemble. This concept has been evangelized by MIT researcher Skylar Tibbits[41].

More specifically, the fourth 'D' in 4D printing refers to the ability of a static object to change shape and potentially self-assemble over time utilizing different materials, which begin to interact with its environment. 'Smart' materials can be 'programmed' to change shape with the introduction of an energy. The concept and many of the technologies associated with 4D printing are still in their infancy.

Utilizing a 3D printer to build the object layer by layer, intelligence (via more rigid or flexible materials) can be imprinted directly into the actual structure dictating the transformation and the eventual shape of the object. The Citi GPS report[42] forecasts that self-assembly could radically impact a number of industries such as architecture, engineering, furniture makers, healthcare, aerospace, automotive and more.

The potential of 4D printing for development in remote locations is an obvious game changer. 4D printing could potentially allow for large foldable structures that automatically erect in distant, extreme locations that lack traditional construction crews. Self-assembling structures that are tightly folded could also resolve the many logistical problems of delivering large and delicate objects on bumpy

39. Maker Movement & 3 D Printing: Industry Stats, www.web-strategist.com
40. "Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy," McKinsey Global Institute, May 2013, www.mckinsey.com
41. 4D Printing Technology, www.sjet.us/MIT_4d%20PRINTNG.htm/
42. Disruptive Innovations II: Ten more things to stop and think about, May 2014, www.academia.edu

The use of advanced nanomaterials in medicine could drive significant economic impact by 2050.

space shuttles with limited carry capacity. The technology could also potentially enable medical devices to be implanted into small crevices before transforming to the desired shape.

Although the jury is out on the premise of 4D printing, it is a fact that 3D printing is already beginning to fulfill its promise. The McKinsey report also predicts31 that global sales of products in certain consumer product categories could grow to $4 trillion a year (at retail prices) by 2025. It is possible that many consumers of these products could have access to 3D printing by 2025, whether by owning a 3D printer, using a 3D printer in a local store, or ordering 3D printed products online. That means by 2050, we will see real 'democratization of manufacturing' with extensive use of 3D printing by both individuals and industry.

Nanomaterials and nanotechnology

Nanomaterials and nanotechnology represent an exciting frontier. A number of nanomaterials have emerged, which include carbon nanotubes, fullerenes and buckballs, dendrites, quantum dots and nanocrystals, titanium dioxide and silver nanoparticles, silver nanowires, etc. They are being tried out in multitude of applications, such as in coatings, paints, sensors, chemical catalysts, and food packaging. For example, silver nanoparticles, which have antimicrobial properties, have been added to laundry detergents and even woven into socks. Zinc oxide nanoparticles are used in some sunscreens. Clay nanoparticles, as they improve the barrier properties, are being used in some plastic food packaging to increase shelf life.

The US National Nanotechnology Initiative tracks and supports progress in key areas[43].

Graphene, which comprises one-atom-thick sheets of carbon hexagons, could be game changing, if its true potential is realized[44]. Graphene is one-sixth the weight of steel per unit of volume but more than 100 times as strong. Graphene can be compressed without fracturing, recovering its original shape after being pressurized to more than 3,000 atmospheres. Graphene also has 35 percent less electrical resistance than copper and ten times the conductivity of copper and aluminum. It has been estimated that graphene could yield terahertz processor speeds (about 1,000 times faster than today's fastest microchips).

In 2011 IBM created the first integrated circuit based on a graphene transistor. However, integrating graphene into chips at scale has so far proven to be challenging. It will be no surprise, if graphene would have replaced silicon by 2050. It is quite possible that by 2025, graphene could be used to create highly efficient solar cells or as a coating in lithium-ion battery electrodes, enabling faster charging and greater storage capacity, a potential boost to the adoption of electric vehicles. Graphene-based super capacitors are also being developed with the goal of producing ultra-efficient batteries.

Another promising nanomaterial is quantum dots—nanoparticle semiconductors with unique optical properties[45]. Quantum dots can efficiently produce colored light, potentially making them useful in electronic displays. They could also be used as medical diagnostic tools in place of traditional organic dyes, targeting tumors and lighting up under imaging. Quantum dots are also a possible candidate for creating qbits (quantum bits), the informational unit for quantum computers.

The use of advanced nanomaterials in medicine could drive significant economic impact by 2050. Several examples of nanomedicine applications are emerging. These include contrast agents for all imaging, diagnostics devices, drug delivery vehicles, tissue repair, neuro-electronic interfaces, etc. There are breakthroughs on 'glowing' new nanotechnology guiding cancer surgery, while also killing remaining malignant cells[46]. Stealth DNA-based carbon nanotubes tunneling into cells to deliver targeted drugs[47]

43. "Future of Nanotechnology" futureforall.org/nanotechnology/nanotechnology.htm
44. "Graphene will Change the Way we Live," bigthink.com/dr-kakus-universe/
45. "Quantum Dots" Flolk.uio.no/yuviq/Nanotechnology/QD/QD.pdf
46. http://phys.org/news/2015-01-nonotechnology-cancer-surgery-malignant-cells.htm
47. http://www.kurzwelai.net

Our energy future will be shaped on emerging technologies that are outside the fossil fuel industry, as we show in this section.

is under development. There is also a breakthrough on nanobot micro motors delivering medical payload in a living creature for the first time[48]. The potential for therapeutics is also huge.

Realizing this potential depends on whether specific nano based drugs can be successfully developed and approved at reasonable cost. Drug development of any kind is generally very costly. However, given the number of nano-based drugs in various stages of development, it is possible that a number of them will come to market within the next couple of decades. Many of these drugs are quite expensive. Abraxane[49], Celgene's nano-based drug, will reportedly cost pancreatic cancer patients $6,000 to $8,000 per month. The challenge will be to do innovations which are not only targeted towards increasing efficiency and safety – but also towards dramatically reducing costs.

For advanced nanomaterials to deliver their full potential through 2025 and beyond, reliable and far less expensive methods will have to be developed for producing substances such as graphene, carbon nanotubes, and quantum dots in high volumes. Major challenges pertain to the production of high-quality forms (long strands of nanotubes or large sheets of grapheme, for example) and effectively handling small, delicate, chemically reactive, and potentially toxic nanomaterials. Until these production challenges can be overcome, the potential economic impact of advanced nanomaterials will remain limited.

Consumers stand to benefit greatly from advanced nanomaterials. Besides offering potential breakthroughs in disease diagnosis and treatment over the coming decade, over the long term nanomaterials could also lead to new electronics products that are more powerful, more energy efficient, and more useful. Advanced nano composites using materials such as graphene and carbon nanotubes could eventually be used to make many objects, including cars and airplanes, lighter and stronger.

As the use of advanced nanomaterials becomes increasingly widespread, they have the potential to deliver enormous value to consumers, both in healthcare and eventually across a wide array of products. However, policy makers will need to address unanswered questions regarding the safety of nanomaterials.

Future energy

The world's energy system is currently dominated by fossil fuels, which will be moving towards the point of exhaustion by 2050. Our energy future[50] will be shaped on emerging technologies that are outside the fossil fuel industry, as we show in this section.

Unconventional energy

Unconventional oil and gas reserves are those that cannot be extracted by conventional drilling methods. In these reserves, oil and gas is trapped in natural fractures in rock (often shale) or adsorbed by nearby organic material. Unconventional fossil fuel deposits include coal bed methane, tight sandstone, and methane clathrates (also known as methane hydrates).

The core technologies used to access unconventional oil and gas reserves are hydraulic fracturing and horizontal drilling[51]. Because of shale's low permeability, which prevents oil and gas from flowing from the rock, fracturing is required to release the pressure of overlying and surrounding rock. Fracturing involves pumping up to five millions of gallons of fluid (usually water-based with some additives) at high pressure into rock fractures to release gas or oil held in pores. Horizontal drilling is the method by which the well bore—the tube that carries the oil or gas up from the earth—is drilled to the appropriate depth and then extended parallel to the surface up to a few kilometers. Horizontal drilling allows recovery of fuel in multiple stages

48. http://www.gizmag.com
49. New Treatments for Breast Cancer, www.webmd.com/Featurco/
50. Technology Futures: Shell Game Changer 2007
51. "Hydraulic Fracturing & Shale Gas Production," www.afdc.energy.gov/uploads/publication/ani_hydraulic_fracturing

Access to energy sources has shaped the global geopolitical landscape for more than a century.

along the length of the well bore, making it much more economical than drilling repeatedly to a great depth.

The technology for extracting unconventional oil and gas is advancing rapidly, pointing to the potential to significantly reduce costs and increased production. For example, it may be possible to double the productivity of fracturing by using micro seismic data and well log data in predictive fracture modeling. Water reuse and treatment technologies could reduce freshwater needs by as much as 50 percent. Longer term, use of non-water fluids such as vapor, refrigerated gas, or petroleum could increase the productivity further and make production easier in water-constrained areas. Several high-potential regions, such as China, Australia, and North Africa, suffer from water scarcity and could therefore find it difficult to allocate water for fracturing. Therefore, such technological advances are crucial.

Proven reserves of coal bed methane in Canada's Alberta Province have been estimated to be equivalent to nearly 13 percent of the world's shale gas reserves, and methane clathrate deposits are estimated to be many times larger than shale gas reserves. However, extraction of these reserves has thus far been difficult. The enormous methane clathrate deposits are located on the ocean floor, making them too expensive to recover in most cases. Development of coal bed methane has been set back by falling natural gas prices due to shale gas availability in North America. However, new technologies may lead to more rapid advances in the development of methane clathrates or coal bed methane, possibly ushering in the next energy revolution.

Access to energy sources has shaped the global geopolitical landscape for more than a century. Increased US production of unconventional gas and oil has redefined US foreign policy priorities. Similarly, if Europe is able to develop large unconventional reserves or diversify its sources of supply with new LNG (liquid natural gas) exports from North America or other countries, its trade and economic relationship with Russia could be affected. There could be major shifts in international energy landscape.

Renewable energy

Renewable energy is energy that is derived from a source that is continuously replenished, such as the sun, wind, or the thermal power of the world's ocean. Amongst this, solar photovoltaic technology will have been, by 2050, a dominant source of energy. Other renewable sources of energy also have the potential to be transformative if technological development and adoption accelerate.

Solar energy

Solar energy can be harnessed through many technologies, including concentrated solar and induced photosynthesis. The potential impact of the increased use of photovoltaics (PV) is large. PV panels are made of materials such as crystalline silicon. Sunlight is converted into electric energy using the photoelectric effect. Solar panels can be used in small arrays to power a single building or home, or deployed in massive solar 'farms' that feed into the power grid.

The present momentum behind solar power is a result of innovations not only in technology but also in regulation, industry and financing.[52] In a number of markets, it no longer needs public subsidies to compete on price with conventional power sources, such as coal, natural gas, and nuclear power. The International Energy Agency, which has historically taken a conservative approach to evaluating solar power's prospects, has projected that by 2050, in the best-case scenario, solar energy could be the single biggest source of power, generating as much as 27 percent of electricity worldwide.

Technological advances that reduce the costs of renewable energy generation have been important enablers of adoption. During the past two decades, the efficiency of solar panels (the percentage of solar energy converted

52. "Solar Power Comes of Age," D. Pinner & M. Rogers, http://fam.ag/IzlIBtP

The biggest surprise in recent years has been the speed at which the cost of solar panels has reduced, resulting in cost parity with grid-based power being achieved in certain areas much more quickly than was ever expected.

into electricity) has risen to 20 percent; in laboratory tests, panels have achieved as much as 44 percent efficiency. The cost of solar cells has already dropped from nearly $8 per watt of capacity in 1990 to less than 80 cents today. Further reductions are on the cards.

Indeed, the biggest surprise in recent years has been the speed at which the cost of solar panels has reduced[53], resulting in cost parity with grid-based power being achieved in certain areas much more quickly than was ever expected. In future these fast "learning rates" are likely to continue. That means parity will be achieved in an increasing number of markets in a relatively short timeframe.

The last decade has seen technological innovations in manufacturing, low interest rates, leaner supply chains, and improved economies of scale; the price of polysilicon, the raw material used to make solar panels, fell by 90 percent over this period. The net result is that the cost of solar panels has fallen by 80 percent since 2005. Prices are still falling, by five to 12 percent in the first half of 2014, and there is room for them to fall further. So-called soft costs—meaning the cost of everything but the equipment, such as permits, installation, and maintenance—account for almost two-thirds of the total price tag for U.S. residential solar systems. Soft costs are about one-third of the price tag in Germany, where, among other factors, national standards have simplified installation and streamlined the permitting process.

Beginning around 2005, Chinese manufacturers entered the solar-panel market to chase growing global demand, and they now account for nearly two-thirds of global production of solar panels. Chinese competition squeezed profit margins and drove many suppliers out of business, but it also led to improved production processes and new economies of scale, cutting costs substantially

In Germany, the renewable share of gross power consumption rose from 25.4% in 2013 to 27.8% in 2014. Germany has added 35 Gigawatts of solar power in the last ten years. German electricity demand patterns show how the demand is met in terms of conventional generation (i.e. nuclear, gas, coal etc.) and solar and wind. On hot sunny workdays and weekends, the peak (which would previously have been supplied by gas) has almost entirely gone over to solar. This is the most valuable part of the curve, as electricity prices are highest during the period of highest demand. For other countries, the hotter or sunnier the climate, the more 'peaky' the load is likely to be due to air conditioning, characteristics, which of course only serve to make solar perform better. Hence, while the amount of units supplied by solar are currently relatively small, their share of the "value" is considerably higher.

In response to the Fukushima nuclear incident, Japan's energy mix has changed almost overnight, with oil being burned and gas being imported and used at $16/mmbtu (with gas price in context at <$4/mmbtu in the shale-driven US market). With this demand for new energy sources in response to the closure of the nuclear plants, Japan introduced what is the world's most attractive subsidy scheme for solar. The fact that solar generates at times of peak demand is what makes it so disruptive.

Intermittency is the key drawback to solar, in that the level of generation is to some extent weather dependent, as well as seasonally variable. However, as the cost of both solar and storage reduce, this problem will be reduced. The other 'timing' issue is that while solar might be at 'socket parity' already, unless the electricity is used in the day, homeowners are only likely to receive a lower feed-in tariff for their generation, rather than the equivalent price of the grid electricity that they are offsetting. Storage is the associated Holy Grail, and in the much longer term could have an even more dramatic impact on electricity markets.

As the rates for solar power begin to match the rates for traditional energy sources in more and more markets, the capacity of solar power installed each year could increase from about 45 gigawatts today to more than 200 gigawatts by 2025. That would fundamentally disrupt the electric power sector.

53. "Solar Panel Cost Trends," Cleantechnica.com/2014/09/04

The nature of solar energy is such that the technology will keep on getting cheaper, while alternatives will gradually become more expensive.

The nature of solar energy is such that the technology will keep on getting cheaper, while alternatives will gradually become more expensive. Moreover, solar not only takes a share of new demand, but also eats into existing demand, and most importantly takes the most valuable part of the demand at times of peak load. Accordingly, solar represents a truly disruptive technology now and for the future. By 2050, solar would have had a material impact on utilities, as well as oil & gas companies, particularly where long-dated assets at the top of the cost curve are concerned.

Solar power could shake up other sectors, too. In the housing industry, for example, the spread of rooftop solar panels could transform construction and design practices. In manufacturing, factories could relocate to areas with favorable conditions for low-cost solar power. In agriculture, hot countries that lack fresh water could harness solar power for desalinating and pumping water, enabling farmers to work previously infertile land. History suggests that when a commodity gets cheaper and cheaper, it gets used in new, unforeseen ways.

Wind energy

Wind energy has come a long way in the last two decades. At a given site, a single modern wind turbine annually produces 180 times more electricity and at less than half the cost per kilowatthour (kWh) than its equivalent of 20 years ago. The size of commercially available grid connected horizontal axis wind turbines has evolved from about 0.022 MW in the early nineteen eighties to about 6 MW today.

The impressive growth in wind energy can be seen by taking the example of EU, who leads the world in terms of manufacturing and development of wind farms. In 1994, there were 1,683 megawatts (MW) of wind energy installed across the EU. By the end of 2005, installed capacity had increased 24 times and some 40 gigawatts (GW) of cumulative installed capacity were providing about 2.8% of European electricity consumption. The European Wind Energy Technology Platform envisions that "in 2030, wind energy will be a major modern energy source, reliable and cost competitive in terms of cost per kWh." In addition, they foresee that wind energy will contribute 21% to 28% of the European Union (EU) electricity demand, which is similar to the scenario described previously for the United States.

Technological advances will continue to take place. For example, as turbines grow larger and larger, rotors must improve their ability to handle large dynamic loads with increased structural efficiency to avoid the costly cubic weight growth. Several approaches are being developed and tested to help alleviate these load levels or create load-resistant designs. High strength-to-weight ratio carbon fibers are now being incorporated into the high-stress areas of wind turbine blades, which will reduce overall blade weight.

The decrease in cost and increase in availability of rare earth permanent magnets is expected to significantly affect the size and cost of future permanent-magnet generator designs.

The cost impact of extremely large cranes and the transport premiums for large tower sections and blades is driving the exploration of novel tower design approaches. Several concepts are under development or being proposed that would eliminate the need for cranes for very high, heavy lifts. One concept is the telescoping or self-erecting tower. Other self-erecting designs include lifting dollies or tower-climbing cranes that use tower-mounted tracks to lift the nacelle and rotor to the top of the tower.

Offshore installations presently constitute a very small part of the market, but their future looks bright. For instance, in United States, approximately 10 offshore projects for about 2,400 MW are being considered.

The demands of offshore wind farms are quite specific and ongoing development is expected in the areas of foundations, access, wind farm electrics, transportation and erection. Many different design concepts are in use, the

Next-generation nuclear technology taps into energy contained in current nuclear waste products to create a closed and sustainable system.

most common among larger turbines being three bladed, pitch regulated, horizontal axis machines.

The current shallow-water offshore wind turbine is basically an upgraded version of the standard land-based turbine with some system redesigns to account for ocean conditions. These modifications include structural upgrades to the tower to address the added loading from waves, pressurized nacelles, and environmental controls to prevent corrosive sea air from degrading critical drive train and electrical components, and personnel access platforms to facilitate maintenance and provide emergency shelter.

To minimize expensive servicing, offshore turbines will have to be equipped with enhanced condition monitoring systems, automatic bearing lubrication systems, on-board service cranes, and oil temperature regulation systems, all of which exceed the standard for land-based designs. Today's offshore turbines range from 3 MW to 5 MW in size and typically have three-blades, operate with a horizontal-axis upwind rotor, and are nominally 80 to 126 m in diameter. Tower heights offshore are lower than land-based turbines because wind shear profiles are less steep, tempering the energy capture gains sought with increased elevation. The offshore foundations differ substantially from land-based turbines.

New offshore technologies will be required to grow wind turbines into 5 to 10 MW sizes or greater. These technologies may include lightweight composite materials and composite manufacturing, lightweight drive train, modular pole direct drive generators, hybrid space frame towers, and large gearbox and bearing designs that are tolerant of slower speeds and large scale. The cost of control systems and sensors that monitor and diagnose turbine status and health will not grow substantially as turbine size increases, and high reliability will be essential due to the limited access during severe storm conditions, which can persist for extended periods.

The evolution of wind technology is expected to continue resulting in a continued improvement in reliability and energy capture. The development of new and innovative rotors, drive systems, towers, and controls is expected to enable this continued improvement in the cost effectiveness of wind technology. Wind energy will be a significant contributor to the world's electricity supply.

Nuclear energy

Nuclear power[54] faces significant social, political, economic, and environmental challenges today. Following the 2011 Fukushima nuclear disaster in Japan, many countries have slowed, postponed, or canceled their nuclear programs. The question of nuclear waste storage is also a deterrent to adoption. However, next-generation nuclear technology taps into energy contained in current nuclear waste products to create a closed and sustainable system. Depending on the advances in new technologies, including fusion, the picture in 2050 may change.

There are currently 435 operational nuclear power reactors in 30 countries around the world and 72 are under construction in 15 countries. Nuclear power generated 2359 terawatt-hours (TW·h) of electricity in 2013, corresponding to less than 11% of world electricity production, the lowest value since 1982.

The International Ministerial Conference on Nuclear Power in the 21st Century organized by the Agency in Saint Petersburg, Russian Federation, in June 2013, was the first major event, which addressed the outlook for nuclear power after the Fukushima Daiichi accident. It concluded that, for many countries, nuclear power was a proven, clean, safe, and economical technology that would play an increasingly important role in improving energy security, reducing the impact of volatile fossil fuel prices and mitigating climate change also recognized that nuclear accidents have no borders and that nuclear safety must be robust, effective and transparent. The Agency's low and high projections for global installed nuclear power capacity both indicate an increase by 2030. There are

54. Next Generation Nuclear Plant: A Report to Congress, www.energy.gov

Policies to combat air pollution, as recently announced in China, make fossil fuelled generation more expensive than nuclear power and renewable energy.

33 countries interested in introducing nuclear power. Of the 30 countries already operating nuclear power plants (NPPs), 13 are either constructing new ones or actively completing previously suspended constructions. A further 12 are actively planning to either construct new plants or to complete suspended construction projects. A further 12 are actively planning to either construct new plants or to complete suspended construction projects.

Until recently, nuclear power has weathered the transition from regulated electricity markets to liberalized (competitive) markets remarkably well. Existing NPPs proved to be competitive low-cost generators, largely because their high initial up-front investment costs were fully depreciated and operators had to bear only operating and fuel costs, which were low compared to those for fossil fuelled generation. This cost advantage was the prime reason that utilities sought licence extensions and performed safety upgrades and power uprates. The situation has now changed: very low natural gas prices, particularly in the USA, caused by a rapid shale gas expansion, have fundamentally transformed the energy economy. They have reduced the competitiveness of commercial nuclear power. The change is reflected in the recent and intended closures of NPPs in the USA. Despite being licensed to operate to 2033, Dominion's 574 MW(e) Kewaunee NPP closed in May 2013 only because it was unable to compete in a liberalized market against cheap natural gas.

Rapid growth in renewable energy driven by subsidies and directives affect nuclear power in liberalized markets in OECD countries with essentially zero demand growth. The situation is fundamentally different though in rapidly growing developing countries with increasing electricity demand. They require the development of all locally available power options, including nuclear.

Most of the capacity growth occurs in countries with existing nuclear power programmes. By 2030, the number of countries with operating NPPs will have grown from 30 to 35. Eight countries will have been added to the group, accounting for 13 GW(e) of installed nuclear capacity in 2030.

The expected commercialization of small and medium sized reactors (SMRs) by the mid-2020s could increase the flexibility of NPP operation. Despite nuclear's share of global electricity generation declining in the low projection to an estimated 9% by 2030, there still is absolute, though modest, growth in global generation. The situation is different in the Asian regions where nuclear electricity generation continues to grow at rates close to those for overall electricity growth. 49. In the high projection, the 2030 share of nuclear power in the total electricity supply is estimated at 13%, slightly higher than its current share. This implies faster growth for nuclear power than for electricity as a whole, and this relationship is more pronounced in developing countries than in the OECD countries.

On the one hand, Germany, a sophisticated technology-literate economy, plans to phase out its nuclear power by 2022 and rely extensively on renewables and efficiency improvements to meet its future energy demand. On the other hand, in 2012 the UAE became the first country in 27 years to start constructing its first NPP, which it plans to connect to the grid in 2017.

Policies to combat air pollution, as recently announced in China, make fossil fuelled generation more expensive than nuclear power and renewable energy. China will build six to eight nuclear power plants annually for the next five years and operate 110 plants by 2030, a plan analysts believed would meet the urgent need for clean energy. China will invest 500 billion yuan ($ 78.8 billion) on domestically-developed nuclear power plants.

Extending both the low and the high projections beyond 2030 involves much bigger uncertainties regarding the technical, economic and political developments that influence energy choices. Still, if the main assumptions adopted in the two projections are maintained, the global nuclear power capacity is estimated to reach 413 GW(e) in the low projection in 2050 and 1092 GW(e) in the high projection. Even in the high projection, however, despite the

Fission, fusion or fossil fuels are the only practical options for reliable large-scale base-load energy sources.

sizeable increase between 2030 and 2050 of 393 GW(e), nuclear power would account for only a 5% share of the global generating capacity in 2050,

All nuclear designs are undergoing innovation to reduce costs and to enhance safety. The Nuclear Technology Review 2014 notes that innovative SMR concepts are at various stages of research, development and demonstration, and that several SMR designs are already under construction. Other designs, such as fast breeder reactors and high temperature reactors, will not play a decisive role before 2030 but would become important thereafter, especially when sustainability considerations call for waste minimization (both in terms of volume and longevity) and for resource conservation.

Fission, fusion or fossil fuels are the only practical options for reliable large-scale base-load energy sources. We have dealt with fission reactors in the foregoing and will now discuss the potential of fusion reactors.

Fusion reactors generate electricity by heating plasma to around 100 million degrees centigrade, whereby atomic nuclei melt together and release energy. Because of the low binding energy of the tiny atomic nuclei, energy can be released by combining two small nuclei with a heavier one. This differs from fission reactors which work by splitting atoms at much lower temperatures.

Fusion reactors could become an economically viable means of generating electricity within a few decades, and policy makers should start planning to build them as a replacement for conventional nuclear power stations, according to new research.

Researchers at Durham University and Culham Centre for Fusion Energy in Oxfordshire, have re-examined the economics of fusion, taking account of recent advances in superconductor technology for the first time.[55] Their analysis of building, running and decommissioning a fusion power station shows the financial feasibility of fusion energy in comparison to traditional fission nuclear power.

The research builds on earlier findings that a fusion power plant could generate electricity at a similar price to a fission plant and identifies new advantages in using the new superconductor technology.

The advantage of fusion reactors over current fission reactors is that they create almost no radioactive waste. Fusion reactors are safer as there is no high level radioactive material to potentially leak into the environment which means disasters like Chernobyl or Fukushima are impossible because plasma simply fizzles out if it escapes.

Fusion energy is also politically safer because a reactor would not produce weapons-grade products that proliferate nuclear arms. It is fuelled by deuterium, or heavy water, which is extracted from seawater, and tritium, which is created within the reactor, so there is no problem with security of supply either.

A test fusion reactor, the International Thermonuclear Experimental Reactor, is about 10 years away from operation in the South of France. Its aim is to prove the scientific and technological feasibility of fusion energy.

The report, which was commissioned by Research Council UK's Energy Programme focuses on recent advances in high temperature superconductors. These materials could be used to construct the powerful magnets that keep the hot plasma in position inside the containing vessel, known as a tokamak, at the heart of a fusion reactor.

This advancing technology means that the superconducting magnets could be built in sections rather than in one piece. This would mean that maintenance, which is expensive in a radioactive environment, would be much cheaper because individual sections of the magnet could be withdrawn for repair or replacement, rather than the whole device.

A collaboration between researchers at the University of Gothenburg and the University of Iceland has been to study a new type of nuclear fusion process. This produces[56] almost no neutrons but instead fast, heavy

55. www.ccfe.ac.uk

56. www.e-catword.com

The looming dangers of climate change may go in favour of nuclear energy in the long run.

electrons (muons), since it is based on nuclear reactions in ultra-dense heavy hydrogen (deuterium).

The new fusion process can take place in relatively small laser-fired fusion reactors fuelled by heavy hydrogen (deuterium). It has already been shown to produce more energy than that needed to start it. Heavy hydrogen is found in large quantities in ordinary water and is easy to extract. The dangerous handling of radioactive heavy hydrogen (tritium) which would most likely be needed for operating large-scale fusion reactors with a magnetic enclosure in the future is therefore unnecessary.

A considerable advantage of the fast heavy electrons produced by the new process is that these are charged and can therefore produce electrical energy instantly. The energy in the neutrons which accumulate in large quantities in other types of nuclear fusion is difficult to handle because the neutrons are not charged. These neutrons are high-energy and very damaging to living organisms, whereas the fast, heavy electrons are considerably less dangerous.

Neutrons are difficult to slow down or stop and require reactor enclosures that are several metres thick. Muons—fast, heavy electrons—decay very quickly into ordinary electron and similar particles.

Finally, the looming dangers of climate change may go in favour of nuclear energy in the long run. Universally binding international agreement limiting GHG emissions would enter into force on schedule in 2020. This would put world emissions on a trajectory consistent with the United Nations Framework Convention on Climate Change objective of preventing dangerous anthropogenic interference with the climate system, i.e. by limiting global temperature rise to less than 2°C compared with pre-industrial times. Nuclear power would be recognized and accepted in many countries as a cost-effective mitigation option.

Other resources

Biofuels[57]

Biofuels are made from organic materials such as corn, are currently not efficient sources of power and require a great deal of energy to harvest, transport, and process. The share of global energy supply from biomass is currently 2 percent and is expected to reach 4 percent in 2025. However, coupled with next-generation gene sequencing there is significant potential for increased power generation from biofuels. For example, research is under way to use photosynthesis from synthetically sequenced cyanobacteria, blue-green algae, to convert atmospheric CO2 into fuel.

Ocean thermal energy conversion[58]

The world's oceans are a huge untapped source of energy. Ocean thermal energy conversion (OTEC) uses the difference in temperature between deep and shallow ocean water to generate electricity. There is immense energy in the world's oceans; however, the technology to capture it is currently immature and produces only a very small amount of power.

Geothermal power[59]

The high temperatures in the earth's core can be used to drive a heat engine or steam turbine to produce electricity. Commercially viable extraction is currently limited to only a few locations situated at tectonic plate boundaries (Iceland, for example) and is currently less than 1 percent of global power production.

Next-generation nuclear power[60]

Nuclear power already supplies nearly 15 percent of the world's electricity. However, the technology faces

57. "Biofuels Issues and Trends," www.eia.gov/biofuels/issuestrends/pdf/bit.pdf
58. Assessment of Ocean Thermal Energy Conversion, S. Muralidharan, 2012, dspace.mit.edu
59. Efficiency of Geothermal Power Plants: A Worldwide Review, H. Moon & S.J. Zarrouck, 2012, geothermal-energy.org
60. Next Generation Nuclear Plant: A Report to Congress, www.energy.

By 2050, we will see a scenario, where distributed renewable generation, combined with cheap storage would have led to significant increase in the adoption of distributed renewable power, particularly solar.

significant social, political, economic, and environmental challenges. Following the 2011 Fukushima nuclear disaster in Japan, many countries have slowed, postponed, or canceled their nuclear programs. The question of nuclear waste storage is also a deterrent to adoption. However, next-generation nuclear technology taps into energy contained in current nuclear waste products to create a closed and sustainable system. Depending on the advances in these technologies, the picture in 2050 may change.

Energy storage system

Energy storage systems play an important role in integrating alternatives to fossil fuels into the energy mix. They provide energy on demand. They convert electricity into a form that can be stored for later use then it is converted back into electrical energy. They help improve the reliability of the electric supply and bring electricity to new users.

Batteries constitute the most widely known energy storage technology. Lithium ion (Li-ion) batteries are widely used[61] in consumer electronic devices such as laptop PCs, as well as in electric and plug-in hybrid vehicles. The Li-ion battery market is expected to double in the next four years to $24 billion in global revenue. Significant changes in the price-performance envelope would have taken place in Li-ion batteries by 2050. Prices for complete automotive Li-ion battery packs could fall from $500, an order of magnitude lower price by 2050. This would have made plug-in hybrids and electric vehicles cost competitive with traditional internal combustion engine and some grid applications. This would have also paved the way for providing distributed energy, based on the levelized cost of electricity (LCOE), a standard measure of electricity costs.

Promising battery technologies include systems based on liquid metal, lithium-air, lithium-sulfur, sodium-ion, nano-based super capacitors and energy cache technology. Other important energy storage technologies include molten salt, flow cells, super capacitors.

Energy storage costs have declined in recent years and are expected to decline even more particularly for Li-ion batteries. This would have enabled increased adoption of hybrid and battery-operated vehicles, as well as higher-performance portable consumer electronics.

Major advances in battery technology are occurring in important components, which could increase the battery capacity over the next 10 to 15 years. Batteries have three elements: a positive terminal (the cathode), a negative terminal (the anode), and an electrolyte (a chemical medium that allows the flow of electrical charge between the cathode and anode). Next-generation cathodes will incorporate 'layered-layered' structures, eliminating dead zones that impede ion transfer. Silicon anodes would increase the capacity significantly with graphite anodes. By 2050, researchers would have or invented new identified cathode-electrolyte pairs that can sustain higher voltages, thereby boosting capacity. These advances, combined with increased production efficiency, would have significantly reduced the LCOE of batteries by 2050.

The potential of energy storage for grid applications would have fully disrupted the energy generation and distribution systems. By 2050, we will see a scenario, where distributed renewable generation, combined with cheap storage would have led to significant increase in the adoption of distributed renewable power, particularly solar. This would have vastly altered the utility industry; the use of oil, gas, coal, and nuclear generation; and the transport industry, ushering in an era of localized energy independence along with drastically reduced emission levels.

Today only 63 percent of rural populations in emerging markets have access to electricity. More than one billion people could still be without electricity in 2025, based on population growth and current levels of electrification. By 2050, hopefully, the dream of electricity for all would have come true.

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61. Li-O2 and Li-s Batteries with High Energy Storage, http://www.nature.com

Next-generation genomics has the potential to give humans far greater power over biology, allowing them to cure diseases or customize organisms to help meet the world's need for food, fuel, and medicine.

Future health

The dramatic changes that will be brought in due to the advance of technology in developing and determining our future health have been well articulated in many thought provoking essays and books.[62, 63, 64]

Next gen genomics

The rate of improvement in gene-sequencing technology over the past decade has been astonishing. When the first human genome was sequenced in 2003, it cost nearly $3 billion and took 13 years. Now a $1,000 sequencing machine could soon be available that will be able to sequence a human genome in a few hours. The rate of improvement in sequencing speed has exceeded Moore's law.

As the costs of sequencing decline and the instrument capabilities increase, the data generated from sequencing instruments will grow exponentially, creating challenges for both data storage as well as analysis. The sequencing data generated per instrument per day has increased from less than 10 kilobases per day to over 100 million kilobases per day, almost a 10,000 fold increase!

With growing access to large samples of fully sequenced genomes researchers can test combinations of genes, diseases, and organism characteristics to determine which genes drive which outcomes. This enables us to better identify and diagnose people at high risk for conditions such as heart disease or diabetes, allowing speedier and effective intervention.

Next-generation genomics has the potential to give humans far greater power over biology, allowing them to cure diseases or customize organisms to help meet the world's need for food, fuel, and medicine. With world population heading towards nine billion plus by 2050, there is a growing need for more efficient ways to provide fuel for heat, electricity generation, and transportation; to feed people; and to cure their ailments. Meanwhile, populations are aging in advanced economies. For instance, by 2050, approximately 15 percent of the world's population will be 60 years of age or older, multiplying health-care challenges.

Next-generation gene sequencing would have impacted health care in a big way by the year 2050. Significant value would have been observed through extending and enhancing lives through faster disease detection, more precise diagnoses, new drugs, and more tailored disease treatments (customized both to the patient and to the disease).

Next-generation sequencing would have made personalized medicine possible. The ability to genetically sequence all patients, along with the viruses, bacteria, and cancers that affect them would have allowed for better matching of therapy to the patient.

Can next gen sequencing have a strong influence on dreaded diseases like cancer? Yes, hopefully it will. Cancer is a genetic disease that is caused when mutated cells grow out of control. Sequencing would be used to tailor treatments that are customized to the genome of the patient and the mutated genome of the tumor. Cancer screening, tumor, and mutation analysis will be able to identify new therapeutic options for patients that fall outside of the typical treatment paradigm and even match patients to clinical trials with developmental stage drugs.

Nobel Laureate David Baltimore had said 'Cancer is an army of cells that fights our therapies in ways that I am sure will keep us continuously in the battle'. As a part of that continuing hard battle, the promising battle lines include, anti-angiogenesis (or choking off the blood supply of a tumor so that it never grows), nanotechnology based therapeutics, which are like 'smart bombs' directed at cancer cells, gene therapy (especially for gene p 53, since almost 50% of all common cancers are linked to a damaged p53), new vaccinations against agents that can cause cancer,

62. "The Edge of Medicine: The Technology that will change our Lives," Palgrave McMillan, New York, 2008
63. "The Singularity is Near: When Humans Transcend Biology," Viking, NY, 2005
64. "Redesigning Humans: Choosing our Genes, Changing our Future ,"Houghton Mifflin, Boston, 2003

Rapid advances in synthetic biology, regenerative medicine, immune therapy, etc. will have a major impact on both the extent and quality of life by 2050.

like the human papillomavirus (HPV), which can cause cervical cancer, etc.

Practical applications of sequencing would have migrated significantly into clinical practices. Cancer, inherited diseases, and companion diagnostics would have expanded into full disease risk profiling based on genomics. Companies such as Myriad Genetics, Genomic Health, and Foundation Medicine are already using cancer genotype analysis to help patients and providers make decisions on potential therapeutic options. These tests are able to identify subtypes of tumors that can indicate the origin of disease and the potential for therapeutic response. Future tests may allow the monitoring of tumor recurrence over the life cycle of a cancer and even the hereditary risk of cancer.

Next gen genomics would have helped in initial screening to identify a predisposition to disease, screening upon disease or symptom onset, testing at therapy initiation to determine the appropriate pharmaceutical, and monitoring during treatment for disease progress.

In the context of personalized medicine, three broad groups would have flourished. The first one are the technology providers, with companies who manufacture sequencing machines and reagent kits to allow the science to take place. The second would be pharmaceutical/diagnostics companies, who will use the understanding of genetics & disease and develop diagnostic tests & medications. The third would be end users, namely the doctors, patients, and payers who are ultimately treated more effectively at lower costs to the healthcare system.

With the global healthcare systems focused today on cost reduction, the effective use of genomic information and diagnostic testing would have not only enabled more effective/efficient patient care, but reduced overall healthcare costs.

The following specific life – extending developments are expected to be potentially achievable by 2050.

- Almost everyone will have their own DNA sequences. This will give access to a vast database that describes the risks, therapies and best practices based on the characteristics of their own specific genes.
- Mitochondrial DNA will be replaced when damaged by disease or aging.
- Most genetic disorders will be curable through gene therapy, which by 2050 will be a mature technology.
- Age damaged immune systems will be replaced by using fresh cells grown from patient's own bone material.
- To replace diseased or worn out organs, doctors will grow new ones from patient's own cells.
- Tissue regeneration will take place without rejection. This will be made to happen, by creating, manipulating and transplanting pristine cells from patient's own body.

Other advances

Rapid advances in synthetic biology, regenerative medicine, immune therapy, etc. will have a major impact on both the extent and quality of life by 2050. The field of "synthetic biology" is developing ways to build living organisms. Simple bacteria can be made routinely by inserting synthetic genomes into empty cells. These organisms will not merely duplicate their natural predecessors but will incorporate whatever traits their designers wish to include in them. From triggering an immune response to conveying new genetic material into human cells to repairing hereditary diseases to carrying out industrially useful chemicals – the promise of synthetic biology looks very high indeed.

We have moved from preventive medicine (vaccines) to curative medicine (antibiotics), to predictive medicine (gene therapy) to regenerative medicine (stem cell therapy).

Fundamentally, what is stem cell technology? In the earliest stages, when embryo gets developed own cells are only general purpose building blocks. They can become any kind of specialized cells that the body needs. These are the stem cells and their versatility makes them uniquely important for clinical therapy. If one has a heart attack,

It is possible that by 2050 the use of precision medicine (using personalized therapeutics) may shift from the current dominant role of chronic targeted therapies, to a more subsidiary role in enhancing the activity of immunotherapeutic agents.

stem cells have the potential to replace the damaged tissue, turning eventually into a specialized heart muscle as needed. If there is a spinal damage, stem cells can potentially replace the lost nerves and restore the ability of a paralyzed patient to walk. It can create a paradigm shift in the way diabetic patients are treated. Stem cells can become pancreatic islet cells, thus enabling a diabetic patient to have normal supply of insulin.

It is important to note that it is not only the developed world, but also the developing world, where research in stem cells is rapidly advancing. For instance, take the case of stem cell research. In India, more than 20 research centers are carrying out basic stem cell research. They are building stem cell based therapies for cancer, diabetes, heart disease and brain disorder such as Alzheimer's disease. China so far has less than ten major stem cell research centers. Yet in Taizhou, a spinoff of Beijing University called Beike Biotechnology is already using stem cells to treat several hundred patients for diseases ranging from cerebral palsy to optic nerve damage. Many of their patients come from the US, where therapies based on stem cells are difficult to find.

Cells will be genetically engineered to deliver compounds that nature overlooked. In many cases, the cells themselves become the producer. Already scientists have produced universally acceptable blood from stem cells. Medical researchers have successfully altered complex organs in human body such as skin, liver, heart and even pancreas. By 2050, these organs will be grown in the laboratory from recipients own tissue after appropriate genetic repair and then inserted into the recipient's body.

Another advance by 2050 will be combining engineering and electronics with biological parts to make complex systems. For example, the recent work on creating artificial retinas for the blind that can link to the optic nerve and send message to the brain. Other experiments are using cells as the serving elements in detectors for pollution, bacteria, nerve agents and many other targets.

Immunotherapy is the treatment of a disease through leveraging the patient's own immune system. In cancer treatment, newer potent T-cell mediated therapies eliminate or slow the growth and spread of cancerous cells by preventing the tumor from evading immune detection. An important component to the success of these therapies is the identification of patients with T-cell infiltrate at the tumor micro-environment at baseline. This is primarily done through predictive immunoassays which can lead to the development of optimized rational immunotherapeutic combination regiments that are tailored for each patient.

Emerging and novel immunotherapeutic approaches can leverage a patient's immune system to eliminate or slow the growth and spread of cancerous cells. New advances in tumor biology are enabling the development of newer potent T-cell mediated therapies. These can prevent the tumor from evading immune detection. Experimental T-cell immunotherapy comprises multiple modalities including checkpoint inhibitors, which work to defeat a cancer resistance mechanism that causes immune cells to see a tumor as 'self'. This enables the immune response to defeat the cancer cells on its own, as well as therapeutic vaccines.

While existing chemotherapy or even newer oral drugs have a powerful initial effect on tumor shrinkage the durability of these responses is often short, and the tumor begins to grow again and starts to spread. The durability of responses with immunotherapy, on the other hand, can last much longer, due to the induction of an ongoing immunological memory. The targeting of cancer cells for an indeterminate length of time and making it a potential tool to transform cancers into something akin to a chronic disease would be a great breakthrough!

It is possible that by 2050 the use of precision medicine (using personalized therapeutics) may shift from the current dominant role of chronic targeted therapies, to a more subsidiary role in enhancing the activity of immunotherapeutic agents. Immunotherapy may form the backbone of majority of the cancer management regimes.

It is not that the technological innovation alone that will matter. This has to be backed up by a business model innovation, a system delivery innovation, workflow innovation, organizational innovation, policy innovation, etc.

By 2050, "biogeneology," which is the study of fundamental processes of aging, could have so advanced that a considerable progress would have been made in preventing, delaying or reversing the aging process.

A combination of several methods[65] will help in this process. These will include growing new organs by using stem cells and tissue engineering, ingesting a mix of proteins and enzymes that will increase cell repair mechanisms, regulate metabolism, reset the biological clock and reduce oxidation, using gene therapy to alter genes that may slow down the aging process, using monosensors to detect diseases like cancer, before they become a problem.

These and other anti-aging therapies will make life spans of over 100 years commonplace. More importantly, based on the animal studies underway at the moment, it appears that quality of life will not suffer as it does today and it will be possible to retain more vigorous mid-life health and energy.

Making technology 2050 work for global good

All the technological advances and breakthroughs described in the previous sections are exciting and promising. However, in order to ensure that the promise of these technologies met its full potential, there will be several challenges; social, cultural, political, policy level, etc. that will have to be dealt with. In this section, we outline some of these.

First and foremost, it is not that the technological innovation alone that will matter. This has to be backed up by a business model innovation, a system delivery innovation, workflow innovation, organizational innovation, policy innovation, etc.

Digital transformation of knowledge and work

Let us start with the technologies under the category of digital transformation of life and work, comprising mobile internet, automation of knowledge work and the cloud.

65. "The Edge of Medicine: The Technology that will change our Lives," Palgrave McMillan, New York, 2008

Starting with the mobile phone itself, the Indian mobile phone revolution makes an interesting case study. Around 10 years ago, India had around 15 million mobiles; today it has 900 million plus mobiles. Such an exponential growth and scaling was possible because of the combination of a policy level innovation, technological innovation and a business model innovation, missing even one of them would not have helped.

First, at a policy level, India decided not to lay additional copper lines and create more land lines. It went for voice over internet, voice over mobile. There was a huge deregulation and incentivization done to attract the private sector players. Second, the technological innovation by Nokia, Ericson, etc. brought the price of a mobile down from $250 to $25, making it affordable to a common Indian. Third, a business model innovation made sure that the call rates were not 10 cents per minute (unaffordable to people with income of US $2 per day!) but a fraction of a cent. This has been described in the paper by C.K. Prahalad & R.A. Mashelkar[66]. It is clear that a combination of technological and non-technological innovation brought out the mobile revolution in India.

Indeed, many organizational, legal, and regulatory hurdles have to also be overcome before technology 2050 could be used.

Consider now the automation of knowledge work. Many knowledge work professions (including legal, medical, and auditing professions) are governed by strict regulatory requirements. Certain types of work will be done only by people with certain qualification. Before introduction of knowledge worker replacement, significant testing and validation will have to be done.

As advanced economies increasingly opt for automation of knowledge work, the demand on outsourced services from developing economies will be significantly reduced. Added to this is the fact that with economic

66. "Innovation's Holy Grail," C.K. Prahalad & R.A. Mashelkar, Harvard Business Review, July-August, 2010.

Merging the physical and digital world also has implications for privacy, security, and even on how companies are organized.

status of currently developing countries rising substantially, 'cost arbitrage', which they enjoyed for a long time will not sustain. The only 'sustainable advantage' will be that of 'value arbitrage'. Those developing countries, who recognize this early enough, will compete even more efficiently in global markets.

In addition to dealing with the employment and macro-economic effects of these technologies, policy makers and business leaders will be confronted with legal and ethical considerations. How will regulators and courts deal with harmful decisions made by computers (for example, if a computer were to give inappropriate medical treatment advice)? Who would be liable in such situations? Organizations might require that a human always makes or approves final decisions, but what would happen when decisions and analyses become so complex as to exceed most people's ability to fully understand or audit them? We have already seen complex but poorly understood computer algorithms drive stock market turbulence. Similar risks could very well arise in other applications.

As far as knowledge workers are concerned, retrenchment, retraining, redefining, repositioning, etc. will be the key words. Some categories of knowledge jobs have already become obsolete, e.g. typists. In addition, much of the automation of knowledge work technology may require the intelligence of organizations to be codified, perhaps in many cases by the very workers who are adopting or even being replaced by this technology. This could create challenges for employers looking to obtain robust employee support for adoption and will require careful communication and change management.

Consider cloud technology now. Public perception of cloud reliability must improve. Amazon Web Services suffered an outage on Christmas Eve in 2012, taking down popular services such as Netflix for almost a day. Reservations on trusting the cloud was a significant hurdle at the beginning. Cloud deployment can raise concerns about loss of control. Trusting the cloud as a permanent and secure repository of sensitive data on a third-party cloud is still a challenge. The questions of ownership and liability for data have to be decided by policy makers.

Technology-led transformation of physical world

Let us consider the Internet of Things. Let us remember that despite many years on the market, RFID tags are still too expensive for many businesses to use as extensively as was predicted a decade ago. The cost of sensors and actuators must fall significantly. Common standards must be set that will enable interoperability between sensors, computers, and actuators. Software must be created that can aggregate and analyze data and convey complex findings in ways that make them useful for human decision makers.

Sensor driven business is a new game. As more operations fall under the supervision of sensor-based systems, privacy, data security and network reliability will be important concerns. With widespread use of sensors, concerns are likely to grow over how the data that are collected will be used. For instance, the information from medical monitors could be used to deny individuals health insurance coverage.

Merging the physical and digital world also has implications for privacy, security, and even on how companies are organized. As with any data connection, the connections that allow remote machines to take action without a human operator are subject to hacking by criminals or terrorists. The data collected via health monitoring could be abused. Even the in-home controllers for some smart grid applications (for example, controllers that can selectively turn air-conditioning or appliances on and off to save energy or take advantage of lower rates) raise questions about privacy and autonomy. These issues will need to be addressed before society and businesses will be able to enjoy the full benefits of the Internet of Things.

Companies must prepare themselves to be IOT ready. Every department within an organization, from production to logistics to customer service and sales, could potentially receive real-time data about how the company's products

Exploration and recovery do carry environmental risks that includes potential contamination of groundwater, pollution of air, potential greenhouse gas emissions from fugitive methane, etc

are being built, distributed, sold, and used. Organizations must get ready to deal with this tsunami of data, which will require a special manpower.

Consumers, businesses and regulators must work together to reach an understanding on liability issues. For example, it is not fully clear who will bear legal responsibility for injuries or damages that are caused by errors in closed-loop systems in which an algorithm dictates the actions of a machine. Also, realizing the benefits of the IOT in policing, for example, may require an unprecedented level of surveillance that the public may reject.

Intelligent cars will require intelligent road infrastructure systems with embedded sensors to provide precise positioning information, sensors at intersections to guide the vehicle. It is unlikely that extensive investments in intelligent roads will be made soon.

As regards autonomous vehicles, the government must help to allay the concerns about technology, safety, liability, and legal responsibilities. Laws regarding autonomous driving will be a critical enabler. Establishing regulations letting autonomous vehicles travel on public roads will create a paradigm shift in the entire governance system of public transportation.

Future energy

The risks and benefits of new oil & gas recovery technologies will have to be weighed carefully. Exploration and recovery do carry environmental risks that includes potential contamination of groundwater, pollution of air, potential greenhouse gas emissions from fugitive methane, etc. The use of large amounts of water, up to five million gallons in a single fracturing, can be big challenge. Continuous development of technologies to reduce the risks will have to be the way forward.

Land acquisition will be barrier in many nations. In many European countries, all mineral wealth from five feet below the surface belongs to the State. Then there is no incentive for the land owner to give access to the land. The governments must revisit this if Technology 2050 has to benefit Society 2050.

Any push for renewables depends on support thorough subsidies. While pushing for the adoption of renewable energy to meet environmental goals, fiscal realities could make subsidies a challenge. A global understanding must be reached to share this burden.

Production of solar energy requires land, which is increasingly becoming a scarce commodity. Innovative approaches to deal with these problems are possible. For instance, the Gujarat Government put solar panels over canals[67]. It was world's first canal-top solar project on Narmada branch canal network. It saved the requirement of land, minimized the evaporation of water from the canal as well as improving the efficiency of conversion by lowering the temperature of the panels. Roof top based solar energy is another innovation, which is being widely adopted.

For solar power, the biggest risk is not that government support will go away but that long-standing regulatory issues will fester. In the United States, for example, utilities are concerned that solar consumers get a nearly free ride, since they rely on the grid on cloudy days and when the sun goes down yet no longer cover the grid's fixed costs. And in some states, when consumers sell electricity back to the grid, they get paid the retail rate for it rather than the lower wholesale rate, a practice known as "net metering."

In response, some utilities want to charge households with rooftop panels for access to the grid, imposing fees known as 'demand' or 'capacity' charges. That would change the economics of solar power substantially, depending on how high the fees went. Some utilities in the United States would like to recover the full fixed costs of distribution from solar customers and also end net metering.

Energy storage has the potential to be a far bigger industry in the future as it moves from smaller scale

67. "Canal Solar Power Project," en.wikipedia.org/wiki/canal_solar_power_project

A number of disruptive technologies are leading to technology led job destruction, like mentioned in the foregoing, as well as creation of new jobs.

application-specific storage to residential, commercial, or even grid-level, and it has the potential to change the way we use and think about energy.

Earlier the discussion on energy storage was mainly on its ability to make renewable energy more cost competitive by eliminating its intermittency. However, as the cost of solar and wind power has dropped rapidly, the tone of the discussion has shifted, since storage is now being seen as being necessary to balance supply and demand on the grid, as well as potentially protecting the economics of conventional power generation by allowing power generators to run at optimal levels.

The greatest challenge for utilities is that much of the power generated from displaced conventional plants is at risk of being rendered uneconomic because of these lower load factors – which is the amount of time a plant runs and how many units it generates. Given that these plants are still needed for higher winter peak demand, they must be compensated via capacity payments.

Future health

Governments can play a critical role in helping next-generation genomics live up to its potential to save lives, feed people, and provide fuels that will be less harmful to the environment.

Ever since the creation of "Dolly the sheep" proved that cloning is possible in 1996, genetic engineering has inspired both visions of a better world and concerns about the risks of such advances. Consider the implication of next gen genomics.

There are several unresolved regulatory and ethical issues in terms of realizing the potential of next gen genomics. Who will own the data of sequenced genomics? The data regarding their own genomic belongs to the patients. What if they do not wish to share the data? What about the confidentiality of patient's information? What if the insurance companies raise the rates or deny coverage altogether after getting access to these data?

We must also deal with widespread public apprehensions about the possible consequences of altering plant and animal DNA. The point can be best illustrated by the current GM crops debate. With reference to GM crops, different nations have adopted different strategies. Some use 'preventive' policies. No matter what, do not allow GM crops. Others use 'permissive' policies. No matter what, within the next so many years, fifty percent of our crops will be GM crops. But the right policies are those that are 'promotional but precautionary'. While using the most rigorous scientific validation, we must be promotional too.

Technology 2050 and Jobs 2050

Technology vs jobs is an old debate. In 1930, during the height of the worldwide depression, John Maynard Keynes famously warned about "technological unemployment" caused by "our discovery of means of economising the use of labour"

The loss of jobs is there to see. By studying large companies in various industries, from Delta Airlines Inc. to Whole Foods Market Inc., as well as many start-ups, analysts have forecast that automation will erase 22.7 million jobs by 2025, or 16 percent of today's total

A number of disruptive technologies are leading to technology led job destruction, like mentioned in the foregoing, as well as creation of new jobs. Three factors are at work. First, some technologies automate physical tasks that humans used to carry out, e.g. advanced robotics. Second, some other technologies can do the intellectual tasks. These include cognitive computing, automation of knowledge work, artificial intelligence, etc. Third, the customer service tasks are also vanishing as new technologies make it possible to create self-help kiosks, or even grocery store scanners. In what follows, we will look at the influence of each one of these three factors separately.

New technologies will create new category of jobs, but also fewer jobs. Job transformation will be the dominant change. The future emphasis will not be just on merely cutting costs but also in driving customer value.

As regards the first factor in terms of robotics and automation, the debate should not be human vs robots, but it will be human and robot.

As regards the first factor in terms of robotics and automation, the debate should not be human vs robots, but it will be human and robot. A human will find himself working side by side with robots. Robots that collaborate with humans over the cloud will be in full realization well before 2050. Robots will assist humans in tasks thus allowing humans to use their intelligence in new ways, freeing us up from menial tasks. Advances in AI and robotics allow people to cognitively offload repetitive tasks and invest their attention and energy in things where humans can make a difference.

Robots will be able to stock store shelves and check out and bag groceries and other store purchases. They will do much of today's custodial work, delivery services, and transportation. But these are more routine jobs involving work flow logic. How about more intelligent jobs?

Look at the jobs for people working in the business of surveillance and how these can change due to the disruptive technology of drones, which are nothing but robots flying in the space of lower skies. Looking at the current evolution of surveillance drones, we can anticipate that that they will have the ability to interpret sound and images. They will also sense chemical compositions to help identify explosive and other harmful elements. They will likely have both infrared detection as well as the ability to see through solid materials and detect heat signatures. They will certainly have facial recognition capabilities and be integrated with a national biometric center. An interesting question is whether they will also have non-lethal weapons, such as lasers.

Robotics will add a new twist to the global redistribution of manufacturing; if a robot can operate as cheaply in Detroit as in Chennai in India or Dhaka in Bangladesh, then why pay to ship materials and finished goods around the world? The social consequences will be driven by chronic underemployment and how we choose to manage it economically. Traditional unemployment schemes will not suffice. Some kind of negative income tax based system may be needed to ensure that everyone has enough to live on. Nevertheless, a huge social and economic gulf will open up between those who work (even occasionally), and those who never work, and this will have dramatic political consequences.

Automation thus far has impacted mostly blue-collar employment; but the new wave of innovation threatens to upend white-collar work as well. Certain highly-skilled workers will succeed very well in this new environment—but far more may be displaced into lower paying service industry jobs at best, or permanent unemployment at worst. Digital technologies have displaced many jobs involving routine tasks such as those in accounting, payroll, and clerical work, forcing many of those workers to take more poorly paid positions or simply abandon the workforce. Increasing automation of manufacturing has eliminated many middle-class jobs over the past decades.

Some new technologies will affect the jobs in a given single category in exactly opposite direction, one creating jobs and the other destroying jobs. Take drivers as a single job category.

Uber is creating jobs for more drivers. By using technology to create a convenient and efficient reservation and payment service, Uber has created a new market where customers seek access to cars rather than ownership. Uber has expanded the demand for drivers—who, with the aid of a smartphone and a smart app, can now serve greater number of customers than they might have when they were working for a conventional taxi service.

On the other hand, autonomous vehicles will destroy the jobs for drivers. A study puts the total estimate of job losses due to autonomous vehicles at 10 million jobs in the next 10-15 years.

The repercussions of moving to driverless cars can have a domino effect on a range of ancillary industries such as the automobile insurance market, automotive finance market, parking industry, and the automotive aftermarket with a suppressed demand for these services.

Autonomous cars will change the dynamics of manufacturing in automotive industry itself. The Daimler, Ford, *History does not bear out the myth that technology replaces people.*

BMW, Volkswagen, Toyota, and General Motors will not necessarily be the vendors we'll be thinking of in the future. If autonomous vehicles mean highly advanced computers on wheels, then they will be dominated by the tech firms like Tesla, Google, And Apple. At the same time the likes of Uber will change the way cars need to be designed and manufactured.

Let us turn to the second factor, where human intellect is involved. Jobs that require creativity, synthesising, problem-solving, and intelligent interpretation will still continue to require human intervention, but that itself is reducing.

Advances in natural language processing have led to the creation of intelligent Interactive Voice Response Systems that are replacing traditional call centres and manual agents, resulting in higher efficiency and lower costs of operation for corporations. IPSoft claims that its cognitive agent Amelia can work along with human call centre agents and is able to learn and understand like a human.

In radiology, a field of medicine that requires several years of extensive study to master. Systems such as the ones made by BD FocalPoint can interpret medical images and look for abnormalities such as tumors with greater speed and accuracy than humans can.

We will rely on personal assistance from devices such as Google Now, Siri, Watson, etc. Much of the interaction will be verbal. We will expect computers that we meet to know us and our history of interaction with them. In general, they will infer what we want, and our role is simply to refine and verify that expectation. We will be well on our way to universal access to all human knowledge via the worldwide network of mobile devices and data centers. Day-to-day interaction with devices and data will be by voice. One industry that will be hugely affected is education.

It seems inevitable that the proportion of the population that needs to engage in traditional full-time employment, in order to keep the humanity fed, supplied, healthy, and safe, will decrease. This will hopefully lead to a humane restructuring of the general social contract around employment.

In terms of the large-scale, mass-produced economy, the utility of low-skill human workers is rapidly diminishing, as many blue-collar jobs (e.g., in manufacturing) and white-collar jobs (e.g., processing insurance paperwork) can be handled much more cheaply by automated systems. And we can already see some hints of reaction to this trend in the current economy: Entrepreneurially minded unemployed and underemployed people are taking advantages of sites like Etsy and TaskRabbit to market quintessentially human skills. And in response, there is increasing demand for 'artisanal' or 'hand-crafted' products that were made by a human. In the long run this trend will actually push toward the re-localization and re-humanization of the economy, with the 19th- and 20th-century economies of scale exploited where they make sense (cheap, identical, disposable goods), and human-oriented techniques (both older and newer) increasingly accounting for goods and services that are valuable, customized, or long-lasting.

"Brain work" will increasingly become a commodity as computing power enables more artificial intelligence. We already see Google Translate displacing translators, investment advice algorithms displacing investment advisors, automated landing systems replacing airplane piloting skills, and so forth.

History does not bear out the myth that technology replaces people. First, people create technology. However, technology is becoming obsolete at an increasingly accelerated pace. Therefore, the need for people who create technology will only grow. Further, people are required to maintain technology. Then people are also required to assist other people in using technology. Finally, most technology requires new labor forms. Therefore, there will be a great demand for experts to design, test, implement, and refine smart automated information systems. All this means generating more jobs in the future and not less. What will change, however, is the nature of jobs.

Technology can deal with logic very well. But logic is only one part of the human mind. Inspiration, creativity and intuition, meaning-making, storytelling and communication

Robotics is more likely to have displaced blue-collar jobs, deepening the divide between the haves and the have-nots, and protecting the 'haves' from withdrawal of labor and similar industrial action.

are all things that humans can do that computers will never be able to achieve fully.

Further, the job-destroying power of automation is balanced by the job-creating power of the economic growth created by greater productivity. Indeed, productivity and cost gains realized through automation make their way back into the economy helping citizens realize services at lower costs, which in turn leads to an increase in consumer savings and consumer spending resulting in more opportunities for employment in the consumer goods market.

Take the jobs connected with review documents. They are already being replaced by predictive coding algorithms, thereby leading to loss of jobs for many lawyers.

Robotics is more likely to have displaced blue-collar jobs, deepening the divide between the haves and the have-nots, and protecting the 'haves' from withdrawal of labor and similar industrial action. Rather than increasing leisure time, the 'haves' will use the freed-up time to achieve more, because maintaining the previous level of achievement would be rewarded less (relative to a living wage). The greater intensity of economic activity will maintain employment for blue-collar workers, but with similar levels of unemployment as today.

Tyler Cowen, a great global thought leader, has written[68] an outstanding book titled "Average is Over." It outlines a dual track economic reality wherein those who leverage automation enjoy an escalating standard of living, while those displaced by automation descend into a dramatically reduced standard of living.

Historically, these forces have tended to balance over the long term and across nations and national regions. At the local level, however, negative impacts can be severe as cities and regions fail to adapt fast enough to changing times, and income disparities become truly dangerous. The biggest question is about speed: will the pace of disruption be so great that labor markets and social norms simply cannot keep up.

Manufacturing companies in China such as Foxconn have plans to replace 1.2 million workers with robots to stay competitive. Rising labor wages in countries like Vietnam and Indonesia are hurting profits of companies such as Nike, who are already looking at alternatives to substitute labor with capital.

In his book "Rise of the Robots: Technology and the Threat of a Jobless Future," Martin Ford[69] states that the advent of Information Technology has replaced workers instead of making them more valuable, leading to increasing income inequalities between workers who possess the skills to adapt to tectonic technological shifts and those who do not.

Robots have largely been seen as machines that can perform routine, repetitive, non-cognitive actions. However, machines are already replicating human capabilities.

A combination of artificial intelligence (AI), dexterity and three-dimensional machine vision (the origins of which may be traced back to the Nintendo Wii video game console), give robots manufactured by Industrial Perception, a Palo Alto based company (acquired by Google), the ability to recognise, move and arrange boxes in complex sequences — a human skill that had not previously been emulated. In 2012, Amazon acquired Kiva systems , a warehouse robotics company that produces autonomous robots to move materials in large warehouses. Amazon has also been testing drones for delivering shipments.

By 2025, the total cost of manufacturing labor is projected to fall between 18 and 33 percent in countries which already deploy industrial robots, including South Korea, China, the U.S., Germany, and Japan, a study on advanced manufacturing technologies by the Boston Consulting Group showed.

Customer service will be almost entirely done with scripted agents. The most job losses will occur in sectors like office support, construction, and sales with self-help services replacing salespeople, and real estate brokers

68. Tyler Cowen, Average is Over: America Beyond the Age of the Great Stagnation, Durham Adult (2013).

69. Martin Ford, Rise of Robots: Technology and the Threat of Jobless Future, Basic Books.

The key words in 2050 will be decentralization and democratization.

and agents. Smart household gadgets would threaten the livelihoods of repair workers, plumbers and electrician.

Finally, a sobering thought. It seems inevitable that the proportion of the population that needs to engage in traditional full-time employment, in order to keep the humanity fed, supplied, healthy, and safe, will decrease. This will hopefully lead to a humane restructuring of the general social contract around employment

Some final thoughts

As we stand today, many paradigm shifts are taking place in the world as it moves from superpower bipolarity to multipolarity, as industrial capitalism shifts to green capitalism and digital capitalism, as information technology creates 'netizens' out of citizens, as aspirations of the poor get fuelled by the increasingly easier access to information, as nations move from "independence" to "interdependence," and as national boundaries become international and the concept of global citizenship evolves.

The current global supply chains have been established with experience drawn from decades, but as technology advances, current global supply chains may also undergo a dramatic change. The key words in 2050 will be decentralization and democratization. Take the case of manufacturing. With advances in 3D printing, distributed manufacturing may assume a dominant position. The situation in energy, water and other utilities will be similar.

Since scientific advances are the bedrock of technological advances, a continuous quest is to ask about the future of science in the coming decade. Science might dramatically alter the landscape of Technology 2050.

The human mind will continue to explore. How was the universe born? Is there life in the outer space? Can aging be postponed? What secrets do genes hold? Will we ever understand how the apparently useless DNA in the human genome contributed to our evolution? As our understanding of the DNA world improves, will we turn to the RNA world? May be build an organism based on RNA in the laboratory? Will we ever understand how decisions are made, imagination is set free or what consciousness consists of? Will we be able to identify the neural correlates of our thinking? Will the attempts to 'quantize' the gravitational field succeed? Will string theory really fulfill its promise of being the true description of the particles of matter or will it be another blind alley? Would we ever be able to provide those uniquely relevant experimental data to prove the so-called 'theory of everything'? Scientists around the world are grappling with these problems.

We have to remember the role of accidental discoveries in history of science and technology. Let us remember that in 1786, Luigi Galvani noticed the accidental twitching of a frog's leg and discovered the principle of electric batteries. In 1858, William Henry Perkins was trying to synthesize synthetic quinine from coal tar and he came across a colored liquid, a synthetic dye. This was the beginning of the modern chemical industry. Leo Bakeland was looking for synthetic shellac and he accidentally found Bakelite. That was the beginning of the modern plastics industry. In 1929, a gust of wind blowing over Alexander Fleming's molds, as we know, created the new antibiotic age.

It is not unlikely that some unexpected breakthroughs will transform the picture overnight. Discovery of an ambient room temperature superconductor can overnight change the levitation based transport systems. Achieving splitting of water at room temperature through a breakthrough in photo catalysis could change the global energy picture overnight. Can we have an accidental breakthrough in at least some types of cancers? Who knows? Stanford University scientists, sheerly by chance, very recently found a method[70] that can cause dangerous leukemia cells to mature into harmless immune cells called macrophages. Will this be a breakthrough in dealing with blood cancer? The jury will be out on this.

The other challenge will be the way the currently emerging economies and the least developed countries chart the

70. J.S. McClellan, C. Dove, A.J. Gentles, C.E. Ryan and R. Majeh, Proceedings of National Academy of Sciences, 16 March, 2015

This will require us to master and lead in what might be termed as 'inclusive innovation', which creates products and services which are available, affordable and accessible to the whole population, who, for various reasons, will continue to remain at the Base of the Economic Pyramid (BoP).

path for Technology 2050, not only as beneficiaries but as active participants in creating Technology 2050.

For instance, take the case of Asia. In terms of technological innovations Asia has so far moved unevenly. Japan had made a head start after the Second World War with such rapid progress that it could be called a technological superpower and joined the OECD in 1962 itself. South Korea and Taiwan became technologically advanced nations, thanks to the emphasis on and investment in higher education, and science and technology. Singapore joined the club of technologically advanced nations by carving out a niche in specific areas (e.g. biotechnology) and also making innovative changes in public policy on welcoming and encouraging foreign nationals who had achieved eminence in science and technology, so that it did not suffer from the disadvantage of having a small human capital base because of its small size.

China's own prowess today in many high technology areas such as advanced space technology, aerospace technology, nuclear technology, etc. is well known. China's achievements range from high speed bullet trains to advanced fighter jets, and from navy carriers to advanced nuclear reactors. Massive investments in clean technology are already showing rich dividends. China has acquired a second position after the leader United States in nano technology even after a late start.

It is now commonly agreed that the twenty fist century will be the century of biology just as the twentieth century was dominated by information and communication technology (ICT). These two technologies will continue their strong influence till 2050.

Similarly, it has been argued that the twenty first century will belong to Asia. Then what will be the Asian position in this century of biology? Or from a technological angle, where will Asia be in modern biotechnology? Asia could be a leader in modern biotechnology by 2050. It could have a dominant position in a variety of frontier fields like stem cell technology, synthetic biology, pharmaco-genomics and so on.

Some of the Asian countries took an early lead in stem cell technology. Today South Korea and Singapore are counted among the leaders. India and China are beginning to build on the promise created through judicious investment in human capital and infrastructure.

And this clearly shows the early advantage that countries such as Singapore, Korea, China and India have had through less restrictive policies concerning stem cell research. For some Americans, any therapy based on a material that has been culled from the human fetus is intolerable, because it might encourage abortion to get access to the necessary cells. A lot of biomedical cutting edge or frontier research in the US got slowed down. In the first few years after the near-total ban on federally funded research in stem cells, several of the leading biologists and research physicians moved to Europe and Asia, which did not have such restrictive policies in place.

In short, Asia has all the competitive advantage to become a leader in stem cell technology and therapy. This unique positioning in regenerative medicine can have an interesting consequence in medical tourism, with some Americans coming to China for stem cell therapy to the Beike Biotechnology in Taizhou. This trickle could potentially become a torrent.

Despite the rise of many emerging economies as economic powers, there will be a disparity of income as well as opportunities for a vast number of people in these countries, even by 2050. The challenge will be to not only aim for growth but for inclusive growth. This will require us to master and lead in what might be termed as 'inclusive innovation', which creates products and services which are available, affordable and accessible to the whole population, who, for various reasons, will continue to remain at the Base of the Economic Pyramid (BoP).

Enterprises had always tried to get more (performance) from less (resource) for more (profit). This needs to change to getting more (performance) from less (resource) for more and more (people), or those billions of have nots whose

The grand vision for Globe 2050 should be that Technology 2050 should lead to a balance of people, planet and prosperity (for all).

income levels are less than $2 to $4 a day. This constitutes the essence of inclusive innovation[71].

The examples of inclusive innovation include world's cheapest car, Tata Nano (priced at just US$2,500), world's cheapest mobile phone sets (priced at US$20), world's cheapest phone call rates (costing just one cent per minute as against eight cents in the US), world's cheapest cataract surgery (costing just US$30 as against US$3,000 in the US), world's cheapest tablet (costing just US$35) and so on. And these are not dreams, they are reality. And they have been achieved by using ingenious technological innovations, business process innovations and work flow innovations.

Affordability will be a key factor in making such "curiosities" commonplace in a matter of decades. Consider the case of the automobile. When the first car hit the American street in the 1890s, skeptics sneered that the "horseless carriage" had no future. In 1900, there was only one car for every 10,000 Americans. In 1908, however, the Model T hit the market, making cars more affordable for many more people. By 1920, there were almost 900 cars per every 10,000 Americans. Between 1920 and 1930, the rate of car ownership shot up to 2,170 cars per every 10,000 Americans. We note the fact that solar power installations are increasing exponentially, especially during the past six years. From 0.3 gigawatts (2000) we have moved to 45 gigawatts (2014). The global solar industry is at an analogous stage to where the auto industry was in 1920. Just as America became a car country' after 1920, in the case of solar power, nations can become 'solar powered nations'.

Finally, inclusive innovations will help firms do well (for their shareholders) as well as do good (for the society at large). It will help the nations achieve competitiveness for their firms as well as achieve the creation of a more inclusive nation comprising a much needed equitable society. Since affordability and sustainability are the two strategies on which inclusive innovation is firmly anchored, it helps the global leadership deal with the challenges of the crisis of global economic meltdown (and no one can guarantee that there will not be another one before or around the year 2050) or deal with the crisis of climate change (with the world still grappling with this challenge as the currently emerging economies continue to consume more and more as 2050 draws near).

The grand vision for Globe 2050 should be that Technology 2050 should lead to a balance of people, planet and prosperity (for all). This alone will ensure that we will see not just the privileged but all the 9 billion plus inhabitants of this globe smile in the year 2050.

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71. "Indovation for Affordable Excellence," R.A. Mashelkar, Current Science, Vol. 108, No. 1, 10 January, 2015.

The Emerging Markets Forum was created by the Centennial Group as a not-for-profit initiative to bring together high-level government and corporate leaders from around the world to engage in dialogue on the key economic, financial and social issues facing emerging market countries.

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