TECHNOLOGY AND INNOVATION

November 2008

2025

TOFFLER ASSOCIATES®

Preface

Technology and Innovation 2025

Toffler Associates, the Office of the Director of National Intelligence, the National Intelligence Council, and the National Security Agency are pleased to present this report on technologies of 2025.

This report is a product of Toffler Associates. It reflects our interpretation of research and discussions with scientists and technologists including thought leaders who participated in a series of conferences in 2008. We also benefited from the insights and the guidance of the sponsors especially Mr. Patrick Gorman, Dr. Mathew Burrows, Maj. Gen. Richard Engel, and Ms. Marilyn Maines. This report does not necessarily reflect the views of all we met nor those of the United States Government. It does not contain consensus findings or recommendations from participants as a whole.

The authors commend the sponsors for rigorously gazing into the future of technology and asking the implications for national, business, and personal decision making.

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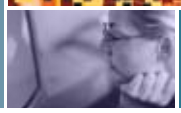



Executive Summary

The team, senior intelligence officers in the National Intelligence Council under the Office of the Director of National Intelligence, present the new administration with a snapshot of the global developments anticipated over the next fifteen years or so.

In America, every four years, citizens charge a Presidential Administration with their trust to protect them from harm and lead them into the future. At that point, a new United States Government leadership team has a chance to take a fresh look at the opportunities, threats, and challenges facing America at home and abroad. Yet the opportunities and challenges do not pause. The forces of change are in fact accelerating as technology, communications, and mobility link us in a blurring and buzzing globalizing world. To help capture an image of such a kaleidoscope of changes, a small team orchestrates the collection and assessment of perspectives on today and tomorrow from a wide range of executives and experts, citizens and foreign officials, academics and business people. The team, senior intelligence officers in the National Intelligence Council under the Office of the Director of National Intelligence, present the new administration with a snapshot of the global developments anticipated over the next fifteen years or so. This is a fractal of that image – technology developments between now and 2025. Toffler Associates crafted this view with the guidance of senior intelligence officers and with the help of scientists and technical experts across America.

The message in this report is simple; its implications are widespread yet personal. We have seen a future with converging, connected, and accelerating technology that will so increase choices for individuals and the ways we interact with technology, that the changes will affect our identity. And, experts tell us, many of these technologies will be mature enough for us to noticeably feel their impacts by 2025. Leaders and individuals will have a chance to shape the specifics of this future.

The image of this future became clearer when we and 40 executives and thought leaders closely examined five specific technology areas and explored their implications for society, business, and government. We examined biotechnology, cyber-technology, nanotechnology, ubiquitous sensing, and wild cards from science and technology. We asked the thought leaders to apply their projections in five crosscutting areas to identify the key technology convergences that would most affect or disrupt society in 2025: economy and wealth, energy and the environment, health and demographics, infrastructure, and governance.

We learned that the technologies were changing in ways that made traditional distinctions between disciplines and areas of science decreasingly relevant. Biotechnologists regularly describe nano-scale developments. Nanotechnologists apply insights from genome sequencing. Research is spread, enhanced, and stolen with cyber tools. Research will lead to carbon-free or carbon-neutral technologies that disrupt industries and policies. The blurring of boundaries between sciences are creating convergences. Breakthroughs across disciplines are stimulating accelerating insights and applications.

We discovered specific, vivid examples of technologies to expect by 2025, for example:

- Implants within the body that remotely and automatically trigger immune responses and individualized medicines.
- $100 genome sequencing and DNA control allowing the production of materials inside the human body.
- Applications that help orchestrate which "me," with different characteristics and attributes, others will see in cyber, virtual, and real worlds.
- Sensors that detect chemical, biological, radiological, nuclear and meteorological changes, carried in everyday personal devices like cell phones.

The individualized applications of these technologies promise enhanced personal performance and increasing choices. Business executives will see opportunities for delivering targeted products and services to smaller and smaller segments of customers. Government officials will be hard pressed to regulate the variety of technical applications and dampen adverse impacts as technologies disperse across populations at irregular rates, creating different "have-nots." Individuals will welcome many of the choices among tailored products and services, but many will experience *future shock* from the dizzying effects of over-choice.

Thought leaders exploring these issues raise questions about identify. As individuals apply bio and nano to increase performance and interact through various persona in an overlapping cyber/physical world, some will question which identity is real. Governments, concerned about protecting us from individuals who threaten us, will ask, "Who is who and how do we know?" Perhaps these questions will not bother many of us, but they should bother some.

The experts we met suggest that leaders and executives must begin considering technologies that will be emerging by 2025 and their potential implications. This report documents fifteen developing technology areas that thought leaders believe will be fairly matured and disruptive by 2025. Eight of the technologies are expected to be at a technology maturity level of 8 (out of 9 levels)[1], and will be fully tested in operational environments and new markets. The report describes each technology area, its technology readiness level, and a range of expert opinions on the expected maturity levels by 2025. It also includes select quotes from thought leaders, identification of major global players, and descriptions of recent developments, convergences, and potential disruptions to societies.

Government officials will be hard pressed to regulate the variety of technical applications and dampen adverse impacts as technologies disperse across populations at irregular rates..."

Introduction

Executives, policy makers, experts and everyday citizens will make a myriad of decisions between now and 2025 that will shape our future; some decisions will be influenced by emerging technological developments. Five technology areas will be maturing in many ways by 2025 so that we will appreciate their impacts unlike before. This report examines how these developments may unfold and assesses some of their effects.

Five technology areas will be maturing in many ways by 2025 that will increase their impacts unlike ever before.

We have organized this report to briefly describe five technology areas and consider five types of implications for society. We highlight some of the disruptions these developments portend. By disruptions, we mean not only momentous negative fallout from the various technology developments, but also consequences that are beneficial to society but present profound changes to familiar ways we live, do business, or ensure our national security. Next, we provide a *techcast*, an assessment of the maturity of specific applications in each of the technology areas. Finally, we examine each technology area in detail. Collectively, from our research, two conferences, and writing this report, we see a future with converging, connected, and accelerating technology that will so increase choices for individuals and the ways we interact with technology, that the changes will affect our identity.

Five Technology Areas

1. Biotechnology. We will see significant advances in a wide range of areas from biomanufacturing and information processing to robotics and cognitive enhancement. The body will become its own laboratory, as we will harness the ability to generate medicines and necessary chemicals within our bodies. Possible obstacles to advances include the difficulty of obtaining funding for truly innovative work, and the regulatory environment. Future developments will also include the building of complex systems and the addition of biological parts to engineering and electronic devices. Biotechnologies such as algae, programmed cells, bio-catalytic systems, and enzymes will play a role in alternative fuels, and the manipulation of viruses and bacteria could pose a potential threat.

2. Cyber-based technology. The growth of low-cost, ubiquitous computing may shift the balance between the haves and have-nots, and will also empower developing countries, as we are already seeing with initiatives such as the "One Laptop Per Child"[2] program. As computers spread, communication will become extremely cheap and wireless networking will become ubiquitous. Computer capabilities have already escaped the confines of desktops, laptops, and servers. In parts of the developing world where computers are currently scarce, programming mobile phones is increasing, skipping generations of traditional wired and computing infrastructure. Across the globe, hundreds of computers chatting with themselves in a single automobile and with satellites for GPS is common today and will create more cyber noise in the future. The

proliferation of virtual worlds will create an increasing number of personas—the online "identities" we assume as we participate in different online communities and across different parts of the internet—which in turn will require us to create methods to authenticate and manage them. Cyber-technology will become increasingly integrated with the human body, and this will raise the possibility that hackers may soon target the cognitive or physical abilities of individuals or groups.

3. **Nanotechnology**. Nanotechnology will influence advancements in DNA sequencing, bio-augmentation, performance enhancement, energy generation and storage, and water purification. Positive benefits will include the ability to improve the environment, as well as the health of the individual. We will soon develop the capability to build materials with specific atomic properties, freeing us from working with the constraints of the "natural" properties of materials. There is a real risk, however, that the U.S. will lose its advantage in nanotechnology, due to stricter regulations based on health concerns and a shrinking talent pool, to other countries promoting science education and investment.

4. **Ubiquitous Sensing**. By 2025, sensing will be ubiquitous in many areas of the world and technology will continue to drive cheaper sensors that consume increasingly less power. Nano particle-sized sensors could be dispersed nearly anywhere, making it increasingly difficult to keep secrets or avoid detection. This may complicate future conflicts as we may be unable to detect these sensors and may thus be forced to make decisions under the assumption that adversaries are monitoring much of what are doing. Benefits may include more accurate weather prediction, greater ease and safety in exploring hazardous areas, and a proliferation of "mash-up" tools and business models dedicated to combining available sensor data with a variety of personalized needs. Storage capacity, growth of related algorithms, and growth of processing power are three key technical factors that will affect the development of ubiquitous sensing in the future, while concerns over privacy as well as international and national regulations may limit growth.

5. **Wild Cards**. A "fifth technology area" we called "wild cards," representing developments that do not fit cleanly into a single definable technology area like the ones above. Three types of "wild card" in particular could have uncertain and potentially highly disruptive effects: (1) carbon-free or carbon-neutral technologies, and the ensuing disruptions they will bring as oil-dependent countries may become oil-independent; (2) "the next big thing" in the field of physics – a future discovery or theory as fundamentally changing as Relativity Theory; and (3) the ability to leverage neuroscience and neurotechnology to directly affect the cognitive functions of human beings from outside their bodies. The potential of such "wild card" science and technology developments, and others, could change society in myriad ways that even the most forward-thinking analysts are only now becoming able to understand.

The potential of wild card science and technology developments could change society in myriad ways that even the most forward-thinking analysts are only now becoming able to understand

Five Types of Implications

1. Economy and Wealth. Popular and profitable products and services that will arise by 2025 will include various forms of human enhancement, sensor-related technologies and services, and privacy services—services that will allow individuals to "opt out" or remain anonymous amidst an increasingly sensor rich environment. The decreasing cost of hardware and software will also change profit models for certain types of technology, especially consumer electronics, where some products may become cheap enough to be virtually free.

2. Energy and the Environment. Both the price of energy and concerns about pollution will continue to pressure decisions over the next 5 – 10 years until replacement technology matures. Conflicts over precious resources, such as water or energy, will increase globally during this period spurring migration and population displacements. We will see advancements in different energy technologies, however, that could fundamentally change some countries' energy production and consumption needs. In addition to increased conflict, the U.S. government will also face challenges in dealing with environmental problems caused by neighboring countries, resource shortages, and related international humanitarian crises.

3. Health and Demographics. The convergence of nanotechnology, biotechnology, and advances in IT infrastructure will lead to more remote healthcare services, perhaps making self-surgery possible within the home. In addition, developments in bio-enhancement, and the convergence of biotechnology and robotics, will create a digital divide between people in those societies that can afford human enhancement and those that cannot. Our definitions of what it means to be "human" will be questioned, and we may see the emergence of "post-humanism", and human-level artificial intelligence.

The convergence of developments in alternative energy technologies, bio-generation technologies, information technology and healthcare will allow people to live in increasingly remote decentralized communities.

4. Infrastructure. Three drivers will have particular influence on future infrastructure: a ubiquitous IT network, demassification of energy sources, and decentralization of many organizations and entities. The convergence of developments in alternative energy technologies, bio-generation technologies, information technologies and healthcare will allow people to live in increasingly remote decentralized communities. Infrastructure will also become increasingly linked into the network, as technological advances could continually improve peoples' ability to live "off the grid."

5. Governance. As people are increasingly connected across the planet, they are sharing information and creating new bonds. Their affinities are multiplying and could potentially shift. As virtual worlds grow in importance, loyalties born of those worlds will extend into the physical realm, and may compete with loyalties to the state. Some believe these virtual worlds will need governance as the economies they create become more substantial and create opportunities for both wealth and crime. Government-like structures may arise to serve temporary purposes, surrounding particular issues, and serving self-forming communities that may form online. In addition to local and issue governance, technology-enabled non-governmental organizations may grow to provide many services that have traditionally been provided by the government.

Potential Disruptions

Thought leaders and executives see multiple drivers shaping our world between now and 2025; technology and their innovative applications are only one driver. Yet, technology and innovation are a key source of disruptions – both negative and positive ones – as our social systems and economies shift during this period of accelerating change. Now couple science and technology developments with demographics changes, concern about the environment and climate change, and proposed shifts from fossil fuels to alternate sources of energy. And consider the convergence of these forces. During the same period, globalization will continue to accelerate, driving complexity, innovation and a myriad of new opportunities and challenges. Many of these developments will continue to fuel knowledge-based economies and societies, disrupting industrial-age structures, organizations, and business models. These disruptions can cause new conflicts and challenges for some and create opportunities for others.

The particular technology developments we explored highlighted disruptions at a different, more personal and social level. For example, with the expected developments of personalized bio- and nanotechnology applications and ubiquitous sensing capabilities, many thought leaders emphasized the potential impact on privacy. There could be an inverse relationship between technological *capabilities* and societal *permissiveness*. New privacy laws and regulations will increasingly tie up the government in "a morass of red tape" as officials strive to catch up with technical advancements. Thought leaders generally agree that the government will continue to fall behind the technology curve, causing it to be perceived as unresponsive.

As humans augment performance and health with technology, some may alter their view of technology itself; others will not. In the past, technology was seen as an instrument or tool fashioned from science and engineering. Technology was separate and outside us. Some say that food additives, steroids, drugs, contact lenses, knees, and stents are already common technologies inside of humans today. By 2025, many will have much more technology inside of them and consider that normal, even "natural." Others will resist. Disruptions may manifest as large scale political and economic shifts, as pressures on social norms such as privacy, and as personal distinctions. Maturing technologies will not cause all these disruptions, but we expect them to be relevant to the decisions citizens and leaders make.

Disruptions may manifest as large scale political and economic shifts, as pressures on social norms such as privacy, and as personal distinctions.



TECHCASTING

Measuring Technical Readiness Level

Based on the themes that surfaced from the Technology and Innovation 2025 Conference, and the Technology Implications Workshop, participants identified 15 technologies that present important potential implications for future national security.

Toffler Associates developed and sent a survey to participants of the Technology and Innovation Conference, and to a variety of other experts. Survey recipients included heads of academic research departments, leaders in industry, members of government, and other subject matter experts. The survey asked participants to provide their assessment of the likely Technology Readiness Level (TRL)[3] of 12 of the 14 technologies between now and 2025, and their assessments of the ways in which the technology might be disruptive to national power.

Survey recipients included heads of academic research departments, leaders in industry, members of government, and other subject matter experts.

Toffler Associates sent the survey to approximately 100 individuals, who were in turn encouraged to forward the survey to colleagues with expertise in the survey areas. Survey results reflect 24 responses.

Participants scored the TRL for each technology for today's environment, 2010, 2015, 2020, and 2025. Toffler Associates developed a weighted average for the scores given by participants for each year. In order to convey the variety of responses received for each technology area, and the level of agreement, we also grouped the responses into "high", "medium", and "low" levels of readiness, and displayed the number of respondents who indicated "I don't know" when asked to rate the readiness level. We have displayed these responses at the beginning of each technology section in this report.

Forecasting Technical Readiness Level

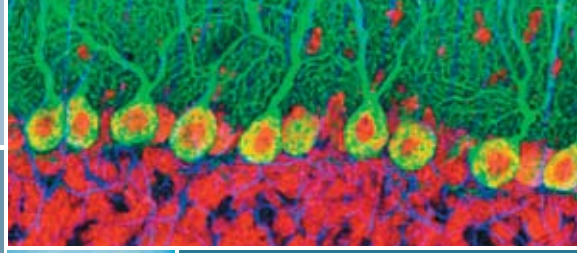
As a result of the Technology and Innovation 2025 conference (May 27-28, 2008), the Technology Implications Workshop (June 18, 2008), primary and secondary research, a Technical Readiness Level (TRL) forecasting survey (administered from June 2 – June 30, 2008) and other Toffler Associates findings and analysis, this is the analytical summary of the findings and conclusions.

TECHCASTING

Technology Area	Average TRL Rating for each time period*				
	Today	2010	2015	2020	2025
BIOTECHNOLOGY					
Ability to control DNA or bacteria as "factories" for production of materials	3.6	4.9	7.0	7.9	8.5
Bio-implants or enhancements that provide enhanced human performance	5.0	5.8	7.4	8.1	8.2
Ability to remotely trigger automatic production of immune responses and medicines within the body via implants or other means	2.5	3.6	5.4	6.8	7.7
NANOTECHNOLOGY					
Significant proliferation in diversity of high-powered, portable energy generation and storage devices	4.0	5.0	6.9	8.3	8.7
$100 genome sequencing	2.6	4.0	6.4	7.6	8.1
Cheap portable water desalinization/ purification technology	4.3	5.4	7.2	8.3	8.9
Desktop manufacturing of complex devices	2.5	3.2	4.5	5.9	7.0
CYBER-BASED TECHNOLOGY					
Persona management and cyber world converging with the physical world	N/A	N/A	N/A	N/A	N/A
Low cost, high powered computers	6.6	7.5	8.3	8.9	9.0
UBIQUITOUS SENSORS					
Bio/health monitoring	N/A	N/A	N/A	N/A	N/A
Chemical, bio, radiological, nuclear, and meteorological sensors in everyday personal devices such as cell phones	3.3	4.5	6.3	7.2	7.9
WILDCARDS					
Solar technology that is cheap enough to replace oil	4.3	5.3	6.7	7.6	8.2
Carbon neutral energy	5.3	6.4	7.7	8.4	8.5
Revolutionary advance in physics	N/A	N/A	N/A	N/A	N/A
Ability to "hack" people via neural, computer, or other means to attack cognitive function neutral energy	2.2	2.7	2.8	4.0	4.7

* Scores do not include participants who responded with "I don't know"—further breakdown of responses is included in each technology section below, n=20

Toffler Associates sent the survey to approximately 100 individuals, who were in turn encouraged to forward it to colleagues with expertise in the survey areas.

BIOTECHNOLOGY

Summary

Biotechnology is defined as "a collection of technologies that capitalize on the attributes of cells, such as their manufacturing capabilities, and put biological molecules, such as DNA and proteins, to work for us."[4] Advances are creating the ability to use cells to manufacture products, and the ability to control processes at the cellular level. Nanotechnology is increasingly influencing biotechnology, as work involves manipulation of materials at the cellular level. An exciting development of this technology is the promise of medicines that will soon be tailored to the individual genetic code of the patient. However, this technology also opens up the possibility of bio-weapons targeted at specific individuals or genetic populations.

Magnetic particles forming inside a microbe
Credit: Ames Laboratory

An exciting development of this technology is the promise of medicines that will soon be tailored to the individual genetic code of the patient.

Technology Area	Average TRL Rating for each time period*				
	Today	2010	2015	2020	2025
BIOTECHNOLOGY					
Ability to control DNA or bacteria as "factories" for production of materials	3.6	4.9	7.0	7.9	8.5

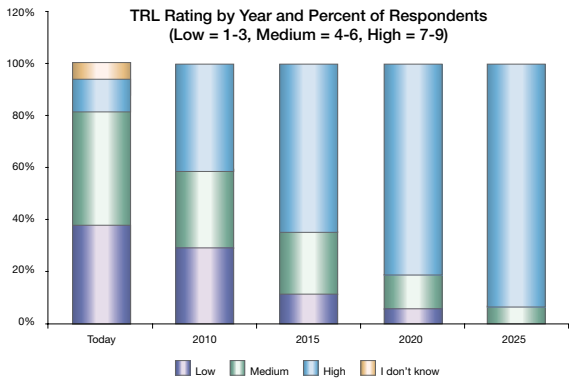
Description

In the future, drug companies may provide implants to patients that cause their bodies to produce needed medications or therapies. This may even include the ability to target cancerous or other diseased cells.

In addition, "cellular factories" may provide ways of producing chemicals or other materials that currently require more intensive processes to create.

Participant Views

- "We can't make things with biological parts right now. But it's just a matter of time."
- "It's a matter of time before they build complex systems. How to build organisms, to control and manipulate them."
- "There may be bio-inspired robots. They may have self-organizing behaviors for military purposes which can be both powerful and terrifying."
- "In the future, we have to look at biocatalysts as standard energy for these military guys."
- "For example, there are mechanisms to break down cellulose for energy. Also you can put electrons on metal to give electricity…biocatalytic systems with high surface, self assembled DNA, enzymes that convert carbon dioxide to oxygen or to water."
- "Bacteria will be used to produce food, supply, etc. or turning garbage into energy."
- "Assuming everything works well with bio-fuels, you're still going to need water and there are shortages there already and we are seeing the conflicts."
- "The barriers to entry are very low – knowledge intensive, not capital intensive, and can level the competitive field around the world."



- Participants noted that this technology could create "garage terrorists" and they would be very difficult to track.

Major Global Players

- United States (e.g. Massachusetts Institute of Technology, Harvard University)
- China
- India
- Brazil
- Singapore
- Indonesia

Current Developments

- Researchers are working to exploit the ability of a virus to replicate rapidly and combine with semiconductor and electronic materials, to coax them to grow and self-assemble into functional electronic devices[5]
- Researchers have designed a new type of DNA computer that works in human cells, perhaps paving the way for a distant technology capable of picking out diseased cells from otherwise healthy tissue[6]
- Advances in RNA Interference, which blocks the action of genes, could prove to be a future cure for a variety of ailments, including cancer, viral infections, genetic diseases, and even heart attacks[7]
- Researchers at Penn State University have designed a tabletop reactor that uses bacteria to break down biodegradable organic material. Adding a small jolt of energy to the system causes hydrogen gas to bubble up to the surface. This may prove to be a powerful way to generate hydrogen for fuel sources.[8]
- By genetically modifying *E. coli* bacteria, researchers at MIT have been able to cause the bacteria to generate energy from light rather than its normal energy source of sugar. These findings could ultimately be used to genetically engineer bacteria that can more efficiently produce biofuels, drugs, and other chemicals.[9]

Convergences

- Research in this area continues to converge with research into nanotechnology, and is also spurring developments in energy generation (as in the example above of hydrogen production from bacteria)

Potential Disruptions to Society

- Workshop participants postulated that using "crops for fuel" will continue to exacerbate the food shortage problem and cause a growing number of global conflicts.
- "Atomically precise synthesis/manufacturing would produce very strong and light weight materials that also have multi-functionality – self-healing properties, computational capabilities, self-replication. This would change manufacturing processes and materials."[10]
- "Custom materials for a variety of manufacturing needs will be integrated into existing chemical companies who do this type of work today."[11]

Researchers have designed a new type of DNA computer that works in human cells, perhaps paving the way for a distant technology capable of picking out diseased cells from otherwise healthy tissue.

Technology Area	Average TRL Rating for each time period*				
	Today	2010	2015	2020	2025
BIOTECHNOLOGY					
Bio-implants or enhancements that provide enhanced human performance	5.0	5.8	7.4	8.1	8.2

Description

Though bio-enhancements arguably exist today (eyeglasses, for example), most serve to compensate for degraded performance, due to disability, injury, etc. We refer here to implants or other devices that would allow for performance beyond the "normal" human condition.

Participant Views

- Bio-enhancements could also provide improved medical care: "[Could this mean] the emergence of the Cyborg? Integrated medical devices, enhancement devices… Like the auto: Integrated sensors reduced the cost of fixing cars."
- "I'm talking about becoming part of the cyber world. A grid of sensors across your skin. A thin shirt layer with sensors that enable you to feel heat or pressure."

New research fusing electronic microchips with living brain cells could one day lead to chip implants to combat neurological disorders.

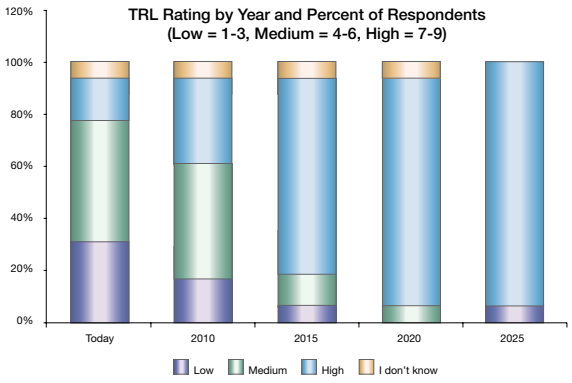
- "You could make interfaces between people and devices…you could integrate and communicate brain to brain…It will change the way you do brainstorming."
- "People are now putting brain chips in to fix brains with congenital defects…"
- "It will change what it means to be human…an augmented versus un-augmented human will accentuate the have's and have-nots."
- "What's good is people living to be [the age of] 120, but what's bad is people will live to be 120. The real "120" story is if it [becomes] extremely expensive for people to live that long and whether or not people will pay to keep you alive that long."
- "Human performance enhancement could change our economies, social lives and warfare."

Major Global Players

- United States (e.g. Sarcos, Cyberkinetics)
- Global pharmaceutical companies
- Sports industry
- Foreign and domestic militaries
- Countries with permissive laws, policies and regulations in R&D (e.g. China)
- Singapore
- Sweden
- Israel
- Indonesia
- Western Europe
- Japan

Current Developments

- Massachusetts-based Cyberkinetics is currently developing technologies to allow interface with the human nervous system. Immediate applications are in the area of spinal cord and other nerve injuries, but future applications could target people with normal body functioning.[12]



- New research fusing electronic microchips with living brain cells could one day lead to chip implants to combat neurological disorders. Connecting neurons to semiconductors successfully is the key to future breakthroughs in human–computer synthesis.[13]
- Researchers at the National Institute for Neurological Disorders and Stroke, in Bethesda, MD, are studying how applying gentle electrical current to the scalp can improve learning. They have developed a device that stimulates certain areas of the brain to enhance functioning. According to researcher Eric Wasserman: "We're beginning to think about whether this technology has a role in cognitive enhancement in healthy people."[14]

Convergences

- As with many of the other technology areas, developments in nanotechnology, because of its greater ability to impact the body at the cellular level, will fuel developments in bio-enhancement.
- Bio-enhancement will also converge with developments in cybertechnology: Raytheon, through a newly acquired company called Sarcos, is developing a robotic suit for the US Army. Known as the Exoskeleton, it's essentially a wearable robot that amplifies its wearer's strength, endurance, and agility.[15]

Potential Disruptions to Society

- Bio-enhancement could be disruptive through a variety of possibilities ranging from eliminating physical impairments to enhanced vision, hearing, and smell, to direct digital communication with networks and improved cognition and memory.
- Secondary and tertiary impacts would likely impact the economy. If people live much longer, there might be more need for social services, or an employment crisis (with people not retiring, there would be far fewer job opportunities for younger generations), or other burdens on the economy.
- In terms of demographics, there could be unintended disruptive consequences to this technology if developers are not careful, such as a "population bomb" – in the words of one participant, "if you put a drug in all people so that no one would get malaria, it would have population, demographic and economic implications."
- This technology would affect our homeland and national security if we (or our adversaries) could convert it into applications, especially if they were able to do so without our knowledge.
    - There could be integrated human performance enhancement with brain alteration, enhancing the military to be less afraid and more aggressive, with quicker reaction times.
    - Bio-enhancement technologies open up a possibility of taking "suicide bombers" to a whole new level (i.e., "bio-bombers") and could create other new kinds of threats as well, and our current physical security infrastructure and other countermeasures could be useless against them (in the words of one participant, "today's fence is about 8 feet high, what if someone can jump easily over a 12 foot fence? What good would the old fence do?")

Bio-enhancement would affect our homeland and national security if we (or our adversaries) could convert it into applications.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
BIOTECHNOLOGY					
Ability to remotely trigger automatic production of immune responses and medicines within the body via implants or other means	2.5	3.6	5.4	6.8	7.7

Description

By this, we mean the ability to cause the body to produce its own medicines or other compounds, or to produce immune responses targeted at diseases or other ailments, via implants or remote triggering.

Participant Views

- "Drug companies can make cellular devices to make drugs in your body all the time."
- "People [will be] making organs for drug screens."
- "We are talking about living devices. We do magnetic particles. People are taking living devices and adding sensors and other capabilities. These are cells that self-replicated, mammalian cells, etc to sense stimuli and respond to drugs onsite at no cost."
- "They have already personalized the genome. It's just the beginning of this."
- "The question is, what if you can use your brain to remotely control IEDs IImprovised Explosive Devices)?"

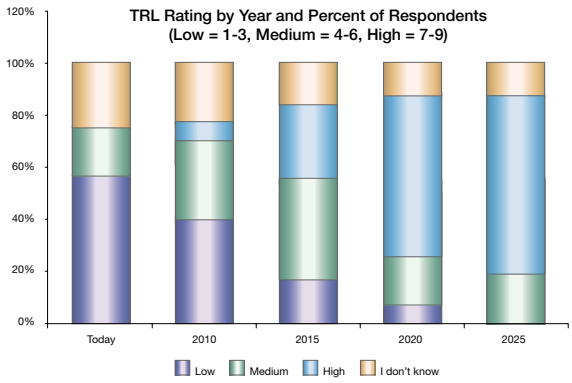
This could eliminate the need for hospitals for many ailments, giving countries with currently limited healthcare infrastructure a way to compensate.

Major Global Players

- United States (e.g. Harvard Medical School, University of Pennsylvania, University of Maryland)
- Biotechnology and pharmaceutical companies
- China
- Western Europe
- South Asia
- Latin America (Brazil)
- India

Current Developments

- Researchers reported in Nature Nanotechnology that they triggered immune system cells to begin a biochemical process that produces histamine (the chemical responsible for allergic responses) by dusting them with iron particles and applying a magnetic field.[16]



- "In the lab, our group showed we can produce a tiny nanofactory and attach it to a target cell magnetically. The nanofactory then makes small molecules from surrounding materials and delivers the molecules—potentially drug molecules—to the targeted cell."[17] – *Dr.William Bentley, University of Maryland*

Convergences

- Nanotechnology will continue to converge with biotechnology in this area, producing developments that allow greater and greater control of cellular functions.

Potential Disruptions to Society

- "The body could be caused to poison itself via triggering by cell phone or other remote devices."[18]
- It could eliminate the need for hospitals for many ailments, giving countries with currently limited healthcare infrastructure a way to compensate.
- This could provide a way for allied or enemy troops to heal themselves in the field.
- Populations could be controlled by the triggering or suppression of desired moods.

NANOTECHNOLOGY

Summary

Nanotechnology involves "research to discover new behaviors and properties of materials with dimensions at the nanoscale which ranges roughly from 1 to 100 nanometers (nm)."[19] This research is significant because the properties of even very ordinary materials are quite different at this level. Also, materials at the nanoscale are small enough to penetrate cell membranes, making nanotechnology a key facilitator of advances in biotechnology. Scientists may soon be able to manipulate the basic properties of materials at the atomic level, removing us from the need to work with their properties as they are.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
NANOTECHNOLOGY					
Significant proliferation in diversity of high-powered, portable energy generation and storage devices	4.0	5.0	6.9	8.3	8.7

Description

By this, we refer to devices that could power a house, as well as to devices that might power a vehicle or other objects, and to devices that would allow storage of large amounts of energy.

Participant Views

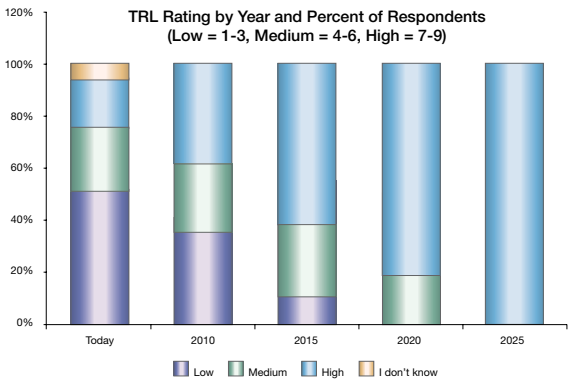
- "Chemical energy could be used. We don't know how to use it now, but it's a big resource. Nano may open the way to this."
- "With chemical bonding, there is energy there… it could be things other than just burning oil and coal"
- "If soldiers can carry their own portable power source, there would be huge benefits to the nation, decreasing infrastructure and logistics costs."

Major Global Players

- United States (e.g. Massachusetts Institute of Technology, EEStor)
- United Kingdom

Current Developments

- An MIT battery expert and co-founder of A123 Systems of Watertown, MA expects that battery capacity will double in the next ten years.[20]
- A Texas startup called EEStor claims to be close to producing a battery that will dramatically outperform the best lithium-ion batteries on the market in terms of energy density, price, charge time, and safety, and will also pack 10 times the punch of lead-acid batteries at half the cost and without the need for toxic materials or chemicals.[21]
- Research underway at Los Alamos National Laboratory is exploring methods of using layers of carbon nanotubes and lithium hydride to convert radiation from the decay of radioactive



An MIT battery expert and co-founder of A123 Systems expects that battery capacity will double in the next ten years.

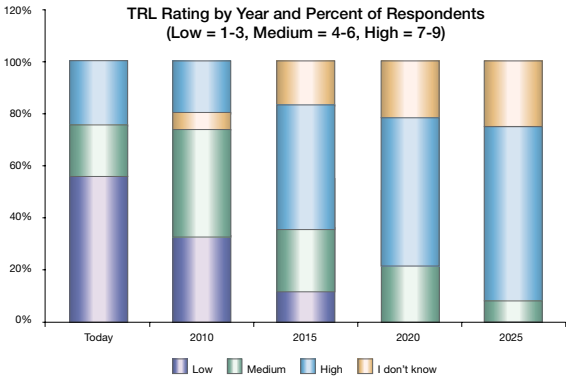
materials directly into electricity. While most likely a decade from application, the technology could significantly shrink production of nuclear energy, allowing its use in spacecraft, aircraft, and even land vehicles.[22]

Convergences

- Developments in biotechnology could also fuel growth of portable energy storage/generation devices. As indicated earlier, researchers have been able to modify bacteria to produce hydrogen, and to derive energy from light.

Potential Disruptions to Society

- Large-scale electricity storage and transportation; portable devices
- "Home and office energy needs will disrupt existing energy network but a few visionary companies will incorporate this approach into their business strategy."[23]
- Devices currently not portable because of power requirements could become mobile.
- Increased reliance on alternative energy sources would disrupt existing oil-economy dependent regimes. "If the Middle East doesn't get oil money and they shift to a knowledge economy, there could be a disruption to current regimes."[24]



Participant Views

- "It will be possible to change DNA—it will dramatically change the situation. It will be very disruptive."
- "You could control how tall you are, that sort of thing. It will change the roots of human nature, and will have military applications and other implications."
- "I'm working on the $100 genome project, and it will feed into that. If you can get genome sequencing cheaply, you could splice the genome."

Major Global Players

- United States (e.g. Complete Genomix, BioNanomatrix, Applied BioSystems, Dover Systems and Church Laboratory of Harvard Medical School, Navigenics, NIST)
- United Kingdom (e.g., base4 innovation, University of Warwick, Sanger Institute)
- China (e.g., Beijing Genomics Institute, Watson Institute of Genome Sciences at Zhejiang University)

$100 genome mapping will be within the reach of virtually anyone.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
NANOTECHNOLOGY					
$100 genome sequencing	**2.6**	**4.0**	**6.4**	**7.6**	**8.1**

Description

Research is currently underway to develop a "$100 genome" mapping ability that would be within the reach of virtually anyone. If successful, a $100-genome technology would transform genetic analysis, delivering at a stroke more diagnostic information for each patient than all the genetic tests available today, at a fraction of today's costs.

Current Developments

- By threading long DNA molecules through nano-sized channels on a specially fabricated chip, two companies, Complete Genomics and BioNanomatrix, are working on an approach to sequence a person's genome in a single workday, and for under $100.[25]
- The technology necessary to achieve a $100 genome is still at least five years away, says George Church, a geneticist at Harvard Medical School.

- The Polonator, a new gene sequencing machine that will be available later this year, is expected to be available for only $155,000. The Polonator tags DNA bases with fluorescent markers and uses a fluorescence microscope to read off the sequences.[26]
- Navigenics now offers mail order genetic screening. Patients send saliva samples in a special container, and Navigenics then uses microarrays to screen the subscribers' DNA for genetic variations linked to 18 diseases, including colon cancer and heart disease. This service is currently available for $2500.[27]

Convergences

- Advances in cyber-technology and nanotechnology will continue to make genome sequencing faster and cheaper.

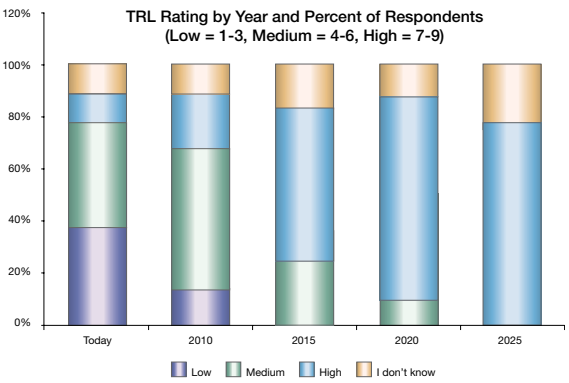
Potential Disruptions to Society

- On the positive side, cheap genome sequencing will allow personalized, proactive medical diagnosis. However, if personal genome information is stolen, it could mean a whole new form of identity theft, or at the extreme could even enable biological weapons targeted at specific individuals.
- By condensing a wide range of genetic tests into a single, cost-effective platform, the technology would for the first time make personalized medicine feasible, enabling improved diagnosis and treatment of a wide variety of health conditions, as well as the ability to practice individually-tailored preventive medicine.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
NANOTECHNOLOGY					
Cheap portable water desalinization/ purification technology	4.3	5.4	7.2	8.3	8.9

Description

While water purification and desalinization technologies currently exist, they are either too large or too expensive, and may lack the ability to filter many pathogens that exist in water supplies. Problems with inadequate access to clean water and sanitation are expected to grow worse in the coming decades with water scarcity occurring globally, even in regions currently considered water-rich. Addressing these problems calls out for a tremendous amount of research to identify robust new methods of purifying water at lower cost and with less energy, while at the same time minimizing the use of chemicals and impact on the environment.



Participant Views

- "Water will be a major issue within the next 20 years – water will be more important than energy … twenty years from now, 80% of the countries worldwide will have problems with water."
- "With cellular energy and the investment in nanotechnology, you could store energy that's efficient and economical – and it can be used for water treatment as a spin out."

The Polonator (source: http://www.polonator.org/)

While water purification and desalinization technologies currently exist, they are either too large or too expensive, and may lack the ability to filter many pathogens that exist in water supplies.

The amount of money invested in water and wastewater technologies in the U.S. rose a whopping 436% between 2006 and 2007.

- "If you stipulate that by 2025 there will be fairly affordable energy—clean energy—you've gone a long way to solve the water problems…if you use energy to make the water clean, then you've gone a long way to solving the food problem through irrigation. There's a very nice perfect storm that occurs, but it starts with a breakthrough hybrid solution to produce clean/affordable energy."
- "Nanotechnology has the potential to replace certain current capabilities, such as energy production and usage, water treatment, and communications, with much cheaper alternatives that are not capital intensive. This might provide developing societies with the cheap energy, clean water, and ubiquitous communications that we depend on and take for granted."
- "There are biocatalytic systems with high surface self-assembled DNA, enzymes that convert carbon dioxide to oxygen or to water."

Major Global Players

- United States
- France
- Russia

Current Developments

- "The discovery of unexpected magnetic interactions between ultra-small specks of rust is leading scientists at Rice's Center for Biological and Environmental Nanotechnology (CBEN) to develop a revolutionary, low-cost technology for cleaning arsenic from drinking water. The technology holds promise for millions of people in India, Bangladesh and other developing countries where thousands of cases of arsenic poisoning each year are linked to poisoned wells."[28]
- Ovation Products in New Hampshire has developed a portable water filtration system that can convert sewage waste into potable water. The company envisions the device fitting into apartments and homes, and being used in developing countries.[29]
- The amount of money invested in water and wastewater technologies in the U.S. rose a whopping 436% between 2006 and 2007, according to the Cleantech Group, an environmental industry association.[30]
- "Membrane bio-reactors" is a nanoscale filtration technology leveraging a new generation of microbe killers designed to disinfect, decontaminate or recycle fresh water supplies.

Convergences

- Developments in nanotechnology and biotechnology will continue to converge to produce solutions to the problem of water filtration and purification.

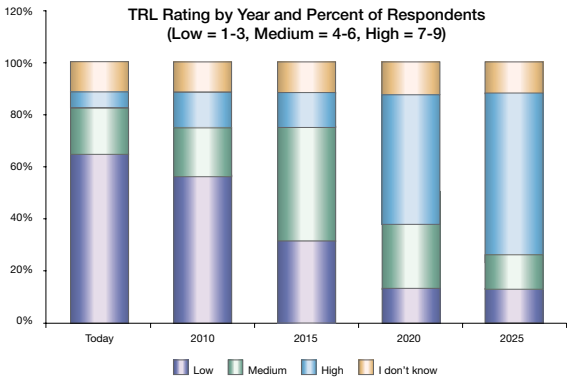
Potential Disruptions to Society

- Advances in water filtration could solve the growing world need for drinkable water. According to the United Nations Environment Program, over 200 million Africans are facing serious water shortages, and that number will climb to 230 million by 2025.[31]
- Likewise, better water filtration could eliminate many forms of disease from developing countries, spurring their development.
- Workshop participants believe that this technology will be a stabilizing factor and that if it is not developed soon, there will be more global conflicts due to water shortage.
- Participants noted that water purification technology will increase urbanization and allow people to disperse as the availability of water is often a function of transportation also.
- Participants also noted that having portable water purification technology would make military deployment much easier.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
NANOTECHNOLOGY					
Desktop manufacturing of complex devices	2.5	3.2	4.5	5.9	7.0

Description

This technology includes desktop or equivalent-sized devices that would allow "home" production and manufacture of a variety of simple and complex items.



Participant Views

- "I heard a talk by a professor who has a group in Tokyo – he talked about manufacturing facilities for microfluidics….he said could take huge plants and convert them to something that could fit on a table."
- "If you look at new computers, new media and internet, ... desktop or micro-manufacturing has huge implications ... costs will go down – at some point there will be disruption."

Major Global Players

- United States (e.g. Nanorex, Cornell University, Desktop Factory)
- United Kingdom

Current Developments

- Cornell University researcher Hod Lipson launched the Fab@Home project with PhD student Evan Malone in October 2006. Their Freeform fabricator – or "fabber" – is about the size of a microwave oven and can be built for around $2400. It can generate 3D objects from plastic and various other materials, and works with a software package that provides the designs for the objects.[32]
- Desktop Factory now offers a $4995 desktop 3-D printer that can print plastic objects up to 5 x 5 x 5 inches using 3D software.[33]

Convergences

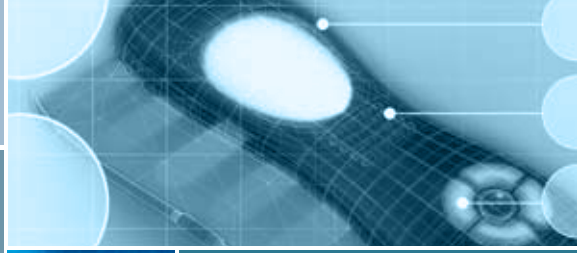
- Development of desktop manufacturing devices is influenced heavily by developments in software, and other cyber-related technologies. In addition, if desktop manufacturing were to converge with biotechnology, the future could see home manufacture of replacement organs or production of drugs.

Potential Disruptions to Society

- Custom manufacturing of a wide variety of items needed at home and office will disrupt current supply chains.
- Home manufacture of weapons and other devices will become easier.

The Desktop Factory 3-D Printer

The future could see home manufacture of replacement organs or production of drugs.


CYBER-BASED TECHNOLOGY

Summary

Within this section, we explore both the physical aspects of cyber-based technology, in the form of cheap computing and its implications, and the virtual aspects of cyber-based technology, in the form of the rapidly evolving "virtual" world that this technology is facilitating. As virtual worlds grow, the question arises: "How do you know who you are dealing with online, and how will people represent themselves?"

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
CYBER-BASED TECHNOLOGY					
Persona management/cyber world converging with the physical world	N/A	N/A	N/A	N/A	N/A

The proliferation of virtual worlds, and the ensuing growth of peoples' personas are blending the virtual and real dimensions of our lives.

Description

Both the Technology and Innovation 2025 conference and the Technology Implications workshop generated considerable discussion on the possibilities and implications of the "interaction of [cyber] worlds with the brick-and-mortar world through a virtual interface." The proliferation of virtual worlds, and the ensuing growth of peoples' personas are blending the virtual and real dimensions of our lives. People will have an increasing number of identities, leading to the need to ways to authenticate and manage them, i.e., "refereeing" and "persona management."

Participant Views

- "I see the need for refereeing. How will that trust trend continue? People self-organizing information?"
- "How about mobility in naming? How do I know who I am talking to? Who is John Doe and what does that mean?"
- "We'll have different personas—a virtual life and a personal life."
- "We may see an emergence of Persona Management."
- "Virtual everything—virtual worlds, virtual economies become even more important."
- "There will be millions of dollars of pseudo cash."
- "There's a real exchange rate. People are paying real money for virtual things. A merging of the cyber economy or cyber worlds. The question is what percent of the world economy has access or is accessible?"
- "You will have less freedom because your identity will be detected more easily."
- "My social network has little to do with geography; does that mean people won't think of themselves as Chinese or Americans in 25 years?"

Major Global Players

- China (e.g. Beijing Cyber Recreation Project)
- United States (e.g., Linden Lab, ElectricSheep)
- Sweden (e.g., Paynova international online payment services, and MindArk Entropia Universe virtual world)
- Russia
- France
- Korea
- Singapore
- Hackers
- Israel
- Gaming and entertainment industry

Current Developments

- China - Beijing's Cyber Recreation Project (CRP), which is jointly owned by the Chinese government and industry, is creating a Second Life-style virtual world to allow people to buy customized goods from Chinese manufacturers. This Chinese initiative, based on Internet Protocol version 6, aims to build an open and accessible environment. Handling currency conversions, global integration and interoperability are core requirements for success. The Beijing Cyber Recreation District is the "online counterpart" to Beijing's China Recreation District (CRD), a real-world mega-project that will boast entertainment and shopping. As of November 2007, over 200 game and multi-media content producers were working on site to integrate the virtual world with the real world.[34] Current planning is for 150 million avatars and 7 million on at any one time but longer-range projections are for "billions of avatars" to eventually be supported (the current Second Life capacity is about 40,000 avatars at any one time).
- Singapore has also taken a major stride toward creating a virtual world infrastructure for the nation similar to the ongoing China Recreation District. The Singaporean government has formally solicited ideas from industry in support of its goals for 2015 to use virtual worlds to "1) process, manage and distribute [digital media and entertainment] content and services, and (2) create content and services."
- Virtual Worlds Management's *Youth Worlds Analysis* provides details on more than 100 worlds. In all there are 60 youth worlds currently live. Another 53 are in concept, development, or testing phases. The "tween" category (ages 8 to 12) has the most interest with 62 worlds live or in development, followed closely by "kids" worlds (age 7 and under) with 52 worlds live or in development, and then "teens" worlds (ages 13-18) with 44 worlds live or in development.[35]

Convergences

- Virtual worlds will become more complex as developments in brain-machine interface provide more immersive environments in which the body may connect more fully to the virtual environment.

Potential Disruptions to Society

- Several participants raised the possibility that virtual worlds such as Second Life could be used to facilitate criminal financial activity – people are already transferring money between virtual worlds and the real world; will it be possible to hide in a virtual world, and/or hide assets?
- It has already been speculated that terrorists may be using virtual worlds to train for potential terrorist attacks, and also to pass money via "virtual" economies from jihadists in one country to jihadists in another.[36]
- More and more product tests are done using computers and modeling and simulation, with potential disruptive implications for supply chains.
- This technology development could redefine borders, nation-states, loyalties, self-identification (what it means to be "friend" or "foe"), and affiliations. Several participants elaborated on this idea, noting for example that "in Second Life, there are orthogonal loyalties – before, you identified as an American ... now, is it that your national identity is weakened, or is it that there are new ways of coming to decisions?" Some even believe that virtual-world conflict will leach over into the real world – imagine wars fought in World of Warcraft where a real country wins by proxy.
- The volume, velocity, and variety of data and information will cause data management issues.

The blurring of virtual and physical worlds could redefine borders, nation-states, loyalties, self-identification, and affiliations.

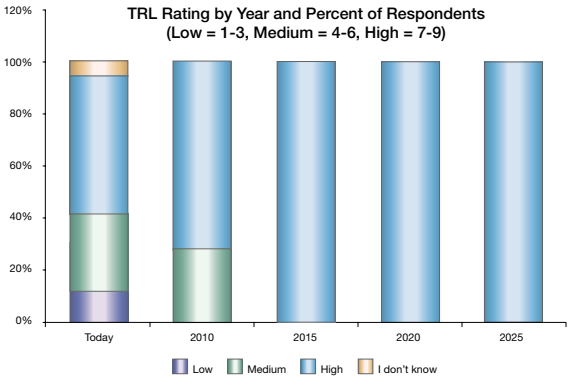
- Participants discussed the potential benefits of a persona management capability, to include fewer fraudulent sales, reduced illegal border crossings, improved global tracking, and the availability of records to bioscience industry. Workshop participants noted that this technology would have major economic impacts in the future but the killer application has not been developed yet.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
CYBER-BASED TECHNOLOGY					
Low cost, high powered computers	**6.6**	**7.5**	**8.3**	**8.9**	**9.0**

"In terms of availability and cost, we think that the $200 computer will cost about a dollar in 2025."

Description

Following Moore's law, the number of transistors that can be inexpensively placed on integrated circuits increases exponentially. This technological trend is expected to continue to result in a doubling of processing power approximately every two years for at least another decade. The low-cost high-power computers enabled by this phenomenon will spur numerous global technological and social changes.



Participant Views

- "In terms of availability and cost, we think that the $200 computer will cost about a dollar in 2025. But, if you are living on a dollar a day, will you spend any part of that to buy a computer?"
- "Just through Moore's Law, by 2025 the $200 computer will be $1 or less… we could give them away at McDonalds."
- "As you provide computers to children [in developing nations], that will make the [lead in cyber technology] flow in that direction."
- "Look at price of storage ... in 1991, [it was] $7 per megabyte – now it's 10 cents per gigabyte ... in 2025, you could store 140 terabytes on your glasses for 15 dollars."

Major Global Players

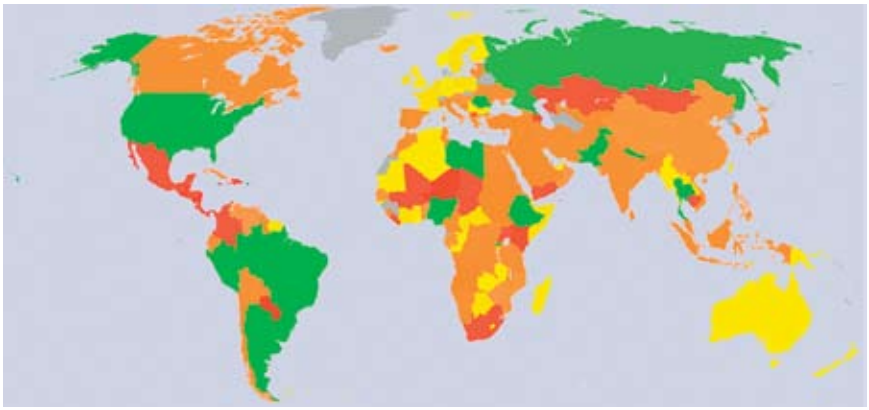
- One Laptop Per Child (OLPC)
- Microsoft
- LINUX
- Intel
- MIT Media Lab
- Quanta Computer
- Asus
- Everex
- Sony

Next Generation $100 – Laptop (OLPC)

Current Developments

- OLPC is pursuing a smaller 2.0 version of its XO computer, scheduled for release in 2010, in which dual touch screens will replace the keypad. The new version is projected to have lower power consumption and a $75 price.[37] The machines are being made by Quanta Computer (Taiwanese company), and countries will get versions specific to their own languages.
- In May 2008, OLPC announced that the $100 laptop will now have the option to run Microsoft Windows as well as LINUX while still keeping the cost relatively low ($198.00). OLPC's founder said that the move is important to enable the mass global acceptance of the machine.[38]
- Recent OLPC participating country developments include:
  - Mongolia: Interface to be translated into Mongolian; Project Read will soon purchase an additional 2000 computers with grant money from the World Bank.[39]
  - Haiti: The first set of laptops were distributed on June 23, 2008
  - Nepal: The World Food Program sponsored a multi-caste team of Nepalese women that carried XO laptops atop Mount Everest at the end of May 2008. The women demonstrated their XOs at base camp and formed a mesh network around the machines, which were powered by portable solar arrays.
  - Brazil has officially opened a request for proposals for 150,000 "educational laptops" for its Um Computador por Aluno project (One Computer per Student, in Portuguese)[40]
- Following the idea of the XO computer, a Seattle-based nonprofit organization called Literacy Bridge hopes to create a low-cost audio player for the developing world. The $5 "Talking Book" is an iPod-sized flash-based mp3 player that fills up on health, educational, and other audio programming at Linux-based content distribution kiosks.[41]

A team of Nepalese women carried XO laptops atop Mount Everest at the end of May 2008 and formed a mesh network, powered by portable solar arrays.



Source: *One Laptop per Child*

OLPC Global Rollout Plan [42]

- countries OLPC plans to pilot
- countries OLPC plans to include in the post-launch phase
- countries that have expressed interest at the Ministry of Education level or higher
- countries currently seeking government support

The growth of cheap computing will extend the ability of terrorists to create command and control networks.

Convergences

- Terrorists have already shown that cell phones can prove to be a viable means of creating cheap command and control networks; the growth of cheap computing will extend the ability of terrorists to create such networks.
- Developments in bio-enhancements and human-machine interface, and further computerization of key elements of the core infrastructure, combined with greater access to cheap computers, could put cyber-based attacks closer within reach of terrorists.

Potential Disruptions to Society

- "Social bifurcation of the haves and have-nots [as we know it may change] – maybe a third world player can become a first world player."[43]
- [Low-cost high-power computers] "will disrupt existing medical and legal professions (among others) and warfare. They will enable many new applications ranging from automated personal surveillance to accurate personalized weather forecasting to personal expert assistants to automated highways"[44]
- "The XO-1 ... will lead to even more powerful, yet cheaper computers [and] this will be disruptive in two ways: 1) computers and associated networks will proliferate; and 2) within 15 years there will be a plethora of Third World, computer literate people developing new applications."[45]

UBIQUITOUS SENSORS

Summary

As sensors become cheaper and smaller, they will continue to proliferate in everyday devices, and even in the human body itself. As sensors become more capable of analyzing every aspect of the environment, the information they generate becomes more valuable in adapting to that environment. Here we explore the implications of health monitoring through sensors, and the possibility that complex sensors may soon be a part of common, everyday personal devices. We also explore the privacy implications of sensors: should we be able to "opt out" of the sensor-rich environment? And what does it mean when we believe it is likely that our adversaries are monitoring our capabilities and movements?

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
UBIQUITOUS SENSORS					
Bio/health monitoring	N/A	N/A	N/A	N/A	N/A

Description

Ubiquitous wireless networking and sensor technologies will increase global information access for anyone. Emerging networking and sensor technologies may help to alleviate the rising costs of healthcare, which some fear could reach unsustainable levels within a decade. Home health monitoring and telemedicine is not a new concept, but the next generation of bio/health monitoring will take consumers into total remote monitoring. The field now includes technology such as home and mobile health monitoring, teleretinal imaging, sensors for remote diagnosis and advice to patients, teleradiology, remote cardiac monitoring, and video conferencing. Bio/health monitoring creates many opportunities in the healthcare industry, but it also presents new threats and vulnerabilities.

Participant Views

- "On the positive side, health sensors could be in all public places. If something goes wrong, it picks out the person with the problem and calls for help. It would have to come with the option to opt in or opt out—a health monitoring system."
- "They could aggregate all your data for your doctor; they could create temperature profiles over time."
- "The sensors could also be used for short-term epidemic reduction. It would be like with SARS, when they took peoples' temperatures going onto and off airplanes. This is a clear approach to what you're talking about."
- "Chemicals and nano labs could be mass-produced. Sensors could take my blood sample and determine my health ... the Japanese [already] put [that capability] in toilets; the International Space Station does it."
- "We talked about biomonitoring for your health. But for your glasses to be able to sense whether you have a disease, I'm suspicious of how ubiquitous those sensors would be – the cost would have to be below 50 cents per unit for it to work."
- "We could have telemedicine or home care all around… with elderly care, if you leave someone in their own house for a few years instead of (putting them) in nursing care that saves a lot of money."

Bio/health monitoring creates many opportunities in the healthcare industry, but also new threats and vulnerabilities.

A wearable textile patch, in development by a consortium of European research institutes and companies called Biotex, will allow monitoring of a patient's health by measuring the chemical composition of their sweat.

Major Global Players

- United States (e.g. Massachusetts Institute of Technology, National Institutes of Health, General Electric Healthcare, sports and fitness industry, etc.)
- European Union (e.g. European Public Health Alliance)
- France
- Japan
- Taiwan

Current Developments

- On June 26, 2008, the Appropriations Committees in both the Senate and the House of Representatives released spending measures that increase funding for the Office for the Advancement of Telehealth (OAT) at the Department of Health and Human Services (HHS).[46] The House provided OAT $7,100,000, while the Senate provided $8,000,000. Both levels are increases from the FY 2008 level of $6,700,000, and from the administration's request of $6,819,000.[47]
- MIT is working on a wearable sensors/wearable health monitoring research is to enable adaptive, real-time, continuous and non-invasive healthcare for home and out-of-hospital environments. 1) novel biosensors that can measure high-quality biological signals, and 2) advanced system identification and signal processing algorithms to extract valuable clinical information therein.
- A wearable textile patch, in development by a consortium of European research institutes and companies called Biotex, will allow monitoring of a patient's health by measuring the chemical composition of their sweat.[48]
- In remote monitoring, sensors are used to capture and transmit biometric data. For example, a tele-EEG device monitors the electrical activity of a patient's brain and then transmits that data to a specialist. This could be done in real time or the data could be stored and then forwarded.
- Examples of remote monitoring include:
  - Home-based nocturnal dialysis
  - Cardiac and multi-parameter monitoring of remote ICUs
  - Home telehealth
  - Disease management
- Aurora Health Care uses sensor technologies to monitor patients' chemical levels and vital signs, sending signals to the Aurora offices for review and (if necessary) response by trained nurses.

Convergences

- Just as current internet "mashups" are creating myriad combinations of different internet data streams, future developments in cyber tools will likely mean more and more websites devoted to analyzing personalized bio-information collected by ubiquitous sensors. A recent website, *whoissick.org*, allows users to send in reports of recent illnesses in their area, along with reported symptoms. The website combines this data with Google Maps to show areas where reports are particularly high.[49]
- Bio-sensors could converge with developments in genome sequencing to produce monitoring programs designed to proactively assess patient populations for diseases or conditions for which they have a genetic predisposition.
- Bio-monitoring devices increasingly will converge with wireless technology: Dallas-based Parks Associates, an international market research company, is predicting that by 2012, more than 3 million seniors will be using networked health monitors in their homes.[50]

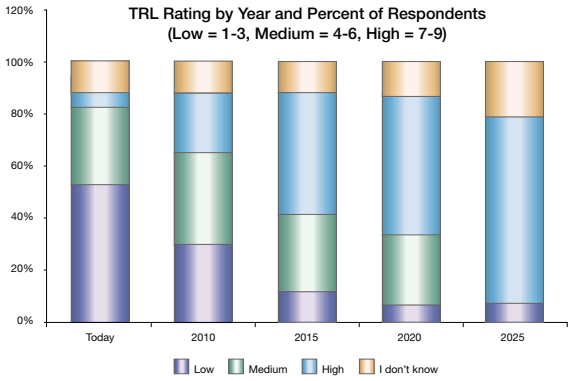
Potential Disruptions to Society

- Widespread access to sensor-collected health information along with cyber warfare tools will increasingly empower states, individuals and ad hoc groups to threaten the US and other developed nations with attacks on their healthcare systems.
- US Government agencies' agreement on division of responsibilities and coordination with each other and commercial activities could be substantially changed by advances in this area.
- Bio-sensors could raise ethical/privacy debates if insurance companies decide to make bio-monitoring of patients with predispositions for certain diseases or conditions a prerequisite for coverage or treatment.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
UBIQUITOUS SENSORS					
Chemical, biological, radiological, nuclear, and meteorological sensors in everyday personal devices such as cell phones	3.3	4.5	6.3	7.2	7.9

Description

This refers to sensors capable of detecting a wide variety of phenomena, including various types of threats in the surrounding environment, and that could be placed in cell phones or other personal devices.



Participant Views

- "There will be an over-sampling of data due to ubiquitous sensors. There will be so many sensors, it will be impossible to falsify."
- "If we made nanoparticle-sized sensors, we could disperse them anywhere...they can be used to monitor trace gasses...the EPA is already looking into this, using them in factories."
- "How are we going to store all the logged data [from these sensors]? The CPU analysis required to derive information is huge ... we could derive all sorts of environmental changes, but the trick is deciding what to calculate and what to analyze."
- "The false alarm factor is huge—there is going to be a [false alarm] event, and the implications of an event itself will create a social backlash."
- "If we rely on one style [of sensor for this], it will cause problems – we need a standard where we only make conclusions when we have multiple types of data from multiple sensors."
- "Every cell phone can sense nuclear, biological, and chemical signatures. ... you can use them to monitor public places. Then you can create a way to keep people out, to triage after an event. To know where to draw the lines, who has been exposed."
- "Ubiquitous sensors are continuing to grow, and there is growth in handheld computing devices connected to the internet. GPS, PDAs, Blackberry, pager, merging with cell phone – they are all merging into a common device."
- "I have read *Transparent Society* where the author describes a possible future with citizen reporters behaving like sensors catching information for us—everyone is a sensor by carrying around a computing device with a lot of associated metadata."

Major Global Players

- United States (e.g., Massachusetts Institute of Technology, California Institute of Technology, University of Southern California, University of Cincinnati, NASA)

A prototype of NASA's nanotechnology-based biosensor (Credit: Nasa)

"Everyone is a sensor by carrying around a computing device with a lot of associated metadata."

Privacy will be radically changed in an environment where ubiquitous sensors, including in the phones and PDA's of everyone around us, can pick up chemical and other signatures.

Current Developments

- Researchers at the University of Cincinnati's Center for Microelectronic Systems and MEMS are working to develop micro-fluidic sensors that could provide bio/chemical sensing in a handheld device.[51]
- A tiny carbon-nanotube-based chemical sensor in development at MIT can detect low parts-per-billion concentrations of gases. It can also go from detecting one gas to another within half a minute, and is so small that 500 could be placed on the surface of a dime.[52]
- Researchers at NASA Ames Research Center have developed a nanotechnology-based biosensor that can detect trace amounts of as many as 25 different microorganisms simultaneously and within minutes.[53]
- Researchers at Purdue University are working with the State of Indiana to develop a system that would use a network of cell phones, equipped with tiny solid-state radiation sensors, to detect and track radiation to help prevent terrorist attacks with radiological "dirty bombs" and nuclear weapons. The GPS capability already present in the cell phones would allow the threat to be located and tracked.[54]
- At the 2007 DHS Science and Technology Stakeholders Conference, S&T Director of Innovation Roger McGinnis outlined a proposal for a system, called "cell all", which would utilize sensors in cell phones to continually monitor the environment for harmful biological and radiological compounds, and relay the information to a central processing system. In response to this, two companies, eV Products, and Gentag, Inc. have announced plans to develop cell phone-based radiation detectors.[55]

Convergences

- Convergences of sensors and cybertechnology present interesting opportunities. An expert in sensors commented that: "Database technology has grown, but it's mostly desktop applications. Some tools need to be developed to help visualize the big picture. So, you're getting a humidity time series of data, or something else. The whole software aspect is unbounded. You could take this data and perform semantic searches. Aside from searching for humidity, you could search for whether someone was there two days ago."[56]
- Cell phone sensor technology will be driven by advancements in nanotechnology and biotechnology, particularly as these areas produce smaller sensors that consume less power.

Potential Disruptions to Society

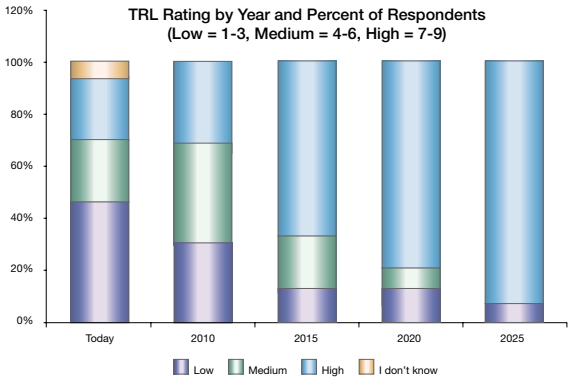
- Privacy will be radically changed in an environment where ubiquitous sensors, including sensors in the phones and PDA's of everyone around us, can pick up chemical and other signatures. Some are concerned that these sensors will support surveillance and reconnaissance by governments or other entities that we will be unable to regulate, and that it may be difficult for this to work on an "opt-in or opt-out" basis.
- The tie-in of these kinds of widely dispersed chemical, biological, radiological, and meteorological sensors to the emergency response infrastructure and related procedures could cause significant disruptions if not thought through carefully. If a cell phone picks up a signal of a toxin, it likely would dial into emergency response – but imagine hundreds or thousands of people at a mass event like a conference or a football game – if all the cell phones are calling at the same time, there could be large-scale panic, and major complications coordinating the police or other response. Implementation without some kind of triage for effects like these could pose risks.
- Widespread use of sensors for chemical/biological threat warning and monitoring opens up the door for sensor hacking and "spoofing" with wide-reaching impacts – for example, a cell phone virus could be used to fool the bio-sensors as if a real virus were spreading, with the potential for widespread panic and disruption.
- The proliferation of sensors could lead to a growth in demand for counter-measures and counter-surveillance technologies. Certain segments of society could go to great lengths to avoid monitoring, to include the creation of alternative identities or the use of active (disruptive) counter-measures. We could see the development of "sensor-free zones" to offset the growth in monitoring.

WILD CARD TECHNOLOGIES

Summary

The Tech 2025 conference facilitators asked a subset of the participants to discuss what they envisioned might be some "wild card" technology developments in the 2025 timeframe. The group discussed a range of ideas including new sources of energy, new innovations in physics, and radical neuroscience/ neurotechnology developments that could affect human cognitive functions. In this section, we explore the implications of some of these "wild card" technologies.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
WILDCARDS					
Solar technology cheap enough to replace oil	4.3	5.3	6.7	7.6	8.2



Description

Solar energy today remains expensive relative to other forms of energy. We refer here to solar technology that becomes attractive enough in cost to become a viable widespread substitute for oil.

Participant Views

- "I think if you look at the utilities, and power companies, a large number are investing in new directions. I came from a conference in Houston, and there were several companies who were looking at wind and solar thermal."
- "There's lots of roof space, and cheap land, and the cost of building (solar) panels and installing them will drop. I would bet my retirement savings that the cost of photovoltaic energy generation will be below oil in the future."
- "The biggest problem with solar is the sun. We don't have good cheap, long-term storage batteries… [but] I see improving batteries – the possibility for solar and other improvements is closing in."
- "There is work with plastic solar arrays that are cheap; and carbon nanotubes ... if they do achieve one of those and achieve efficiency and people can put it on their house – if we have 17 years (til 2025), you can solve some of your infrastructure problems."
- "Are the leaders in energy production today going to be the leaders tomorrow? Not based on current investments."

Major Global Players

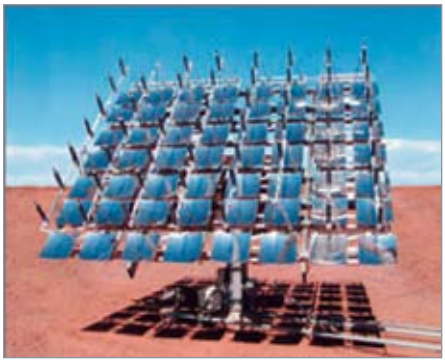
- United States (MIT, DOE, National Renewable Energy Laboratory, NASA, DoD)
- Canada
- Korea
- China
- BP Solar
- Philippines (Department of Agrarian Reform)
- Netherlands
- Australia
- New Zealand
- Germany
- United Kingdom

"I would bet my retirement savings that the cost of photovoltaic energy generation will be below oil in the future."

Researchers have pushed the efficiency of plastic solar cells to more than 6%, a doubling in only two years.

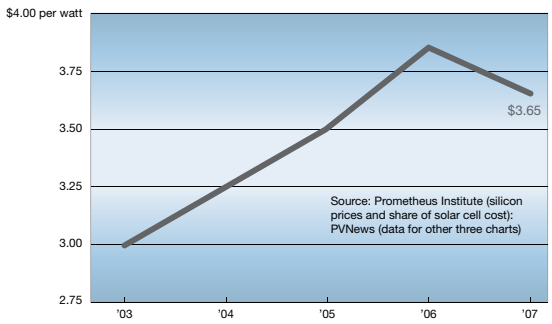
Current Developments

- SolFocus's first power-producing installation will be generating 500 kilowatts of electricity by the end of 2008.[57] This technology will generate more power than conventional solar panels but use just one-thousandth as much expensive semiconductor material. The company expects that by 2010, electricity from its arrays will be about as cheap as electricity from conventional sources; the estimated cost is 24 to 28 cents per kilowatt-hour, and SolFocus expects that figure to fall to 13 to 14 cents per kilowatt-hour by 2010.
- Researchers at Wake Forest University's Center for Nanotechnology and Molecular Materials announced in 2007 that they have pushed the efficiency of plastic solar cells to more than 6%.[58] This beats the 3% that today represents the highest efficiency ever achieved (in 2005), a doubling in only two years. Experts expect to see higher numbers within the next few years that will continue to make plastic devices the photovoltaic of choice.
- Researchers at TU Delft and the FOM Foundation for Fundamental Research on Matter have found irrefutable proof that the so-called avalanche effect by electrons occurs in specific, very small semiconducting crystals.[59] This physical effect could pave the way for cheap, high-output solar cells. The findings are to be published in the scientific journal *Nano Letters*.
- In late April, the Department of Energy (DOE) announced up to $60 million in funding for advanced concentrating solar power (CSP) technologies over five years. The DOE researches and develops a clean, large-scale solar thermal technology known as concentrating solar power (CSP). This research and development focuses on three types of concentrating solar technologies: trough systems, dish/engine systems, and power towers. These solar technologies are used in CSP plants that use different kinds of mirror configurations to convert the sun's energy into high-temperature heat. The heat energy is then used to generate electricity in a steam generator.[60] The announcement complements President Bush's Solar America Initiative, which seeks to make solar energy cost-competitive with conventional forms of electricity by 2015.[61]
- With silicon supplies tight, the price per watt of solar panels started rising in 2003, ending more than two decades of steady declines (in 1980, the price was $30/watt in today's dollars). With the supplies now rising again, many observers agree that solar-power prices will now drop.[62]



This MicroDish made by Concentrating Technologies uses Spectrolab solar cells. It is the world's first gird-tied high-concentration CPV system to use the latest high-efficiency cells. The dual-axis tracking modules use small mirrors to focus sunlight on high-efficient multifunction cells.

Average price per watt of solar panels



Convergences

- Nanotechnology is paving the way toward improved solar cells. New research shows that a film of carbon nanotubes may be able to replace two of the layers normally used in a solar cell, with improved performance at a lower cost.[63]
- Solar cell technology is being combined with advances in building materials: researchers at MIT are developing flexible "solar textiles" that can be integrated in building walls or roofing to provide a means of generating power. As Sheila Kennedy notes: "The boundaries between traditional walls and utilities are shifting." [64]

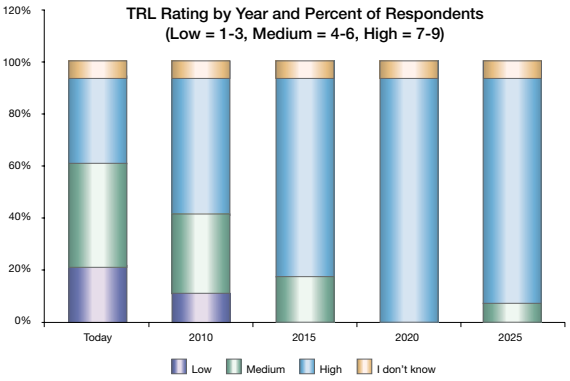
Potential Disruptions to Society

- This will disrupt existing energy networks, and the strength of petrodollar investors, and countries reliant on oil for global influence. Significantly cheaper solar power could result in drastic shifts of national power as new economies emerge, freed from the constraints of previously limited natural resources.
- It will become easier for self-sufficient communities to spring up "off grid."
- Widespread, cheap solar power could give developing nations the energy to desalinate water and raise bio-engineered food, increasing self-sufficiency and raising standards of living across the board
- Solar technology developments will create pressure for other forms of clean energy.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
WILDCARDS					
Carbon neutral energy	5.3	6.4	7.7	8.4	8.5

Description

This refers to energy production that does not produce carbon dioxide, or to energy production whose carbon emissions are completely offset by removal or absorption of the carbon emitted. Geothermal energy, wind power, and hydroelectric power are all forms of carbon-neutral energy.



Participant Views

- "Nuclear energy would be a great alternative to the burning that we do now."
- "Peak uranium is [projected to be in] 2025, so nuclear fission [as a large-scale] energy [alternative] won't happen. [Other] renewables, each of which have a 10x capacity to replace fossil carbon, are biomass, drilled geothermal, wind, burnet biomass, solar voltages, etc."
- "I have never seen anyone advance a fission nuclear reaction that doesn't run out of energy; geothermal is a nuclear reaction at the core; we're throwing 30% of the energy to replace coal by throwing the heated water off the oil wells; if you drill down you get 200° C water."
- "There is another fusion—aneutronic fusion—and it's much better than what we had before and DOE won't do anything with it."
- "Biomass that is not dependant upon fresh water or arable land, but on seawater and algae."

Significantly cheaper solar power could result in drastic shifts of national power as new economies emerge, freed from the constraints of previously limited natural resources.

Major Global Players

- United States
- China
- Iceland
- New Zealand
- Norway
- Costa Rica
- Netherlands
- United Kingdom

Current Developments

- In April of 2008, Iceland, Norway, New Zealand, and Costa Rica formally announced their vows to compete to become the first countries in the world to be completely carbon neutral.[65]
- A San Diego start-up, Sapphire Energy, says it is using algae to make oil that can be refined into gasoline and other fuels that are both renewable and carbon-neutral, and it plans to produce 10,000 barrels a day within five years. The algal oil produced is chemically identical to light sweet crude oil, and though burning the fuel creates carbon dioxide, the company claims the photosynthetic process that creates the oil more than offsets this.[66]
- Los Alamos National Laboratory has developed a concept, called Green Freedom™, for large-scale production of carbon-neutral, sulfur-free fuels and organic chemicals from air and water. The process extracts carbon dioxide from the atmosphere and makes it available for fuel production using a new form of electrochemical separation.[67]

A San Diego start-up, Sapphire Energy, is using algae to make oil that can be refined into gasoline and other fuels that are both renewable and carbon neutral, and it plans to produce 10,000 barrels a day within five years.

Convergences

- Growth of carbon-neutral energy will be influenced by developments in both biotechnology and nanotechnology.
- Developments in solar technology will also drive progress toward carbon-neutral energy, as will developments in hydroelectric and geothermal power.

Potential Disruptions to Society

- Participants noted that carbon-neutral energy technology would provide more efficient battery and energy storages.
- Increased reliance on alternative energy sources would disrupt existing oil-economy dependent regimes. "If the Middle East doesn't get oil money and they shift to a knowledge economy, there could be a disruption to current regimes."
- Carbon-neutral energy on a mass scale is believed to hold the potential for a major impact on global warming and associated treaties that are already in place or in the process of negotiation to regulate and manage nations' carbon emissions.

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
WILDCARDS					
Revolutionary advance in physics	N/A	N/A	N/A	N/A	N/A

Description

Despite revolutionary advances in basic science in the last 100 years alone, there is still much we don't know about the functioning of our universe, both at the astronomical and quantum levels. At the same time, however, the number of brilliant minds exploring the edges of physics has expanded significantly since the days of Einstein. The combination of many bright minds exploring many unknowns opens up the possibility of a fundamental breakthrough in our understanding of physics. While it is difficult to predict when this breakthrough might occur, or in what field, let alone the effects such a breakthrough might have, many participants argued that the possibility of such a fundamental breakthrough still requires consideration when thinking about technology in the year 2025.

Participant Views

- "(There were) 40-50 people in Einstein's day thinking about those types of issues ... in the 1960s and 1970s during Feynman's time, thinking about physics had grown ... over the next 10 years, the numbers of people looking at those problems will be exponential – you can make an argument that because of the growth in the number of people doing this around the world (an advance) is more likely."
- "There's this thing called String Theory – it's coming to the end of its string ... what happens when we get the next flavor of physics and (it) reverses the rear-view mirror? Einstein and a few others mumbled theories, and in a few years others were able to develop nukes."
- "A wild card may be that someone will figure out how gravity works, which we can't say now ... that would change so many things. We don't want to rule that out ... somebody out there is thinking about how to explain gravity."

Major Global Players

- United States
- Europe (European Organization for Nuclear Research (CERN))
- Japan (High Energy Accelerator Research Organization, Yukawa Institute for Theoretical Physics)

Current Developments

- Research underway shortly at the Large Hadron Collider (LHC) in Switzerland will be exploring our fundamental understanding of matter, energy and the nature of space-time. The LHC is likely to confirm—or destroy—the Standard Model of particle physics by determining if a hypothetical particle called the Higgs boson exists (which would explain why particles have mass). If successful, changes to the Standard Model could accelerate developments in nanotechnology, quantum computing and biotechnology.[68]
- Princeton University's Ali Yazdani is overturning accepted thinking on high-temperature superconductors. Yazdani's research has helped explain why some superconductors function at higher temperatures than normal and has identified tiny hotspots of superconductivity at temperatures far higher than previously realized. Commenting on these discoveries, physicist Jochen Mannhart of the University of Augsburg in Germany noted "one can dream about superconductors that work at room temperature."[69]
- Leveraging a deeper understanding of intermolecular forces known as Van der Waals forces – the same microscopic forces that allow geckos to hang upside-down – Professor Nicola Pugno (Polytechnic of Turin) has designed a "spider-man" suit that would allow users to cling to a surface and detach easily. The suit, much like

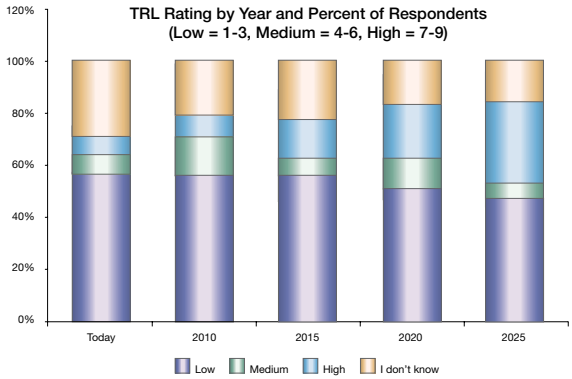
Jochen Mannhart of the University of Augsburg in Germany noted "one can dream about superconductors that work at room temperature."

What if future hackers could attack cyber-enabled devices in our bodies to produce certain types of behavior or impair neural or cognitive functioning?

Technology Area	Average TRL Rating for each time period				
	Today	2010	2015	2020	2025
WILDCARDS					
Ability to "hack" people via neural, computer, or other means to attack cognitive function	2.2	2.7	2.8	4.0	4.7

Description

Human-engineered computer viruses currently target computer systems. But what if future hackers could target our own bodies, attacking implants or other cyber-enabled devices in our bodies, or attacking the mind or brain itself, to produce certain types of behavior, or to impair neural or cognitive functioning?



Participant Views

- "I can design peptides to disrupt cognition. I can put it in water or food."
- "[You could use] neuroscience as a weapon You can disrupt someone's behavior without killing them. You could just make everyone stupid."
- "You could do memory hacking."
- "You can put codes in the brain. They are working on this in rats."
- "You could also make people dumber, and they'd be more apt to be suicide bombers."
- "[One of the] fastest moving sciences is neurotechnology – understanding how the brain works and connection to the brain – the mechanical or drug interface with the brain, manipulation of the brain, etc – could be electrical [manipulation] even."

Major Global Players

- Global Pharmaceutical companies
- Electronic industry with implantable devices
- DARPA
- Participants postulated that it would be difficult for non-state actors to bring together all of the key players, but Governments through their research infrastructure could create neuroscience technology applications.

Current Developments

- A group of computer scientists have determined that hackers could potentially disrupt pacemakers by remote control hacking. Devices that could prove vulnerable in the future include spinal-cord simulators and drug-delivery pumps.[71]

Convergences

- New discoveries in quantum theories open up the possibility for new advances in biotechnology, nanotechnology, and cybertechnology – especially the realization of practical quantum computation.
- Advances in superconductors combined with advanced energy technologies open up the possibility for a true energy revolution with low-cost, ultra-efficient energy generation, transmission, and storage.
- Discovery of new physical phenomena opens up the possibility for new and more sophisticated sensing technology.

Potential Disruptions to Society

- Just as advances in atomic theory led to the development of nuclear weapons in the early 20th century, new advances in 21st century physics could lead to exotic and powerful weapons that tip the balance of military power in the future.
- Similarly, a revolutionary physics advance impacting any number of technology fields (energy, quantum computing, materials – to name just a few) could have the impact to upset the economic and political balance of power, especially if controlled by a single nation or group.

the gecko's feet, would be self-cleaning and water resistant, leading to speculation for potential military, medical and commercial applications. Imagine a window washer or construction worker able to scale a structure with just a pair of gloves and no cumbersome ropes or tools – not to mention covert applications.[70]

- John-Dylan Haynes and colleagues at the Bernstein Center for Computational Neuroscience in Germany recently used a combination of functional magnetic resonance imaging (fMRI) technology and pattern recognition software to predict whether test subjects had secretly decided to add or subtract two numbers that were shown to them in a laboratory test. The test subjects' decisions were correctly discerned in more than 70% of the cases.[72]
- DARPA recently discontinued a program called "Biologically Inspired Cognitive Architectures" which had been dedicated in the words of one analyst to "reverse-engineering the brain." The program, begun in 2005, had been funded with the ostensible aim of discovering how to use computers to handle "cognitive support tasks" in order for soldiers to be able to dedicate more of their mind and attention to directly-combat-related tasks. DARPA had described the program's goal as "develop[ing] integrated psychologically-based and neurobiology-based cognitive architectures that can simulate human cognition in a variety of situations."[73]
- Scientists at a facility in China dedicated to research on advanced robotics engineering have succeeded in remotely controlling a flying pigeon. After implanting electrodes in the pigeon's brain and then activating them from a computer, they directed the pigeon to comply with specific commands to fly up or down and right or left. Chinese news sources reported that the experimentation is underway with the intent that the discoveries and related technologies "can be put into practical use."[74]
- Scientists at the State University of New York and Drexel University have shown that by removing the physical constraints associated with the delivery of cues and rewards, learning paradigms based on brain micro-stimulation enable new conditioning approaches. The scientists have developed a model for "rat navigation guided by remote control," in which the animals can be manipulated remotely to take particular actions, similar to the way that intelligent robots are controlled.[75]
- A new Research Centre for Neurotechnology opened in 2007 in Frankfurt/Main, Germany, with funding totaling several million Euros over a period of five years. It is part of the Federal government's Bernstein Programme for neurotechnology. According to Dr. Christoph von der Malsburg and Dr. Jochen Triesch, the Centre will be "investigating how areas of the brain are organized to form a functioning whole, instead of concentrating on individual functions … the model is the process by which babies learn to see their visual environment through autonomous discovery."[76]

Convergences

- Developments in this area will depend heavily on developments in bio-enhancement. The pacemaker is currently the most common implanted device, but as other bio-enhancements and implants become common, the potential for "hacking" these devices will theoretically increase.
- Advancements in biotechnology will also influence the ability to disrupt normal cognitive functioning. As one conference participant noted: "*There are a lot of ways to disrupt the nervous systems, peptides, pheromones, and small molecules.*"

Potential Disruptions to Society

- Bio-engineered drugs that will cause one to change loyalties and allegiances.[77]
- Bio-assassins – agents engineered to kill a specific person or race of people.
- Attacks that target pacemakers or other devices critical to normal body functioning.
- Workshop participants noted that it would be possible for terrorists to obtain the capability and influence others to use these technologies to target and attack critical nodes and infrastructure, such as power plants or water systems. They also pointed out that since all of our systems are increasingly interconnected, it would be possible to affect the financial markets with such attacks. They also agreed that the impact of this scenario would be bigger than just the attack itself since it would cause panic and hysteria, potentially drawing out the effect for years.
- A key element of the country's knowledge basis—selected individuals or large groups of people—could be attacked, and their cognitive abilities impaired.
- Positive impacts would be language enhancement, accelerated learning, ability to change the intentions of adversaries, and ability to change or modify behaviors.

DARPA recently discontinued a program called "Biologically Inspired Cognitive Architectures" which had been dedicated in the words of one analyst to "reverse-engineering the brain."

CONCLUSION

The technological developments maturing between now and 2025 and the innovative ways they may be applied reflect an acceleration and shift that can seem both promising and challenging to decision makers. In the Industrial Age, developments in steam power, combustion engines, automobiles, aerospace, and telephony seemed slow to mature – their development and spread required large industrial infrastructures. In the Information Age, developments in bio, nano, cyber, and sensors are possible with a smaller and more differentiated infrastructure, and they are occurring simultaneously around the globe. Global information networks are increasing the pace of this technological innovation. This deeper, more widely spread development of knowledge is different from our recent past and portends further changes.

The convergences of bio, nano, cyber, sensors and wild card technologies are causing even greater acceleration of change. But at the same time, knowledge is being created at such a rate that much of what we know about these technologies and their application rapidly becomes obsolete as it is overtaken by newer discoveries. Our institutions will be challenged to respond to the combination of these technological changes and the many other drivers of change simultaneously. We expect many systems and institutions to be desynchronized by these changes and efforts to resynchronize them will add to the sense of disruption that many people feel.

Knowledge is being created at such a rate that much of what we know will soon be obsolete.

Many thought leaders we worked with in this effort are highly optimistic. Nearly all who contributed to these findings see technological developments as promising, and as stimuli for new opportunities. At the same time, some cautioned about vulnerabilities and called for leadership and action to address these vulnerabilities before we feel their impact. This report serves as one input to decision makers who can aid us in adapting with the changes and creating our future.

Appendix I: Definition of Technology Readiness Levels

TRL 1 Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of concept: Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4 Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

TRL 5 System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment: Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

TRL 7 System prototyping demonstration in an operational environment: System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.

TRL 8 Actual system completed and "mission qualified" through test and demonstration in an operational environment: End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation completed.

TRL 9 Actual system "mission proven" through successful mission operations: Fully integrated with operational hardware/ software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Appendix II: The Technology and Innovation 2025 Conferences

The Technology and Innovation Conference held May 27-28, 2008 was one of many events which the National Intelligence Council (NIC) used to gather information for its Global Trends 2025 study. At the conference, experts were asked to consider and assess how advances in five key technology areas—and the ways they might converge—will affect society.

We asked the conferees to:

- Identify major developments expected between now and 2025 in five technology areas: biotechnology, nanotechnology, ubiquitous sensor, cyber, and wild card.
- Identify key technology convergences expected to impact or disrupt society between now and 2025 in five areas: economy and wealth, energy and environment, health and demographics, infrastructure, and governance.

Convergences among these five technologies were of particular interest, with the understanding that predicting how technologies will interact is extremely difficult, because the changes wrought by these interactions could be the most disruptive. With this in mind, we brought together leading authorities from multiple technological communities and put them together in groups that crossed disciplinary boundaries. The participants are renowned experts in their individual disciplines and known for possessing a real-world understanding of their areas of expertise.

By encouraging participants to bring as many ideas as possible to the table, we gained a unique understanding about the potential impacts of advances in the five technology areas. Although time constraints prevented the participants from delving deeply into any one technology, this approach produced innovative insights and identified many potential convergences. The goal of the conference was met thanks to the intellectual depth and flexibility of our invited guests.

US Government officials held a separate Conference on 2025 Technology Implications on June 18, 2008. Technical experts from across the government assessed the potential impacts of the technology advances described in this report. Their conclusions and judgments are classified.

Appendix III: Technology 2025 Participants & Acknowledgements

Prepared by Toffler Associates®

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In collaboration with the

National Security Agency Signals Intelligence Directorate
Signals Intelligence National Intelligence Officers (SINIOs)

Office of the Director of National Intelligence (ODNI)
Assistant Deputy Director of National Intelligence for Strategy, Plans and Policy

National Intelligence Council (NIC)
The National Intelligence Council sponsors workshops and research with non-governmental experts to gain knowledge and insight and to sharpen debate on critical issues.

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*nano*Science and Technology Studies Group

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Plus the assistance of hundreds of individuals across industry, academia and other government agencies who participated in outreach sessions, the Tech 2025 conferences, and numerous interviews and discussions.

notes

[1] See appendix for Technical Readiness Level definitions

[2] One Laptop Per Child is a non-profit organization with the mission of developing an "ultra-low-cost, powerful, rugged, and versatile laptop" (the XO) designed especially for children, to be sold to governments in developing nations for distribution to children

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[77] Tech 2025 Conference Participant

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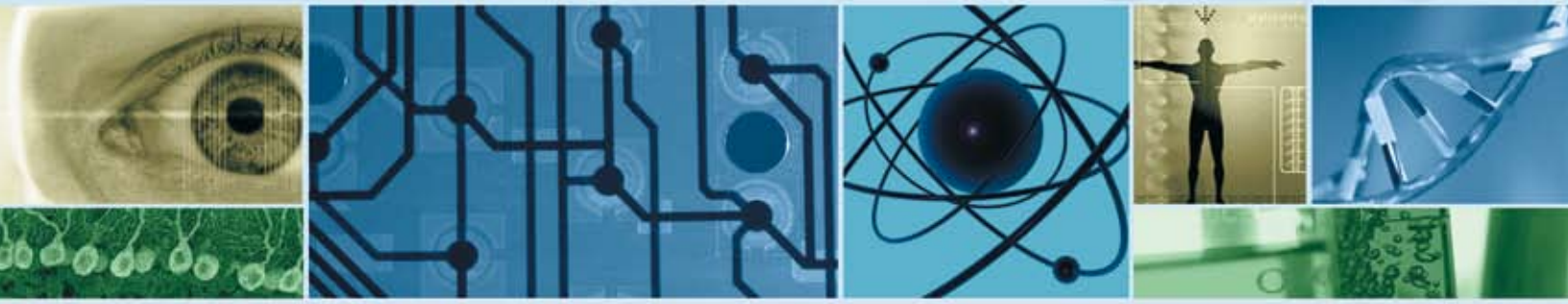

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