CHAPTER 6

Emerging Technology Prospects

Technology has long been considered the main driving force in economic development, but today's "technology revolution" is literally changing the world with phenomenal rapidity. Capital is being replaced by knowledge, and knowledge is thought to comprise the "infinite resource."[308] With the onset of this knowledge-based economy, the labor force in modern nations is busy using powerful information systems to create various forms of new knowledge and applying it to solving life's problems. The decoding of the human genome, for instance, was made possible by employing a dozen supercomputers to manage the 3 billion bits of information in the DNA molecule. Progressive corporations have become "knowledge enterprises" in which 70% or more of their assets are knowledge in various forms. For the first time in history, knowledge—the very heart of scientific and technological advances, innovation, and productivity—is being harnessed systematically on a massive scale.

The result is that breakthroughs are appearing everywhere. We can now realistically envision hybrid cars that double fuel efficiency while reducing pollution; fuel cells that promise to replace oil with hydrogen; genetic control over the process of life itself; computer power that is cheap and abundant; mobile communications at lightning speeds; robots acting as servants and caregivers; and so much more to come. This technology revolution is still at an early stage, but the potential for acquiring new forms of knowledge to solve environmental and other problems is so vast that it is limited only by human imagination and will.

While most technological advances originate from the developed nations, the forces of globalization are more closely integrating science and technology into the developing parts of the world like Asia and the Pacific. The PRC, India, Japan, Singapore, and others in the region have become active players in scientific research and commercial development. For instance, Japan is the world's leader in consumer electronics, robotics, and hybrid cars. The Republic of Korea has the globe's most advanced Internet system. Singapore has the world's most sophisticated information infrastructure. Studies confirm that Asia is beginning to rival Europe and the US in patents, scientific publications, and technology in general.[309]

This chapter provides an overview of progress in eight broad fields covering the entire span of scientific and technological innovation: manufacturing and robotics, transportation, the Earth system, space, information technology (IT), e-commerce, medicine and biogenetics, and institutional change. For most fields, the emerging capabilities of three or more of the most "strategic" technologies are summarized and their future prospects for economic development and environmental improvement are evaluated. In all, 44 technologies are reviewed representing major applications based on the underlying capabilities in information systems, biogenetics, nanotechnology, and other common scientific fields, so various combinations often appear. The technologies selected are hardly exhaustive, but they focus on the breakthroughs likely to exert the greatest influence in the years ahead.

The study method uses a "strategic analysis" that draws on a wide range of sources to summarize the state-of-the-art in each technology, focusing on trends and breakthroughs that are likely to advance progress as well as obstacles along the path. Where information is available, data points and examples are offered on the present use and future growth of each technology. Results of a technology forecasting system—TechCast[310]—are also included to estimate when each technology is likely to enter the mainstream, usually defined as a 30% adoption level, and the anticipated economic potential. In cases where indications differ, the ambiguity is resolved by integrating the diverse information into a reasonable synthesis termed "best forecast."

EVALUATING EMERGING TECHNOLOGIES

From previous technological revolutions—such as the progression from animal power to the internal combustion engine over barely more than a decade— observers have consistently noted that technology is a two-edged sword. For every problem that technology solves, it seems to spawn a new one, often when it is too late to withdraw. There are very few instances in human history—such as Japan's rejection of guns in the 17th century and Europe's current ambivalence toward genetically modified food products—where societies have systematically decided not to adopt a new technology. Accordingly, this report notes the generic environmental problems that may "co-evolve" with the technology revolution and indicates where additional investigation may be needed. Such warnings are believed necessary to counter the ever-hopeful technological optimists who believe that business need not worry about pollution or ecosystem destruction as new technology will make all past environmental concerns obsolete. However, evaluating technologies that are still rapidly evolving also poses some real challenges.

As an example, USEPA has developed guidelines for evaluating emerging technologies in the chemical industry.[311] The evaluation system, called "cleaner technologies substitute assessment," is adaptable to other forms of technology assessment. There are six main components:

(i) process information: physical and chemical properties, manufacturing processes and product formulation, environmental fate, human health hazards, environmental hazards, process safety, market information, international trade issues;
(ii) risk: workplace practices and source release assessment, exposure assessment, and risk characterization;
(iii) competitiveness: regulatory status, performance assessment in meeting functional requirements, and cost analysis;
(iv) conservation: energy impacts and resource conservation;
(v) additional environmental improvement opportunities: pollution prevention opportunities and control technology assessments;
(vi) choosing among alternatives: risk, competitiveness, and conservation; social benefits and costs assessment; and decision information summary (essentially advantages and disadvantages).

UNEP's Production and Consumption Branch also has developed an environmental technology assessment (ETA) to help decision makers understand the likely impact of the use of a new or existing technology. ETA is used to identify technologies that are compatible with sound environmental performance by providing information so that potential environmental problems and costs can be identified and avoided from the outset. The key elements of ETA are the following:

(i) description of the technology: the goal it is intended to satisfy, the characteristics of the technology, and the key stakeholders;
(ii) assessment of the environmental pressure and impacts of using the technology: resources, labor, infrastructure, and supporting technologies required;
(iii) evaluation of environmental risks and significance of the impacts;
(iv) comparative assessment of alternative technologies;
(v) recommendations on technology choices.

In the European Union, transport options were assessed by the project titled Forecasting and Assessment of New Technologies and Transport Systems and their Impacts on the Environment (FANTASIE).[312] The technique used for forecasting involved a hierarchical approach building up from basic technologies and technology applications to vehicle concepts, then transport concepts, and finally transport systems. After several false starts that proved too complicated, the assessment essentially opted for a simple multi-criteria analysis based on expert judgment.

The technology assessment in this report attempts to combine aspects of these approaches, albeit in a fairly unstructured manner. Nevertheless, where significant environmental implications are identified, the lack of a rigorous impact assessment is noted and more extensive and rigorous analysis, including considerable public input, is warranted.

Manufacturing and Robotics

Mass customization: Progressive companies are using "virtual integration" to respond quickly to an explosion of diverse tastes while reducing costs. By taking customer orders online via the Internet and using automated production methods, manufacturers can eliminate sales outlets, salespeople, inventory, production work, and other "industrial age" functions. The result is higher quality, lower-priced customized goods delivered in days while earning greater returns for investors. "Mass customization will proceed with gravitational force," said Alvin Toffler, a renowned futurist. "People desire greater individuality as they become more affluent and technology now allows it." A leader in this field also has predicted that, "…mass customization will be as important in the 21st century as mass production was in the 20th."[313]

As of 2004, total online purchases were only about 6% of retail sales. Not all of this is customized, so mass customization is still considerably below mainstream usage for various reasons. Business practices remain cumbersome, and sensitive issues are involved such as threats to the privacy and security of customers buying online.

But the underlying technologies that support customization—e-tailing, more powerful IT systems, broadband, and computerized manufacturing—are all expected to reach critical mass by 2010. Companies are currently selling customized personal computers, jeans, shoes, cars, bicycles, and other goods in different colors, sizes, materials, and options to suit different tastes. Mass customization is also used to offer a diversity of financial services, interactive TV, music, hotel services, and other intangibles.

TechCast estimates that mass customization will reach the 30% "mainstream" adoption rate and a potential global market of about $250 billion by 2012. A variety of forecasts point toward 2010–2012 as the take-off period when mass customization is likely to reach mainstream use in developed countries. Because this technology applies to everything from toothpaste to services, it should have a dramatic impact on economies, spurring growth, paring costs, satisfying needs for convenience, and reducing environmental impacts through everything from lower paper use to a wide range of other efficiency gains in production and transport.

Micro-machines: Tiny machines with micro-electro-mechanical systems (MEMS) are made using the same photolithography method that creates silicon chips. MEMS are used successfully for air bag actuators, digital light processors, optical switches, and other applications. Research on MEMS is supported by 600 organizations in business and government, and it is still growing. We are now at the threshold of what one scientist has called "a second silicon revolution."[314]

Although micro-machines were originally thought of as simply smaller versions of full-scale machines, the parallel advance of nanotechnology (see below) and bioengineering is creating a far greater spectrum of possibilities. "Hybrid" versions of MEMS, often combining nanotechnology and biotechnology features, are used to form clever arrangements of atoms that perform machine-like tasks. All these technologies are rapidly converging to form fully functioning, intelligently controlled microscopic machines—tiny robots—the size of a grain of rice, or even a speck of sand or a microorganism. This is the real race to the bottom.

As our ability to manage the world of the infinitesimally small expands, the range of applications is also growing to encompass a variety of new medical treatments, small control devices, sensors, and endless other uses. For instance, MEMS may be used to cleanse the human body of dangerous cells, to create clouds of "smart dust" able to perform intelligent tasks, and to form networks of sensors that communicate with one another. Estimates put the Japanese MEMS market at roughly $2 billion by 2010, and the global market is expected to increase from $13 billion in 1996 to over $34 billion by 2020.[315] TechCast estimates mainstream use by 2016, producing a global market of $65 billion. The best forecast is that MEMS are likely to become widely used about 2015 with a global market of $25 billion, maturing at $60–$70 billion later.

Nanotechnology: The "nanosphere" consists of objects measured in one billionth of a meter and is now undergoing a revolution as research increasingly yields control over this tiny world. Nanotechnology products currently available include non-stain fabrics, organic light-emitting diodes, nanocomposite materials, nanoemulsion cleansers, nanoscale paints, TV screen coatings, and various industrial processes, and many more specialized and exotic applications are emerging.[316]

The original concept proposed by Drexler[317] outlined how nanomachines, themselves built from atoms, would assemble individual atoms to compile any physical object. That idea now seems limited by physical constraints at the atomic level and is being challenged by other scientists.[318] Instead, much attention is now focused on using carbon nanotubes (elongated Buckminsterfullerenes or "Bucky-balls"), which are carbon molecules with unusual properties. For instance, nanotubes have 100 times the tensile strength of steel at one-sixth the weight, which provides a 600-fold increase in strength-weight ratio. This feature is so extraordinary that it has made the old vision of a "space elevator" feasible. Scientists at Los Alamos Laboratories are designing a satellite that will orbit roughly 100,000 kilometers above a fixed spot on the equator connected to the Earth with a thin film of carbon nanotubes 1 meter wide.[319]

The idea that virtually any type of extraordinary item can be made by manipulating matter at the molecular level has the entire world fascinated. Governments, companies, and venture capitalists pumped $6 billion into nanotechnology research in 2003 alone, producing daily breakthroughs.

The medical applications are particularly promising, based on the ability to control matter at such fine detail. The National Cancer Institute and NASA are funding a $12-million-a-year program to develop "nanosensors" that will monitor the body for problems like cancer and automatically repair damage. The US National Science Foundation estimates that half of all medical treatments and drugs could be affected by nanotechnology. Given the size of the global health care market—measuring several trillion dollars per year—such applications alone will ensure the future of this technology and its many benefits.

One of the largest applications may lie in expanding the power of computers. In addition to their great strength, nanotubes can carry electricity 100 times faster than silicon, can form far smaller transistors, and can spontaneously assemble into precise formations free of error, much the way crystals form. At least two firms are introducing nanotube memory chips that store terabits of data per square centimeter, about a million times the current data densities.[320] If these early examples prove effective, nanotechnology could be a leading candidate to extend the power of computers beyond Moore's law, which is expected to run into physical limits soon.

At least 3,000 nanotechnology patents have been filed since 1996, and the National Science Foundation expects nanotechnology to grow into a $1 trillion market worldwide by 2015.[321] Others estimate the potential market at $1 trillion–$2 trillion when it mainstreams by 2010–2015. TechCast studies forecast nanotechnology to be used in 30% of all products by 2018, plus or minus 6 years. We conclude that nanotechnology is likely to reach mainstream use about 2015, but there is a wide variation in this forecast ranging from 2010–2020. The potential annual market by that time is likely to be in the trillion-dollar range.

Smart robots: Simple versions of mass-produced mobile robots are already used today for manufacturing, delivering mail, vacuuming floors, mowing lawns, and other routine tasks. In 2003, there were over 600,000 personal service robots in households around the world (mostly robotic vacuum cleaners), with 4 million new units projected to join them over the following 3 years.[322] In addition, approximately 800,000 "dumb" robots now work in factories around the world, performing repetitive tasks such as welding and assembly. As computer power, artificial intelligence (AI), and other enabling technologies mature, "intelligent" versions are rapidly being developed that run, walk and climb stairs, speak with humans, and perform complex tasks. Governments and corporations around the world are pouring resources into this new field, and the rate of progress suggests that truly capable robots are likely to serve important roles in industrial work, home services, health care, military, and leisure activities within 5 to 10 years.

The technical challenge is unprecedented, of course. Smart robots require acute sensory devices to understand their environments, speech recognition software that allows accurate and comfortable machine-human conversations, the intelligence to learn and make better decisions, and even to understand and respond appropriately to emotional displays. This requires a high level of AI, a field still in its early stages of development.

Japan leads the industry, primarily because robot pioneers see huge potential in assisting modern societies with aging populations and a shortage of caregivers. Robots are expected to play a personal role as companions for the elderly, providing comfort, reminding them to take medications, and altering authorities if they are in crisis. Today, there are five workers for every senior citizen in OECD nations. By 2020, the ratio will decrease to 3 to 1. In Japan, it will be 2 to 1. Consumer surveys suggest that most people can accept robots in their homes easily, often with enthusiasm.[323] The Government of Japan has provided generous funding for research into AI and humanoid robotics, and Japanese corporations are making rapid advances in this field.

Another driving force in robotics is the military. The American military, for example, has awarded $154 million in research grants to turn all nascent technology into a battlefield package. They are supporting robotic, unmanned tanks, land cruisers, and aerial vehicles, all linked by intelligent sensors and data networks. By the end of this decade, the US could be sending fully functional robotic warplanes into battle with the ability to identify targets and make corrections as the situation changes, and robot soldiers also are in the works![324]

The health care industry is gearing up to serve millions of patients using robots to carry sick people, take temperatures, and draw blood. Most humans lack the ability to be consistent, reliable, and precise and to perform repetitive chores and exert great strength—exactly the tasks at which robots excel. It is these human weaknesses (such as mildly shaky hands) that may make robotic arms increasingly used in complex surgery. For instance, the Da Vinci Surgical System, already in use, is a high-resolution 3D telescope with robotic arms that are inserted into the patient through small incisions.[325]

At the University of Illinois, researchers believe that robots should get out of the factory and onto the farm. Instead of using high-powered, gas-guzzling tractors to weed crops, destroy bugs, take soil tests, or harvest crops, an army of AgAnts communicating with each other and covering the entire field will achieve the same functions and consume less energy. Pesticides could be delivered to plant surfaces in precise doses instead of from airplanes or spray booms that result in drift and wastage. Perfecting farmbots on Earth may also create the technology needed for "terra-forming" on other planets, making them suitable for human occupation. Gastrobots have been suggested that could munch on vegetation, or even flies, as they strive to derive their fuel supply from a microbial fuel cell.[326]

Today's robotics industry is simply a logical outgrowth of the age-old human drive to extend the power of our limited bodies by making machines that are stronger, faster, more agile and precise, and less vulnerable. These unique advantages make robots almost certain to be used where humans cannot perform or are subject to great risk: fire, cold, darkness, radiation, long waits, etc. All these traits suggest robots have a big future in the hostile environments of heavy industry, construction, mining, warfare, and space.

A renowned robotics authority sketched out how this wave of progress is likely to advance. By 2006, 2.1 million robots will be sold as everyday tools to perform routine tasks. By 2010, the boundary between humans and machines will be breached in ways unimaginable to most people today, much as the World Wide Web did 10 years ago, making robots as common as personal computers (PCs). By 2015, one third of all US military vehicles are likely to be unmanned. By 2020, robots should be able to learn and make choices without reprogramming. By 2025, the robot market is likely to exceed the automobile market.[327] TechCast estimates mainstream use at about 2018, with a global annual market potential in the trillion-dollar range.

Intelligent materials: "Intelligent" materials are appearing that offer interesting possibilities for reacting to their environments in adaptive ways. For instance, aircraft wings are being designed that sense and dampen aerodynamic flutter at high frequencies, and other materials control stress in bridges and buildings. Plastics change shape on command, and other materials react to electricity, heat, solar energy, and magnetic fields. Polymers offer advantages in surgery, high-performance textiles, and self-repairing components in vehicles.[328]

Intelligent structures require sensors, some form of decision-making system, and actuators so they can respond to changes in their environments. Advances in micro-machines, AI, biotechnology, nanotechnology, and microcomputers are, however, giving even ordinary materials intelligent features. Some of these systems involve tiny electromechanical devices while others rely on chemical responses.

For instance, "electronic paper" composed of a layer of tiny half-black, half-white balls can display electronic images in real time. Intelligent gels and aerosols are used to control pacemakers and drug delivery systems. Surgical sutures can morph into perfect knots in response to the patient's body heat. Plastic polymers can flex and relax, like artificial muscles that boost the power of soldiers, astronauts, and robots. Sensors in bricks and walls can monitor a building's temperature, vibration, and movement. Clothing can generate electricity as the sun's energy falls on a person's back. Smart plastic labels with radio frequency identification (RFID) tags can trigger warnings and send signals.

The only forecast available for this field is TechCast's estimate that 30% of products will use intelligent materials by 2019, eventually producing a mature market of $94 billion. This is a somewhat exotic technology with valuable but limited applications, so the TechCast data appear reasonable.

Environmental Implications of Expected Advances in Manufacturing and Robotics

Most of the technologies in manufacturing and robotics will help to dematerialize production processes. If minimal raw material can be mined, processed, shipped around the world, and fabricated into products, the outcome clearly will be positive for the environment. For example, some of the possible uses of nanotechnology to positively address current environmental concerns include the following:[329]

(i) better catalysts and solid electrolytes for fuel cells which can use fuels other than hydrogen at ambient temperatures;
(ii) super-strength materials in turbines and wind-generation units subject to storm damage;
(iii) high-performance capacitors and batteries that would complement solar energy systems;
(iv) continued miniaturization (such as continuing the trend from vacuum tube to transistor to microchip) to reduce the use of materials and in information and communication technology progressing toward the paperless office;
(v) passive energy systems such as electrochromic windows that darken automatically as the intensity of sunlight increases;
(vi) thermo-electric devices for geothermal energy production;
(vii) improved ion exchange resins for extracting minerals from waste streams;
(viii) bio-waste as feedstock for the chemical industry.

In December 2003, the joint Royal Society and Royal Academy of Engineering Nanotechnology Working Group in the UK conducted a workshop on the environmental applications and impacts of nanotechnology. Possible positive environmental benefits noted by the participants included (i) the production of paint requiring little or no solvent; (ii) energy-saving applications including infrared reflection to reduce heat loss; (iii) reduced traffic congestion through better sensors and communication technology; (iv) reduced chemicals used in agriculture; (v) improved desalination and filtration; (vi) bioremediation using nanosensors to detect pollutants; and (viii) more precision with catalysts, for example, in fuel cells. Few negatives were noted, although the possible interaction between microbes and nanoparticles does need more research. It was also noted that there are already many nanoparticles in pollution (such as from diesel exhaust fumes) although this is no justification for adding to the load.

The environmental impacts of the expected phenomenal growth in robotics illustrate the dual-edged sword nature of all technological advances. Robots will be able to work in environments where humans should not (e.g., bomb disposal, clearing mine fields, cleaning up contaminated sites, vacuuming up asbestos fibers, painting cars in enclosed spaces, etc.). They will extend the frail powers of humans to restore degraded environments by becoming extensions of our own capabilities and senses (e.g., doing repetitive jobs like cloning plants using tissue culture, conducting continuous monitoring of polluted environments, and even replanting forests). Replacing humans in the workforce may be beneficial, if more interesting and less risky jobs are available to the displaced workers.

However, as glorified computers with arms and legs, robots at the end of their useful lives will face the same disposal issues as the current e-waste problem in developing countries. Hence, it will be important to ensure that recycle-ability is built into the design of robots, as is being done for modern automobiles. Robots will also be major energy users, so renewable energy developments such as gastrobots that would power themselves from waste products processed in fuel cells are important.

Transportation

Automated highways: A conceptual model of automated highways able to control speed, steering, and braking has been developed over the past few years to make more efficient use of existing road networks. Vehicles equipped with special sensors and wireless communication systems would travel over electronically equipped lanes under computer control at closely spaced intervals, perhaps in small convoys or platoons. Although little government support is provided in the US, the EU and Japan are actively pursuing the concept as a way to better manage vehicular traffic.

There certainly are ample traffic management problems to be addressed. Auto congestion in the US consumes five billion hours of delay and productivity losses of $50 billion each year. Highway crashes cause 40,000 fatalities and 5 million injuries annually, costing an additional $150 billion. Similar levels of congestion pervade Asia and the Pacific, and the problem is expected to double by 2020.[330] Building new highways is expensive and intrusive, so automating existing highways offers a potentially cheaper, faster, and possibly safer approach than the continual expansion of endless roads. Automated highways cost less than $6,000 per kilometer, compared to $600,000 or more for 1 kilometer of new highway, and studies indicate that automation would double or even triple highway capacity.[331]

There are doubts about reliability, of course. Technical feasibility has not been proven beyond a few laboratory and controlled test track demonstrations. In one test, cars traveled at high speed—bumper to bumper—with no help from drivers. Carmakers are starting to incorporate navigation, global positioning systems, cameras, crash-avoidance radar, and intelligent cruise-control systems into their luxury models, and they should become far cheaper and easier to use.

Hybrid cars: Under the leadership of Japanese carmakers, this first alternative to the internal combustion engine has been so successful that it seems likely to revolutionize car design. Hybrid autos are powered by a small gasoline engine operating only at high speeds where it is most efficient while a battery powers the vehicle at lower speeds. This results in huge fuel efficiency gains and reductions in pollution. Electric motors drive each wheel, and regenerative braking conserves energy.

Hybrids were more costly at first, but Toyota's second Prius model is comparable to a Camry in size, price, and performance and has a high-tech style that many buyers prefer. The company is building versions for most of its other cars. Ford is planning to build 1 million hybrids by 2007.[332]

The CEO of Ford Motors thinks hybrids could make up 75% of the car market by 2025. The director of global forecasting at J. D. Powers thinks, "…sales should increase dramatically as more hybrid vehicles are built," and a Japanese auto executive has predicted that, "…companies will start earning returns in 3–5 years." A German auto executive warned, however, that, "…internal combustion engines will still have 95% of the car market in 2015 and 85% in 2025." TechCast expects hybrids to reach the 30% adoption level by 2013. Integrating these estimates suggests a best forecast of 30% adoption by 2015, which would easily translate into a global market in the trillion-dollar-range. Hybrids are likely to be a transition technology leading to fuel cells, however, as discussed below.

Fuel cell cars: With the realization that a revolution in transportation design is imminent, the entire auto industry is pouring billions into research on fuel cells, developing test vehicles, and reducing costs through mass production. Fuel cell cars are considered the logical follow-up to hybrids, because both types are similar in many ways. Hybrids and fuel cell cars both use electric motors to drive wheels, batteries to store energy, regenerative braking to conserve it, and may in time use composite bodies that are lighter. Amory Lovins, the well-known authority on sustainable development alternatives, is developing a "hypercar" along these lines with even more advanced features, and expects to be able to increase fuel economy by a factor of 10.[333]

Fuel cell autos are still uneconomical, because the cost of the fuel cell system is estimated at $30,000, to say nothing of the cost of hydrogen. Methods for extracting hydrogen are still being developed and are not yet commercially feasible. These are partly driven by concerns for safety from the risk of hydrogen combustion in a crash. Some contend that hydrogen should be extracted from oil-based fuels as needed rather than stored on board, which also would solve the problem of safety. One method developed in Canada uses a canister to store hydrogen as a hydride, which can be exchanged at fueling stations, also solving the safety problem. The drive to create this promising new market is bringing forth creative solutions, including the use of nanotechnology and cheap plastic photovoltaic cells to split water into hydrogen cheaply. Wind power and other renewable energy sources are also planned for making hydrogen commercially widespread at low cost.

The range of development activity currently underway is impressive. Japan is planning to have five million fuel cell cars in use by 2020, while Germany's Daimler-Chrysler thinks costs will match conventional cars by 2010. General Motors is committed to the technology and hopes to become the first carmaker to sell one million fuel cell cars.[334] One authority on fuel cell autos concluded, "Conventional wisdom is that fuel cell vehicles will progress by 2010 to where hybrids are today, selling hundreds of thousands per year."[335] TechCast estimates fuel cell cars will make up 30% of new car sales by 2022, eventually creating a global market that may reach several trillion dollars.

Maglev trains: Maglev trains that run at speeds of 500 kilometers per hour or more have been tested and debated for decades, but the PRC's introduction of the world's first commercial train in Shanghai may well determine the future of this technology.[336] With a long history of conventional high-speed trains, Europe and Japan have been developing maglev trains for years as a more convenient alternative to short flights between large cities. Maglev uses one third as much energy as conventional rail and 70% less energy than conventional high-speed trains and airplanes.[337] Such trains are less polluting than aircraft, provide immediate access to city centers, and are more comfortable because they ride on a cushion of air.[338]

Critics claim there is little advantage in speed and the costs are too high. Conventional trains are reaching speeds close to maglev, while maglev costs are estimated at $30 million–$50 million per kilometer of track. Some experts believe there is no reason why it has to be more costly and that maintenance and operating costs are actually lower. An improved version called "inductrack" uses passive magnets rather than electrically generated fields, and it also is less expensive to build, maintain, and operate. This controversy is reflected in widely varying degrees of official support across the world. Britain, Germany, and Japan are canceling maglev projects for various reasons while Los Angeles City and the US Department of Transportation are starting demonstration projects. The maglev system in the PRC is popular, but it is subsidized by the government and losing money.

TechCast estimates 30% of heavy traffic corridors in industrialized nations are likely to use maglev trains by 2032 and that the global market should be roughly $85 billion.

Hypersonic planes: The supersonic Concorde may be yesterday's technology, but the prospect of hypersonic flight is alive and well as the global economy increasingly requires people to fly across the world. Despite brilliant advances in IT that will soon make global communications exceedingly vivid and useful, the fact is that travel demand is not lessening but continues to grow, albeit augmented by other technologies.

A new generation of hypersonic planes is being planned with lightweight, highly reliable scramjet engines that suck in oxygen from the atmosphere at high speeds to be burned with hydrocarbon fuels. Hypersonic planes are also considered attractive as inexpensive space launch vehicles. NASA recently flight-tested its scramjet plane at Mach 10. Governments and corporations are gearing up to deliver these vehicles over the next decade or two, potentially making it possible to reduce flying time from Asia to the US to 3 hours.[339]

Some experts think long-duration hypersonic flights will become common within the next two to three decades. TechCast forecasts they will be used for 30% of long flights by 2030, producing a global annual market demand of $55 billion.

Small aircraft: Although the idea that people would fly to work in private aircraft sounds outrageous, this is now a reality for many people, and it could sweep through modern society. Two trends make it possible. Costs of owning small aircraft are falling dramatically, and technology now makes piloting a small plane almost as easy as driving a car. This is the reason why sales of helicopters and personal jets are soaring in many countries, and trends suggest it may increase to the point of rivaling commercial travel.[340]

The prospect of endless small aircraft flooding the skies certainly would require an overhaul of air traffic control systems. How would thousands of flights in metropolitan areas be controlled? The US Federal Aviation Administration has been experimenting with "free flight" rules in which aircraft are equipped with global positioning, radar, and collision avoidance systems, so they can monitor their location vis-à-vis other aircraft and maintain safe distances. The administration finds that free flight can be safer than controlled flight, and it can vastly increase the carrying capacity of the skies.

Inexpensive aircraft are increasingly available, and a growing number of busy people find them very convenient. A good helicopter can be bought for $150,000— not much more than an expensive auto. Operating costs have also dropped such that a typical helicopter commute to the office only costs roughly $10—again, about the same as driving a car. Air accidents have plunged 90% since the shift from propeller engines to jets, and some planes are equipped with their own parachutes that can float the plane down gently if necessary. Moreover, because today's small planes are easier to control and are equipped with global positioning systems, average people can learn to fly easily.

This may make sense to those who can afford it, but filling the air with an endless blur of small aircraft driven by ordinary people leaves disturbing questions unanswered. Will normal traffic congestion expand to create traffic jams in three dimensions? Are we prepared for the inevitable rise in the death toll from accidents? Do we really want to see fuel, oil, broken parts, waste material of all kinds, and other junk raining down from countless small planes? No forecasts are available, but the growing use of small aircraft is likely to spread despite these controversial issues.

Global shipping: Continued globalization depends on cheap shipping, currently threatened by high and rising fuel costs. This is a huge industry, roughly comparable in size to land travel, so many of the innovations in automotive propulsion technologies—hybrid engines, fuel cells, etc.—could benefit shipping in time.

The global marine economy was $1.1 trillion in 2000 (although this includes offshore oil drilling) and is growing at 3% per year. The largest sector involves the explosion of jumbo-sized cargo ships sporting mechanized systems for "roll-on and roll-off" of shipping containers, largely a result of globalization, with Japan and the Republic of Korea emerging as the dominant shipbuilders. A Japanese firm recently built the largest ore carrier in the world with a capacity of 300,000 tons. The demand for transporting goods by ship increased an average 13% per year along two main trade routes running from Asia to North America and from Asia to Europe. The PRC has recently emerged as a major source of exports to these markets.[341]

The industry is being transformed by many of the same new technologies revolutionizing all fields. Perhaps the most striking innovation is the dramatic impact of the sophisticated online IT systems that are increasingly used for everything from logistics to navigation to security. The concept of the "smart ship" or "intelligent bridge" has emerged in which total access to information is provided to support decision making by the ship's master, owners, managers, shippers, and port management. For example, US customs now requires cargo information to be electronically submitted through an automated manifest system (AMS) 24 hours before containers are loaded on vessels coming into the country. Large shipping companies now provide integrated online logistics management using global IT networks to search and track individual containers from order to delivery.[342]

Because oceans cover two thirds of the Earth, it is to be expected that ecological matters weigh heavily on the industry. A rising tide of microscopic plastic fragments thought to be discharged from ships now permeate most bodies of water, soaking up toxic chemicals that are believed to poison sea life. Tests conservatively estimate their number has tripled since the 1970s, and that marine species eat them readily.[343]

One promising idea involves ocean biomass carbon sequestration. Large regions of the oceans are deficient in the micronutrients needed to support plankton, so it is proposed that ships disperse trace amounts of nutrients, mainly iron, to support plankton blooms. The plankton absorbs carbon dioxide and then sinks to the seabed in weeks to become a permanent part of the Earth. The enormous potential of this concept is noted by the fact that 2,000 gigatons of carbon are contained in the world's forests and landmass, whereas the oceans hold 60,000 gigatons.[344]

Environmental Implications of Transportation Technology Advances

This evaluation draws heavily from the EU's FANTASIE report, published in 2000. The study examined a six-level hierarchy of the transport system, building up from base technologies to transport systems, four growth scenarios, five problem areas (urban passenger transport, urban freight transport, rural passenger mobility, interurban passenger transport, and interurban freight transport), as well as four time frames (out to 2030).

Telematic technologies that include automated highways are regarded as positive for the environment and for safety and efficiency, and they have socio-economic benefits.[345] While there is no doubt that fuel cell technology and hybrid vehicles will reduce local emissions, the ultimate impact depends on the fuel and technology combination chosen and rate of infrastructure development. Full LCA is needed to determine the contributions to resource use and GHG emissions. Thus, fuel cells will surely improve local air quality and reduce urban traffic noise, and regardless of the fuel source chosen, fuel cell efficiency will be about 50% greater than a 1995 petrol engine. Mining, processing, and disposal of catalysts may also be negative for the environment. Private vehicles will still pollute with rubber particles from wheels and bushes, grease from moving parts, plus the inevitable problem of collecting used car bodies for recycling from remote areas and island nations.

Hybrid vehicles linked to fuel cell deployment will enable substantial reductions in resource use, zero emissions in urban areas, and reduced traffic noise. Advanced conventional propulsion systems, followed by fuel cells and hybrid technology combined with lightweight new materials, reduced aerodynamic drag and friction, will gradually improve air quality as the older vehicle fleet is slowly replaced. Nitrogen oxides and particulate emissions in urban areas are projected to fall in Europe to about 14% and 31% of 1995 levels, respectively by 2030 mainly due to the adoption of a highly efficient all-purpose car. Unfortunately, without some form of financial incentive, these new technologies are likely to lead to higher manufacturing costs, and hence, higher cost to the user.

In the small aircraft field, tilt-rotor helicopters that combine the functionality of helicopters and fixed-wing aircraft are more fuel-efficient and offer considerable noise reduction in urban environments. High-speed rail such as maglev trains have a high electricity demand, and if that electricity is generated from fossil fuels, then the technology has a high environmental impact that must be compared to that of the next-best transport alternative. Close to the rail lines, high-speed trains may also increase urban noise. Supersonic/hypersonic aircraft are unlikely to be accepted because of strongly negative environmental impacts, including carbon dioxide emissions and noise.

Rather surprisingly, some of the environmental impacts not detailed in the FANTASIE report include the indirect negative impacts associated with creating the infrastructure for new transportation systems and to meet growing demand. These include (i) fragmentation of forest areas by road and rail routes; (ii) death and injury of slow-moving wildlife crossing high-speed roads; (iii) soil erosion during construction of road, rail links, and airports with consequent reduction in water quality and siltation of streams and estuaries; (iv) increased risk of hazardous and toxic waste spills as traffic volumes increase; and (v) reduced aesthetics of rural landscapes crisscrossed by transportation infrastructure. These indirect impacts will be particularly important in Asia and the Pacific, where most of the basic infrastructure has yet to be constructed.

Natural Resources

This large field encompasses all those technologies affecting the Earth as an integrated large system: energy, farming, mining, environment, weather, etc. They are combined in one field as many sustainable development alternatives will hinge on breakthroughs in these areas some of which can already be glimpsed.

Alternative energy: Carbon-based fossil fuels presently supply 78% of all energy use; alternative sources include hydro-electricity (6%), biomass (8%), nuclear (6%), and wind and solar (2%). Renewable energy (excluding nuclear) totals 16% and alternative energy is 22%. Hydro electricity is unlikely to grow much further because most rivers are fully exploited and any new dams are controversial, so further growth must come from wind, solar, biomass, and nuclear fission (which remains too distant to be considered here).

Many claim that carbon fuels are still plentiful because new fields and methods are constantly being discovered. The US Geological Survey and the Department of Energy estimate world oil production will last until 2037. The World Energy Outlook 2004 suggests that about $1 trillion is needed for new investment in oil exploration and development to meet projected demand. Primary energy demand is projected to rise by 59% from now until 2030 with 85% of that in the form of fossil fuels. Two thirds of the new demand will come from the developing world, particularly from the PRC and India. The Executive Director of the International Energy Agency has commented, "This analysis shows very clearly that achieving a truly sustainable energy system will depend on technological breakthroughs that radically alter how we produce and use energy."[346]

There already are preliminary signs that oil is in decline. The same method that correctly forecast US oil production would peak in the 1970s now indicates global supplies will peak this decade.[347] The timing of the peak is important, because it means that substitutes must start taking a larger share of the increasing demand for energy once the peak is reached.

Some alternative fuels are now competitive, and further advances along with rising oil prices suggest that alternative energy supply is likely to increase substantially in the near future. Developing nations are starting to use large amounts of oil, which is one reason why prices have been driven up in recent years. Meanwhile, the cost of alternatives is dropping. Wind power now matches oil in cost of electricity production, which is why wind farms are appearing throughout the world.[348] The cost of solar photovoltaic cells is falling, and there are good prospects for cheap plastic versions that should soon make the technology economically viable.[349] Although nuclear power was considered taboo in much of the world from the 1970s onward, the looming oil crisis has resurrected interest. The PRC alone is planning to build 30 nuclear reactors.[350]

Hydrogen is enjoying global attention as a common carrier of energy, but (as noted above) methods for producing hydrogen affordably have to be developed. For instance, fresh water must be used for hydrolysis because the energy required to split seawater into hydrogen increases tenfold. A variety of methods is being developed to use solar energy to split water into hydrogen and oxygen, usually involving nanotechnology and cheap plastic photovoltaic cells. One method developed in England uses combinations of different solar cells to capture energy throughout the ultraviolet spectrum. Researchers think such a system on a garage roof could provide enough hydrogen to power a car 20,000 kilometers per year. Scientists warn that hydrogen could leak into the atmosphere and disrupt the ozone layer, while others note that producing hydrogen from oil and coal would continue to release carbon dioxide.

Overall, the use of alternative energy is growing at a rate of 30% per year.[351] As oil prices continue to rise and the cost of alternatives falls with further technical advances, it seems likely that the era of oil dependency will run its course in two to three decades. TechCast has completed two different studies that both converge on 2017 as the time when 30% of all energy will be derived from alternative sources.

Distributed power: Prominent failures of centralized electrical power systems have heightened interest in "distributed" power grids that are believed to be more reliable. The August 2003 blackout in the Northeast US was the fourth catastrophic failure of the power grid in a decade. It was followed in September of the same year by a blackout in Italy and another one in Scandinavia.

Distributed grids are organized as self-managed networks that can isolate failures in small areas, but they can also carry heavy loads for long distances. The concept is attractive because it can reduce transmission costs, the risk and severity of failures, and vulnerability to sabotage. This approach requires a fine network of small, local power sources, however, which takes a long time to develop. New home construction in developed countries often includes solar panels and other alternative energy sources, and it is increasingly common to allow people to sell surplus power to the grid.

Based on TechCast estimates and other forecasts,[352] we foresee that the amount of power derived from distributed grids is likely to increase from the present level of 7% to 30% by about 2021, plus or minus 5 years.

Genetically modified foods: A convergence of biotechnology and agriculture has created a new field of "life sciences" with huge potential for designing plants and animals that grow faster, resist disease, are self-fertilizing, and contain more nutrients—genetically modified foods (GMF) or GMO. There also are early signs that it may be possible to create foods—"neutraceuticals" or "therapeutic foods"—that enhance natural ingredients to alleviate chronic illness. For example, the tomato plant has been genetically engineered to produce anticancer nutrients, and eggs have been modified to produce cholesterol-lowering substances.

Progress is slow at present due to fear of manipulating such basic functions as the code to life. A majority of Europeans reject the concept causing stores to phase out GMF. Even in the US where the public seems complacent, one survey found 38% of Americans would use genetically altered food, while 56% would not. Producers do not yet label GMF as such which concerns many people.

In poor regions of the globe, however, population growth on limited farmland will require huge increases in crop yields to feed a projected increase of 3 billion even as hunger continues as a serious problem. Many current technologies use genetically engineered strains such as drugs (insulin) and enzymes (yeast), so the concept is not new but rather a matter of application on a vastly larger scale.

More rigorous testing is underway to examine safety concerns, and accurate labeling is needed before public trust will allow this sensitive technology to expand. Nevertheless, more than half of all US corn, soybean, and cotton crops already use genetically altered seed, and Britain approved its first use of GMF recently, which was considered a pivotal event. Within 5 years, 10 million farmers in 25 nations are expected to plant 100 million hectares of GMF crops.[353] Given the politically charged nature of this technology, it is hard to forecast when GMF will enter mainstream use.

Sustainable cities: Urban areas around the globe are reeling from population growth, congestion, higher energy costs, pollution, and the need to attract business by becoming congenial cultural attractions. To stave off disaster, many governments and their citizens are defining a new model of "sustainable cities" to manage these rising forces.

For example, the government of Sydney, Australia is engaging leaders from all segments of society to plan a 30-year strategy for making the city "bigger, greener, and sustainable." One element of the plan is to make the city more compact to ease transportation and energy use, while also absorbing a 20% influx of new citizens by 2020. Public transport is expected to relieve congestion while decreasing energy use and pollution. The need for more power is to be provided by solar cells mounted on roofs of homes and offices and by improving energy efficiency. [354]

Technical innovations are also emerging to help. A new type of paint that soaks up noxious vehicle exhausts is now available in Europe. Made of a silicon-based polymer that last 10 years, dangerous gases like nitrous oxide enter the paint, where they combine with nanoparticles of titanium dioxide to produce nitric acid that is washed away by rain. When tested in Milan, air pollution dropped 60% and residents said it became noticeably easier to breathe. [355]

Progressive corporations also are choosing to build sustainable office buildings and other facilities because "green design" is proving to be less expensive in the long term. Ford rebuilt its largest factory by installing skylights and a "living roof" of sod that reduces toxins, boosts productivity, and saves money. Genzyme Corporation's new headquarters has a sod roof, skylights, blinds, and uses waste steam for heating. New York City's football stadium was designed to use solar cells and wind turbines to reduce energy and sells excess energy to the electrical grid. In Malaysia, a new skyscraper uses louvered windows and sky gardens to cool air.

Various experiments are also advancing the science of managing urban ecosystems. Hyacinths are grown by the city of San Diego to treat sewage and are then used for fuel, animal feed, and paper. Disneyworld in Florida has demonstrated the feasibility of creating small shrimp farms that recycle sewage. Sunflowers have been shown to be capable of absorbing 98% of lead from a contaminated site, and the brake fern can absorb high levels of arsenic and thrive.

No forecasts are available, but as pressures cause city officials to consider alternatives, solutions of this type could easily grow to dominate the future of urban management.

Desalinization: Clean water supplies already are scarce in many parts of the world, and the problem is growing. Water use has increased sixfold worldwide over the past century, and half of the world uses unsafe water which causes five million deaths each year.[356] Fortune magazine has predicted that, "Water promises to be in the 21st century what oil was in the 20th century."[357]

Desalinized water was expensive in the past, but it is now becoming an economically viable option with improved technology and better management. Costs have dropped from $5/liter in 1950, to $1/liter in 1960, and they are now approaching less than $0.01 per liter.[358] New desalinization plant construction is expected to represent an investment of $70 billion over the next 20 years.[359]

Organic farming: Despite millennia of natural cultivation, organic farming is one of those promising fields tainted by the disinformation that it offers unrealistic, altruistic claims. The use of increasingly sophisticated chemical fertilizers and pesticides doubled yields over the past 40 years while reducing costs by 40%, so some fear that abandoning these methods will again restrict output.

However, advocates of organic farming contend that chemical fertilizers and pesticides destroy microorganisms in the soil and develop resistance in pests, creating a vicious cycle in which yields drop in time and costs increase as more chemicals are needed. One study found that chemical farming has degraded soil on 40% of the world's farms, and 10 million hectares of land are lost to farming each year.[360]

Another analysis shows that organic farming can use less energy, maintain high crop yields, improve the soil, produce higher profits, reduce drought and erosion, and protect the environment.[361] Many corporate giants are now embracing organic methods, which has added credibility to the technology, and opinion surveys in the US and Europe show that 90% of the public favors organic produce. These trends have caused the organic food market in North America and Europe to grow at 30% per year. As the middle class from Asia and the Pacific expands and consumes and pays greater attention to what they eat, the market in this region also can be expected to grow rapidly.

TechCast studies estimate 30% of farmland globally is likely to be cultivated using organic methods by 2020.

Precision farming: Precision farming involves the computerized control of irrigation, seed, fertilizer, and pesticides to suit variations in land, as guided by global positioning and other information systems. Farmland differs enormously in its grade and fertility; this approach allows farmers to optimize treatment of the soil as it varies meter by meter while minimizing use of labor and resources. Some aspects of precision farming have been growing for years because farmers find it helps reduce the cost of chemical inputs, raises yields, improves crop rotation management, reduces soil compaction, and increases land value.[362] The development of robots (farmbots) discussed earlier will accelerate this technology.

The initial cost is expensive for many farmers, the knowledge needed is daunting, and it also is not clear which technology, soil types, crops, and other conditions work best.[363] These requirements make the practice best suited to large corporate farms that have the investment capital and are able to manage sophisticated information systems.[364]

About 20% of farmers in the US are adopting these practices, and the field is almost certain to grow.[365] TechCast estimates this technology to reach mainstream use at about 2020.

Mining and refining: The enormous environmental and economic significance of the extractive industries is illustrated by the fact that each citizen in a developed country is supported by 102,000 kilograms of minerals, metals, and fuels each year, amounting to 7.8 million kilograms over a lifetime. While this essential function is today performed in industrialized nations with remarkable efficiency, safety, and greatly increased environmental concern, undeveloped parts of the globe continue to operate under primitive conditions lacking capital, advanced technology, or good management. With burgeoning demand for energy, the PRC regularly suffers the deaths of 5,000 miners per year, accounting for 80% of the world's total, though it only produces 35% of mining output. Some 600,000 miners currently suffer from black lung disease, and that number is growing by 70,000 per year. Coal, perhaps the dirtiest and least effective energy source, supplies two-thirds of the PRC's energy and 80% of its electricity. Coal smoke from factories and households hangs over modern cities like Shanghai, contributing to respiratory ailments and coating everything in a film of black dust, reminiscent of London in the 1800s.[366]

In contrast, Africa, Australia, Canada, and the US lead the world in creating modern mining operations, and Latin America and the Pacific are gaining rapidly. As a whole, the industry has witnessed a 68% decrease in commodity prices over the past 35 years even as output has grown by a similar amount. Safety in modern mines has improved to the point where accidents are rare and the risk of fatalities has plunged. Environmental safeguards are now completely integrated into the entire production process—from the initial operations through to land restoration—with the goal of zero environmental impact.

These improvements are the result of the extractive industry's adoption of a range of emerging technologies from the fields of robotics, IT, and bioengineering. Possibly the biggest recent breakthrough is the increasing automation of equipment used for drilling at the mine face; loading ore and debris; hauling it to the surface; and processing ore into metals, minerals, and energy. In addition to vastly improving efficiency and eliminating dangers to miners, automated equipment has been found to reduce wear on machinery and decrease maintenance costs even as it operates round the clock without light, seven days a week. Bioengineering is drawn upon to develop biological processes for extracting minerals and metals from ore and remediating contamination at mines. Sophisticated information technology—including fiber-optic cables, global positioning systems, neural networks, computerized equipment, Internet-based communications, and 3D displays—are used to explore geological areas, create databases of the results, determine where and how to drill and blast, control mining equipment, communicate among personnel, and control processing.[367]

The need to transfer these sophisticated capabilities to developing nations is urgent, obviously, but they depend on sufficient capital, good management, strong legislation, and political leadership. Some developing nations are improving mining industries by privatizing state-owned companies, encouraging foreign investment, reducing tax rates, decreasing trade barriers, and streamlining government policies which should move this crucial industry in the right direction. As indicated, the technologies described have already been mainstreamed in many parts of the world, and they can be expected to find increasing application in Asia and the Pacific in years to come.

Environmental Implications of Natural Resources Technologies

While energy is a crucial underpinning of modern economies, few people in the past considered the environmental effects of how energy is generated. Today, the prospect of global climate change due to excessive carbon dioxide emissions, the looming peak in oil production, and concerns over the security of energy supplies mean that the environmental impact of energy has a primary concern around the world. While nonfossil-fuel alternative sources of energy may address carbon dioxide emissions, this does not mean that such sources are devoid of environmental impacts.

For example, solar energy may be "clean" during the life of a solar cell, but this ignores the environmental effects of mining the silicon (the Earth's second most abundant element), fabricating the solar cells, constructing the solar panel structure, and disposing of the used materials once their useful life is completed. Nevertheless, any negative environmental impact should be compared with the fossil fuel alternative which not only has these impacts but also results in highly polluting or damaging emissions. One of the other major advantages of solar thermal, solar photovoltaic, and solar passive energy systems is that they do not require an extensive electricity grid. However, distributed solar electric systems do require backup batteries for which disposal and recycling are significant environmental issues, especially in Asia and the Pacific.

Of all renewable energy sources, probably none is more controversial from an environmental perspective than hydropower, especially when derived from dams. The environmental impacts of hydro-electric dams include (i) alterations to aquatic ecology, especially fisheries; (ii) deforestation of the impoundment area; (iii) erosion and sedimentation from borrow areas for the dam and downstream from the dam due to higher than normal flows; (iv) water quality problems, especially where vegetation is not removed from the impoundment area, including extensive anoxic zones at depth; and (v) loss of unique natural systems through both inundation and changes in downstream hydrology. Run-of-the-river hydroelectric schemes and mini-hydro schemes have fewer environmental issues, but they are still not negligible. Very large hydropower schemes such as the Three Gorges Dam in the PRC have additional environmental issues such as increasing the risk of seismic activity and the possibility of catastrophic floods. Such large dams also have considerable social impacts as more than 1 million people were relocated from the Three Gorges impoundment zone.

Wind generation, currently the fastest-growing area in alternative energy, has issues of noise, bird kills, and aesthetic degradation—not to mention the environmental issues of creating the materials for the various components of the mill. For all forms of grid-based electricity generation, regardless of the source, environmental impacts are also experienced from the transmission lines, especially where they pass through ecologically fragile areas such as forests. There has been extensive investigation of the environmental impacts of the electrical fields surrounding high-voltage transmission lines because they may have negative impacts on all biological systems. To date, no significant danger has been proven, but concerns remain, not the least of which are from families living under or close to transmission lines.

As for the hydrogen economy, much will depend on where the hydrogen comes from. Hydrogen is really only a storage and release form of energy rather than an energy source in its own right. If the original source of hydrogen is from an industrial process or from fossil fuels, then its advantage of releasing only water when it is consumed is reduced (although still better than burning fossil fuels). The real environmental benefits of using hydrogen as a fuel come from generating hydrogen from a renewable energy source, such as solar energy, and converting it to usable energy in a fuel cell. As a fuel cell converts hydrogen directly into electricity without burning it to produce waste heat, there is a high thermodynamic efficiency and a near-zero emission of pollutants. In vehicle applications, fuel cells also offer less traffic noise and low maintenance requirements. The other advantage of fuel cells is that they can be scaled up from small ones powering laptops to 250 kilowatt units, enough to provide electricity through a distributed grid to 50 to 60 homes at US levels of consumption. As noted, distributed grids offer considerable security and provide for the sale of surplus power from home or office installations back into the grid.

In many ways, nuclear energy could be considered as an alternative energy source although it remains quite controversial in many parts of the world, especially following the Chernobyl disaster in 1986. The principal concern rests with disposing of the waste products and the contaminated building structure once the plant is decommissioned. There is yet no generally accepted method of waste disposal, as many thousands of years are required for nuclear waste to become harmless, and there are few places in the world that can be guaranteed as safe waste disposal sites for such a long time. Even more controversial is fusion energy, though both fusion and fission are still many years from commercial development.

Genetic engineering of the food supply has raised considerable concern over environmental and health effects. Life science corporations claim that their new biotechnology products will make agriculture sustainable, eliminate world hunger, cure disease, and vastly improve public health. Opponents of GMOs are wary of these claims, and they are increasingly able to stop biotechnology in its tracks. In theory, breeders could turn out plants and animals that would (i) thrive in areas previously marginal or unsuitable for agriculture; (ii) double or triple agricultural productivity (thus reducing the area of forests cleared for agriculture); and (iii) require fewer pesticides, herbicides, antibiotics, or other chemicals that are increasingly polluting the environment. Ruminants could be bred to produce fewer GHGs, or pigs could be bred to produce less phosphorus in their excrement. Temperate climate farm animals such as high-yielding dairy cows could be bred to withstand tropical temperatures rather than being confined to air-conditioned sheds. In 2000, a cloned Jersey cow was born with genes for producing lysostaphin, a protein that kills Staphylococcus aureus bacteria, a leading cause of mastitis in dairy cows that costs the US dairy industry $1.7 billion annually. Hence, there is considerable potential for using biotechnology for environmental improvement.

The fundamental concern is that, even as the science of genomics is demonstrating that there is very little genetic difference between species, animal and even human genes are being randomly inserted into the chromosomes of plants, fish, and animals creating previously unimaginable transgenic life forms. The species barrier that formerly stopped unlike life forms from reproducing with each other has been shredded. The long-term implications of removing species barriers and introducing common genes into a wide range of crops or animals are unknown but could include (i) diseases that can easily cross the species barrier (as HIV/AIDS, Ebola, and Bovine Spongy Encephalitis are believed to have done); (ii) disease pandemics targeting the common gene across many species; and (iii) reduction in biological diversity, and hence, increased risk of species and genetic loss.

Other possible environmental problems include (i) the transmission of antibiotic resistance to bacteria in the wild; (ii) the release of larger or more competitive domesticated animals (such as genetically modified salmon) into ecosystems, where they could wipe out native species; (iii) creation of superweeds or superpests; (iv) cross-pollination of related native species or organically farmed varieties by GMOs; (v) increased pesticide or herbicide residues in soils and on crops; (vi) damage to beneficial insects and soil microorganisms; and (vii) creation of new viruses and bacteria due to mutation of GMOs into more virulent forms. [368]

As many of the risks to the environment may be irreversible and relate to the very basis of life, risk assessment techniques will need to be very rigorously applied if the biotech industry is to expand and reach its potential. Normal environmental impact assessment procedures may not be adequate, at least in developing countries. The case of the Monarch butterfly is instructive in this regard. Monarch butterflies are fascinating because of their long migrations and habit of wintering at a few places in Mexico. They feed almost exclusively on milkweed, which grows around the margins of cornfields. In 2000, there was widespread concern that preliminary work showed that the pollen from genetically modified corn was lethal to Monarch butterflies which if true put about 50% of the population of this remarkable species at risk. In some respects, it was not surprising that a modification specifically aimed at delivering a toxin to the European corn borer (a moth larvae) would also affect butterfly larvae. The furor that this case raised forced the US government to take action. Eventually it was found that only one variety of the modified corn was lethal to butterfly larvae, and fortunately this variety did not sell well in the US. Hence, a lucky break rather than serious risk assessment and regulation protected the Monarch butterfly.[369]

Bioprospecting was initially held out as the potential savior of biological diversity globally as “gene hunters” fanned out across the globe looking for extreme genes or lost relatives of modern species. Following adoption of the Convention on Biological Diversity in 1992, the third Conference of the Parties in November 1996 launched the Biotrade Initiative, to cover bioprospecting, non-timber forest products, and ecotourism. However, with a few notable exceptions, bioprospecting has consumed a large amount of investor funds with few blockbuster products identified.

Desalinization is another good example of a technology that when viewed very narrowly appears to have no significant environmental impacts and could really help people living in arid zones. However, desalinization is extremely energy-intensive and could only be regarded as environmentally sound if the energy source was renewable. In addition, an excessive concentration of desalinization plants along a coastal strip could result in disruptions to the aquatic ecology from disposal of waste brine.

The Research Institute of Organic Agriculture in Switzerland completed a 21-year study that showed organic farming is efficient, saves energy, conserves biodiversity, and maintains healthy soils for generations.[370] Crop yields, on average, were 20% lower than conventional fields, but the ecological and efficiency gains made up for this reduction. Not all crops did equally well, however, as potato yields were 60% lower than on conventional fields. Organic soils had up to three times as many earthworms, twice as many insects and 40% more mycorrhizal fungi colonizing plant roots. Soil microbes increased their activity, transforming organic material into new plant biomass faster than microbes in conventional plots. Organic plots also had 10 times as many weed species as plots sprayed with herbicides.

Precision farming and farmbots juxtaposed against organic farming clearly demonstrate the need to make careful technology choices in an area as important as how we grow our food. While precision farming could reduce the use of chemicals and fertilizer, organic farming can make even deeper cuts in their use. The crucial issue is whether organic farming can achieve yields equivalent to those from precision farming. Wherever the balance lies, either approach is likely to be better for the environment than current production systems.

Space

This technology may appear to be of limited interest to Asia and the Pacific and its environmental management. The long-term development of the region, however, could well involve a large and thriving space industry and increasing use of space-based technologies. The PRC has already built a large, profitable, and quite famous sector launching satellites for commercial purposes. Seaborne launches of satellites are taking place in the region’s open oceans, along the equator. Additionally, in the longer term of 30 years or more all large economies are likely to be operating space capabilities in much the same way as jet travel is common now.

Lunar exploration: The Moon has long been considered a convenient launching pad for space missions. It is relatively easy to reach, it is easy to escape its mild gravity, and it has almost all materials needed for space ventures including water. The challenges of building and maintaining a permanent base on the Moon are daunting, but not much more so than those of the International Space Station which has been inhabited for years.

The US government recently announced a $12 billion plan to establish a permanent human settlement on the Moon to send men to Mars, and NASA is now working to accomplish this goal.[371] If this were to proceed successfully, a permanent Moon base would have a big impact on business development, medical research, and space exploration. The PRC also plans to pursue its space explorations with a lunar landing within the next decade.

Despite the obstacles, the Moon is likely to be part of the more ambitious attempt to land humans on Mars within the next two decades or so. TechCast puts it at 2025.

Environmental Implications of Space Technologies

Almost by definition, space technologies have little impact on the Earth’s environment (though they may have significant impact on the Moon, Mars, and perhaps on other planets). The greatest advantage of space technology to the environment has been the global earth observation systems that through satellite images provide the best evidence of changes taking place in the Earth's environment.

If occupation of the Moon and Mars is viewed as an opportunity to mine minerals or other materials that are rare on Earth (such as Helium-3 for fusion energy), then there will be major environmental implications for those environments. Perhaps a global moratorium on such uses, as has been in place for the Antarctic, should be negotiated among the nations engaged in space activities.

Space launch facilities are probably the site of greatest potential environmental damage on Earth. Such facilities store large amounts of compressed gases, require extensive building structures and large impervious areas, and house substantial workforces, often working round the clock. They are generally located well away from populated areas to avoid the danger of a launch catastrophe, but this often means that they are located in areas where there may be an impact on fragile ecosystems. Often located in deserts or close to coastal zones where the flat terrain provides for airport runways, there is a risk of discharge of toxic materials and fuel leaks to desert or aquatic ecosystems.

Environmental impacts from space operations include the primary exhaust emissions during take-off, such as carbon monoxide, hydrochloric acid and aluminum oxide from the solid propellant, and carbon dioxide, carbon monoxide, nitrogen oxides, and carbon particulates from the liquid fuel. Short-term water quality and noise impacts are also likely, depending on the proximity to settlements and water bodies. Over the past few decades, considerable space junk has built up in orbit; there is an increasing chance that such junk could imperil orbiting manned stations such as the Mir international space station. Generally, manned space stations return their waste to Earth. As most of the space junk would burn up on re-entry, there is a relatively small possibility of returning material damaging houses or killing people, although a recent launch in the PRC resulted in a piece of an ejected fuel tank crashing into and demolishing a house. (Fortunately, no one was home at the time.)

Information Technology

Biometrics: Biometrics offers a possible solution to the increasing plague of computer viruses, hackers, spam, data theft, and other security risks. Fingerprints, hand geometry, the iris, and facial features are all being used to identify individuals, although fingerprint recognition makes up to 67% of all applications. One expert thinks biometrics is the, "…first killer application since computer firewalls" and believes the market is, "…set to explode."[372]

The technology is not 100% reliable since the human body is infinitely variable. Three percent of people lack readable fingerprints, 7% have eye pigmentation that interferes with iris scans, and face recognition software can be thwarted easily.[373] No biometric measure has proven to be fail-safe, and there is no storehouse yet of iris, hand and face prints such as there is for fingerprints. These problems can be solved in time, and the use of two or more modes of identification has been found to improve accuracy greatly.

The EU, Japan, UK, and US are all implementing national biometric programs to improve security, particularly at airports and borders.[374] The technology is also being used at retail stores to increase security, speed checkout lines, improve customer convenience, and lower operating costs. Individuals are using fingerprint scanners on their PCs or mobile phones to lock and unlock the system, protect stored data, and access e-mail. Applications are growing at an estimated 35% per year, and it is thought that most security systems will consist primarily of biometric measures in about 5 years.[375]

Broadband: Broadband includes digital subscriber line, TV cable, Ethernet, wireless, and satellite communications. The 30% "mainstream" adoption level was reached in US homes about 2004, and growth is continuing rapidly. Speed, however, remains very low in most parts of the world. Lack of rich commercial content and limited interest may impede a high level of adoption that is enjoyed in some nations like Japan and the Republic of Korea that have 70% penetration levels because of government subsidies, faster connections, and sophisticated content. Still, most people like broadband. A US user survey found 85% of broadband users to be happy with their service in contrast to half of radio and TV users.

Broadband only provides faster communications, so the big question is what will it be used for? Some experts think distance learning will prove to be the next big application because of broadband's ability to deliver a multimedia experience. Forecasts indicate the rise of an "intelligent interface" using speech recognition, AI, and virtual robots during the next 10 years that would make computer use conversational and convenient and should expand demand for broadband. Other forecasts suggest that commercial use of the Internet is likely to reach mainstream adoption levels soon, also boosting the use of broadband.[376]

These applications and predictions are encouraged by the relentless increase in broadband speeds. Broadband in the US operates at a paltry 1–3 megabytes per second (Mbps), but telecommunication companies are poised to install cables running at 20 Mbps. Speeds are already at least that fast in developed Asia, and plans are underway to offer 10 gigabytes per second service—a truly remarkable feat. Even wireless services operate at 70 Mbps and could become faster yet.[377] All of this added channel capacity is likely to raise adoption levels to 50% or more in developed nations within this decade connecting the globe with full motion streaming video, face-to-face dialogue, a cornucopia of commercial transactions, and other powerful applications that can only be dreamed of today.[378]

Intelligent interface: As noted, advances in speech recognition, AI, and computer power suggest that the old computer interface (keyboard, mouse, etc.) may yield to an "intelligent interface" in which people simply converse with computers just as they do with other humans. The possibilities are truly vast. We could rely soon on "intelligent agents" or "virtual assistants" to serve as secretaries, tutors, salespeople, and almost all other routine work roles.

The science of AI underlying this concept is not yet able to perform such complex tasks reliably and conveniently. Speech recognition software, for instance, requires time and effort to train and it often makes mistakes. Although Microsoft's CEO earlier said, "…the future lies with computers that talk, see, listen, and learn," he recently added that it will happen, "…not in my lifetime." AI may be brilliant technically but it also lacks the common sense of humans, making some uses annoying (a good example is the "paperclip" on Windows, which almost nobody uses).

A confluence of several breakthroughs seems, however, to be converging to make computers much more user friendly. Speech recognition is now used to replace the maddening touch-tone call centers. It is also used in car control systems, search engines, mobile phones, and a host of other places.[379] Major IT companies are all working to perfect speech recognition by 2010, while work on basic AI is also proceeding apace.[380] Virtual robots, or avatars, are being used to serve as guides, spokespersons, game figures, and other roles that allow people to interact with comfortable virtual personas. The 64-bit chips now coming out offer a new generation of computing power designed for full motion video and speech recognition, and large wall monitors are becoming available to display this rich content.[381] Recent developments in chip technology that do away with the need to connect transistor elements with wires offer potential for even faster processing speeds.

Major transitions in the basic architectures of computing and communications are extremely difficult to grasp, of course, but the trends noted above seem to suggest that we are poised at the cusp of just such a transition. The 1980s saw PCs replace mainframes, the 1990s introduced the Internet, and today the old interface of hunching over a dumb keyboard is gradually being replaced by an intelligent interface.

TechCast estimates that by about 2012, it will be common to converse comfortably with life-sized images of virtual persons while shopping, working, studying, and conducting almost all other social functions.[382]

Pervasive networks: A variety of information systems are connecting autos, home appliances, office equipment, the environment, and almost anything else into intelligent networks of electronically equipped objects that interact with one another. One expert has suggested that, "In 5 to 10 years, computing and communications are going to be free, pervasive, everywhere. It's going to be in your walls, in your cars, on your body."[383]

The very prospect can often leave people feeling alarmed rather than comforted. If networks electronically control common objects, a network failure could render them inoperable or cause them to behave erratically with unimaginable consequences. Surveys show that 90% of people think computers are too complex now, so extending computers throughout life's many systems could further aggravate public concerns.

Like it or not, networks are beginning to pervade our environment. As of 2000, four billion chips were embedded in everything from coffee makers to carburetors. The average car now uses 30 to 50 chips, and the average American home has 200. Fifty nations are creating a global network of weather stations, aircraft, and ships that will monitor the environment continuously. RFID tags are starting to track everything from groceries to pets to children. Wireless home networks are connecting computers, TVs, phones, and appliances. It is estimated that 1 trillion devices of various types will be integrated into a global system by 2015.[384] Most of these will be small, inexpensive chips costing a dollar or so, but others will be more costly which gives some indication of the enormous economic implications.

Quantum computing: The science of quantum mechanics offers a possible successor to silicon in which information is stored and transmitted through individual electrons. The strange behavior of matter at the quantum level makes some of the proposed computational techniques bizarre. For instance, two or more electrons can become entangled in such a way that a change in one instantaneously produces a like change in the other regardless of distance, offering a mechanism for instantaneous teleportation of information. Because of the Heisenberg uncertainty principle, individual electrons can coexist in two places simultaneously, and this feature of superimposition allows a single electron to carry two bits of information. The field is struggling to mature, but promising advances are underway, and the potential is enormous. A quantum physics research scientist who developed the first commercially available quantum-cryptography system in 2001, thinks, "E-commerce will be possible only if quantum communication widely exists."[385]

This is going to prove to be one of the greatest challenges facing humankind. The sheer difficulty of learning how to manage information at the quantum level is tremendous, of course, but there are other obstacles as well. Quantum computing alters the state of atomic particles to store information which requires energy; to do this on a massive scale for big computing tasks may require huge amounts of energy with associated environmental impacts depending on the source. The indeterminate quality of quantum mechanics may, however, make quantum computers more prone to error than electronic computers.[386] Nevertheless, the potential is mind-boggling. A quantum computer could easily complete in seconds a task that takes a silicon-based computer billions of years. Little wonder scientists think it will be at least 10 years and possibly 20 or more before we accomplish this historic breakthrough.[387]

Quantum computing can also permit perfect cryptography. The vast power of quantum computers should enable cracking even the most sophisticated encryption codes in a flash. Conversely, because it is impossible to observe a quantum state without altering it, quantum cryptography can transmit

information in a way that detects eavesdropping. This may sound very theoretical, but in fact, the first computer network protected with a quantum security system is up and running at Harvard University.[388]

All major governments, computer corporations, and research institutions are investing heavily in this field, and breakthroughs are occurring daily. The ability to entangle electrons has been demonstrated as has the ability to control super-positioning of electrons in two places simultaneously. Researchers are also able to control the direction in which electrons spin, creating the new field of "spintronics."[389]

There is much, much more to be done, obviously, but the power of quantum computers may be available in a decade or two. If the field fulfills the possibilities now being sketched out, quantum computing could create one the greatest economic markets known, amounting to several trillion dollars globally.

Utility computing: "Utility computing" or "computing on demand" involves the use of large mainframe computers to provide computational power, software applications, security, and other services to a wide range of different customers at distant locations as they need it or "on demand." The concept is taken seriously now because one of the world's largest computer companies has made it the focus of its corporate strategy. This is a huge challenge, but if the complexity of this process can be overcome, computing power could become as convenient and affordable as electricity, water, and phone service.

This is no easy task. Managing the process of intelligently directing central computing power and a maze of application software to different clients, often with incompatible systems, is daunting. Furthermore, corporate clients are often reluctant to become dependent on outside sources for something as strategic as computer services.[390] The advantages of providing a more economically efficient solution to computer needs are so great, however, that many consider this the next frontier. Utility computing allows users access to any type of software from a dumb terminal anywhere without buying and maintaining complex systems. It also puts the responsibility for security on the provider, simplifying the life of IT departments enormously. Most in-house servers are only used at 20% of their capacities and PCs at even less. The typical computer user uses less than 10% of the capability of software.

That is why many firms are starting to provide information utility services. IBM is investing $10 billion in its utility computing strategy which it calls "E-Business on Demand." Hewlett-Packard is developing an "intra-organizational" approach in which large networks of the client's own servers provide utility computing to different departments. And various smaller players are doing very well in this new field.[391]

At the present rate of development, it is estimated that utility computing will enter the mainstream about 2007–2010 and that the market potential will be in the hundreds of billions annually.

Virtual reality: Virtual reality (VR) is one of the more exciting promises of the Information Revolution. The ability to immerse oneself in an artificial electronic environment that simulates the sensory experiences found in commerce, warfare, education, medicine, architecture, and entertainment would appeal to many people. Just as flight simulators are indispensable for training pilots, VR is now used to train physicians, assist surgeons during operations, test the design of buildings and vehicles, allow researchers to analyze data in new ways, and create interactive forms of entertainment.[392] Several improvements are under development including 3D effects, comfortable goggles, and sensory suits.[393] Applications are multiplying as the technology improves and as costs drop.[394]

Imagine a roundtable meeting, with a dozen executives. The discussion is animated. The participants are from 10 different countries and they are all conversing in their own languages, yet all can understand each other, instantly. If an uniformed observer wanted to enter the meeting room, he/she would be surprised to learn that there is no physical room. It is a "virtual meeting" in which participants are holographic images beamed over the Internet from various locations to a central processor that uses VR programs to arrange the holograms into a composite image. Computerized language translation studies a small number of translated sentences to deduce the linguistic structure of each participant then uses common dictionaries to translate into whatever language each observer prefers. Much of this technology already exists.

Or picture a highly skilled surgeon conducting microsurgery to reattach a severed arm. A nurse mops her sweating brow while 2,000 kilometers away the patient is not aware that the doctor is actually operating a robotic arm on a virtual image of the damaged limb. The twin robotic arm in the remote surgery work swiftly and quietly with identical movements without a doctor present.

Virtual reality is growing at about 30% per year and could enter homes and offices about 2010 allowing people to enjoy the thrill of walking on Mars, far more entertaining games, insightful forms of education, and almost any other experience imaginable. A leading computer scientist thinks it will be routine to hold meetings in full-immersion virtual reality by 2010.[395]

Wireless: The advances in power and speed of wireless communication are so rapid that many think of it as a model of disruptive technology. Telecommunication companies recorded the first-ever decrease in wired phone service in 2001, and it is expected that wireless communications will soon exceed wired messages. Wireless is growing at a rate of 60% per year while PC sales are flat. One of the creators of the Internet said, "The age of this technology has only just begun. The world is going wireless."[396]

Wireless communication is still plagued by slow speed, clashing standards, spotty coverage, small screens, limited storage, and security problems. For instance, the cellular network transmits at 19 kilobytes per second, slower than modems. Wide area protocol, third generation, and Bluetooth were all expected to provide a common standard but have proved to be slow, expensive, and unreliable though technical progress could easily resolve these issues in a few years. The next generation of WiMax[397] is being introduced, running at 70 Mbps and covering an entire city. EvDO is thought to surpass even this level of performance while operating on existing cellular networks.[398] Ultra-wideband is entering the field, offering 1 gigabit-per-second (Gbps) speeds, comparable to the fastest landlines.[399] Little wonder that the list of corporations rushing into this nascent market reads like a "Who's Who" of IT.

By 2005, it is estimated that 90% of all laptops in the US will have wireless access to the Internet, and 60% of all mobile phones should have wireless Internet access by 2007. Experts think wireless will reach 500 Mbps to 10 Gbps by about 2008 and include good security systems. The global market for wireless is expected to reach $1 trillion by 2010. TechCast agrees that wireless will reach 30% penetration by 2008.

Environmental Implications of Information Technology Advances

In principle, information technology offers considerable environmental advantages. If people do not need to physically move from place to place, to go to work (telecommuting), to purchase goods (e-commerce), to connect with suppliers (B2B), to learn (distance education), or travel overseas for meetings, there clearly will be a net gain to the environment. However, social isolation of a generation devoted to communicating with the rest of the world through a computer may be a concern if these trends are taken to their logical conclusion.

The biggest concern with IT is that the reverse side of increasing information processing capacity is an accelerated obsolescence of electronic equipment. Today, there are millions of tons of "e-waste," much of which is being exported to developing countries for partial recycling and final disposal. In the PRC, after manual sorting and disassembly, most of the e-waste is sent to Guangdong and Zhejiang provinces, where refining and metal recovery takes place in relatively primitive conditions. There is particular concern about the health effects of this industry on workers. Much of the material that is not useful is simply dumped either by the roadside or in landfills. The e-waste is first sorted into printed wiring boards, cathode ray tubes, cables, plastics, metals, batteries, liquid crystal displays, and wood. Copper, aluminum, iron, solder, plastics and other materials can be recycled. However, insulation and materials that might surround the useful products are often burned in the open or manually stripped off cables and other parts. Plastics are shredded, washed, dried in the sun, and manually sorted into different qualities.

Manufacturing computers and other electronic equipment involves the complicated assembly of up to 1,000 different materials, some of which are toxic. Toxic materials that are released from e-waste include lead (40% of lead in landfills is from e-waste), cadmium (in cathode ray tubes, as a plastic stabilizer, and in electronic components such as resistors), mercury (in switches, relays, and batteries), chromium, brominated flame retardants, and dioxins and furans (from low temperature incineration). Hence, there is a significant health hazard for ragpickers on landfill sites and for workers extracting and refining metals and plastics. The EU is moving toward phasing out many of these toxic materials and insisting that electronics firms take back their products for responsible recycling and disposal. However, such measures are not yet widespread in Asia and the Pacific. Rethinking computer design to create a "clean computer" is an urgent need, as the volume of e-waste is growing exponentially.

Some of the possible solutions to these waste problems include (i) safe cleaning of chips; (ii) using different base material for printed circuit boards to eliminate the need for flame retardants; (iii) using lead-free solder, nonhalogenated lead wires and plastics; (iv) using recycled resin in all plastic parts; and (v) a wind-up laptop, similar to wind-up radios, that would eliminate the need for batteries. Finally, the expansion of utility computing would help to eliminate the need for every user to own a personal computer. In the longer term, quantum computing may make the current design of computers obsolete, but the energy required may increase environmental impacts unless renewable sources are dominant by the time quantum computing becomes commercial.

E-Commerce

Business-to-business: Competition to reduce costs and speed operations continues to spur the use of electronic connections between suppliers, host companies, distributors, and other business relationships. Incompatible systems and the difficulty of changing business processes are hindering wide adoption which is why B2B was limited to roughly 12% of commercial transactions in 2003. The problem is compounded because while 80% of US companies search online, most still buy offline. For instance, 9 out of 10 steel companies use the Internet to search but only half buy online.[400]

Nevertheless, the advantages are clear and should drive further growth toward mainstreaming the practice over the next few years. Online transactions save 10–30% of costs by reducing labor and inventory, and they already are estimated to save almost $2 trillion per year. Most companies are doing B2B of some type, and interest spans the globe. "There is strong demand to connect the world into a single global market," said an official in Singapore. TechCast estimates that B2B will reach mainstream status of 30% adoption by 2010, while global sales are expected to reach $2.7 trillion.

E-government: Despite the difficulties of adopting leading-edge technologies, governments around the world are streamlining operations and making them available more conveniently through online processes. In the interim, progress is slow. Most governments have outdated computers and lack the resources for installing expensive, complex Internet systems. E-government requires a large amount of funding upfront that is very difficult to find in fact, 85% of public sector projects to date have been failures.

The need is so great, however, that it is only a matter of time until e-government becomes the norm in modern nations. One IT executive said, "People will always want to browse at shops, but they will never want to wait in line for a driver's license."[401] Governments are running chronic budget deficits, forcing drastic improvements in productivity, while e-government could reduce costs by 25% or more. Electronic procurement systems alone can save 10% of purchasing costs, which amounted $110 billion in the US during 2001.

Most governments are starting to use online systems to collect taxes, process car registration, and even for official signatures. Australia and Singapore transact all government operations online, while 85% of Brazil's tax filings were done online in 2000. TechCast estimates e-government practices will provide 30% of all services to the public by about 2011.

E-tailing: Selling goods and services online was considered a vast frontier during the dot-com boom, but online transactions have not budged past 10% of retail sales. The development of sound business practices and more sophisticated website technologies could still help this infant field grow.

One study found that 70% of virtual shopping carts are abandoned, and many find online shopping cumbersome though another study found that 71% of online consumers say it is more convenient and 83% are satisfied.[402] While these data are hard to reconcile, it may be that online shopping is not comfortable for many people, though regular users tend to like it. Another problem is that distribution channels are hard to break into. For instance, the auto industry has slim profit margins, only dealers can get cars, and selling a new car often requires a trade-in, so it is hard for e-tailers to compete. While 60% of US car buyers do research on the web, only 1% buys online. Although home mortgage sites report heavy traffic, only 2% of mortgages are sold online because people prefer personal dealings. Adding to this list of woes is the fact that the convenient availability of price information tends to drive down rates among competitors.

Secure transactions and broadband have arrived, however, and better displays of merchandise are coming soon which should boost interest. Broadband will soon be in half of all American homes with rapid expansion in Europe and even urban Asia. Biometrics will soon identify computer users with accuracy. Voice recognition and robot salespeople will offer flawless attention to details and convenience. Car radios are being adapted so that occupants can hit a button and place an order while driving. One forecaster expects e-tailing to reach 31% by 2010,[403] while TechCast's forecast calls for mainstream use by 2014.

Entertainment-on-demand: After a decade of struggle, Apple's successful introduction of the iTunes/iPod system seems to have broken the logjam in distributing music and other forms of entertainment online. Better compression techniques and broadband should reduce downloading times in just a few years, allowing people to stream movies in real time. And as storage improves, it will soon be possible to load all available music on one hard drive. By 2010, homes should have TV systems costing less than $100 that can store the equivalent of a video rental store.[404] Major obstacles remain, but the inexorable advance of IT makes this almost inevitable.

One expert expects 42% of all entertainment to be sold online by 2010, but TechCast is more cautious, estimating 30% adoption levels by 2010.

Online publishing: Most publications now offer online versions, but few are profitable because of great resistance to paying for what has come to be regarded as a free good, much like the music industry. This resistance is further aggravated by prices that are no cheaper than hard copies, and competing standards create compatibility problems. The concept of paying a small sum for an article is nice, but micro-payments have not proven feasible. If publishers can find a solution to this dilemma, we may enjoy the enormous advantages of electronic media.

Readers are attracted, because online publications are interactive, searchable, easily updated, and especially useful for texts and reference books. Publishers like the fact that there is no printing cost, no warehousing of inventory, no returns. Broadband and better storage technology should boost use, and sellers are actively searching for distribution methods that work. One publisher gives away books online but sells more hard copies: "We give 3 readers free access for every one who pays, but sales are climbing, so what's the problem?"[405] The Wall Street Journal has almost 1 million paying subscribers to its online version, while The New York Times attracts 10 million visitors to its website who get free content but view paid advertising and pay other charges.

Solutions are bound to appear in time because the advantages of online publishing are too great to resist. TechCast expects 30% of publications to be offered online by 2016.

Virtual education: Virtual education, or distance learning, seems logical because education is a knowledge transferring process, but obstacles abound. Teachers resist changes in their traditional methods, it is hard to convey complex ideas online, and costs still are usually in excess of revenues. A host of universities have canceled programs because the cost of designing one course can exceed $1 million, but upcoming improvements in distance learning technology and delivery methods are likely to overcome these barriers in time.

Most universities are experimenting with approaches to online courses, though only 10% of courses are conducted online. Corporate e-training now accounts for about 30% of classroom training and is expected to exceed 50% soon.[406] Many students prefer a traditional campus experience and find online lectures boring. Some scholars claim virtual education degrades learning, but studies conclude that there is no significant difference with classrooms in terms of learning. Complex or subjective fields may not be appropriate for online formats, but they do offer advantages in teaching languages, mathematics, statistics, information technology, and other highly structured fields. Some claim that a blend of classroom and online methods is best.

Despite this confusion and doubt, virtual education seems likely to play an important role in an emerging era where working adults constitute 50% of college students and information technology pervades life. A 2002 study found that 86% of US students are continuously online using wireless laptops and other devices.[407] It may be that online education will find an important market by reaching out to large numbers of people around the globe, rather than the traditional classroom of 30 students. For instance, the investment in developing online programs and IT systems may be easily justified when reaching an audience numbering in the thousands.

In a study of 3,000 university presidents, 57% said distance learning was equivalent to classroom courses and one third thinks it will be superior in 3 years.[408] Because of the formidable obstacles to changing college practices, however, TechCast thinks it will enter mainstream use at about 2018.

Environmental Implications of Advances in E-Commerce

As indicated for information technology, the main environmental advantages of e-commerce relate to the reduced need for certain commodities, like paper, and for physical movement of goods, materials, and people thus reducing the environmental impact of the transportation system. The downside is the e-waste problems referred to above. On balance, if computing systems become more environmentally sound, e-commerce will have big benefits for the environment but will make a relatively minor contribution to solving global environmental problems. Even if many of the intermediate transactions can be negotiated online, the final goods produced still need to be physically transported to the ultimate user.

The Basel Action Network[409] closely monitors the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (adopted in 1989 and entered into force in 1992). As one of the first countries to join the Basel Convention, the PRC is now drafting an amendment to the Law on Solid Waste Pollution to avoid the dumping of e-waste. Customs statistics show that the PRC imports about 3–4 million tons of plastic waste every year. However, as e-commerce expands and the infrastructure to support it is replaced at ever-faster rates, there will be other countries in Africa and South Asia that will be willing to provide the manual labor needed to disassemble and recycle the electronic equipment. Some simple solutions such as refilling printer cartridges under controlled conditions may help to avoid some of the worst environmental and health side effects of e-commerce.

Medicine and Biogenetics

Artificial organs: An astonishing array of body parts can now be replaced with artificial equivalents: skin, bone, heart, blood vessels, cochlea, heart valves, pacemakers, knees, hips, etc. For example, metal joints replace approximately 150,000 knees yearly in the US alone. Pressure to develop an increasing range of artificial organs is relentless because transplants of living organs are difficult and not always successful. Hundreds of thousands of people die each year waiting for vital organs, while many others suffer from transplant rejection problems. Using a combination of micro-machines, microchips, materials research, and other new technologies, it is conceivable that bionic parts will soon be available to replace nearly the entire human body.

For example, artificial arms today sense electrical currents generated by muscles and use microchips to translate this information into coordinated movements; more advanced versions are underway that electrically connect the arm to the nervous system itself. A prosthetic leg is being developed with motorized joints, electrical connections to nerves, sensors, and a microprocessor that calculates optimal walking movement. The first brain prosthesis has been used to replace the hippocampus where memories are stored, and "brain pacemakers" are being used to control Parkinson's disease and other disorders. Deaf people have received the first implants in their brainstems to stimulate the nerves that permit hearing. Paraplegics control their TVs and download e-mail through implanted chips. Researchers have even invented simple systems to restore sight; video cameras are installed in eyeglasses, transmitting images to chips implanted in the back of the eye, which are then fed to the optic nerve.[410]

Small chips containing personal information have been implanted in many volunteers, and some think they could be used to keep track of children. One forecast expects 50% of Americans to have some form of implant for tracking and identification by 2025.[411] In March 2002, an electrode was surgically implanted into the median nerve fibers of the left arm of Professor Kevin Warwick, allowing him to control a variety of electronic devices.[412] While the prospect raises ethical issues and concern about the future of humans, it also offers many practical advantages, as in helping the paralyzed communicate. Humans have in recent years accepted implanting devices in their bodies from pacemakers to metallic joints. Connecting the human nervous system to a computer is just a logical progression along this well-worn path.

TechCast estimates the use of artificial organs to reach 30% penetration in 2029 and to create a global market of $70 billion.

Genetic therapy: Genetic therapy may represent the Holy Grail of medicine because so much illness is inherited from the approximately 5,000 genetic disorders that have been identified thus far. The decoding of the human genome has not reached the point where genetic blueprints have been mapped for all these diseases, however, and techniques for altering genetic traits remain crude. Several patients have died in genetic therapy experiments discouraging further research, but the huge potential continues to move progress ahead nonetheless. Fortunately, political forces—and prominent patients suffering from genetic illnesses such as the late US President Ronald Reagan—also help to exert more pressure to move the field forward.

The US alone has 1,300 biotechnology companies employing 100,000 people working on genetic problems. Faster and cheaper methods for mapping individual DNA and comparing it to genomic data banks are making it possible to determine a person's susceptibility to certain diseases. Bone marrow transplants have been used to completely rebuild the immune systems of children, and stem cells have been used to repair genetically damaged organs. The first genetic trial to treat pancreatic cancer has been launched. Genetic therapy recently cured mice of skin cancer. An intriguing new technology has been called a "doctor in a cell" because it uses DNA material to analyze cells for genetic illnesses and repair them. Prominent figures in the field predict that cures for most genetic illnesses will be commonly available by 2025.[413] TechCast estimates genetic therapy will reach 30% of its full potential application by 2016 and become an $80-billion market.

Grown organs: Imagine the benefits of being able to grow genetically identical organs in a laboratory from a patient's own cells. No rejection problems, no organ shortages, and no end to our ability to replace damaged body parts. Human skin, bone, and liver tissues are now produced genetically, and the same basic method is being extended to create entire organs. Grown organs could help the hundreds of thousands of people worldwide who are waiting for organ transplants, and many conditions such as spinal cord injuries, Parkinson's disease, and congestive heart failure, to name a few, could be cured by engineered tissue.

The ethical dilemmas are daunting, however. Much like the prohibition against cloning humans, some governments consider embryonic stem cells to be human life, and therefore, off limits to experimentation, while others are criminalizing therapeutic cloning, a technique used to grow stem cells from embryos. And there is always a risk of provoking other dangers such as cancer.

Yet science is making its way through this moral thicket. Embryonic stem cells can be used to repair damaged cells, cure intractable disease, regenerate organs, and prolong life. A Harvard neurobiologist calls them "magic seeds." Scientists have recently found that they can use stem cells from adults, thus overcoming the moral objections related to embryos. The nascent field of tissue engineering is generating laboratory-grown bone, cartilage, blood vessels, skin, and nerve tissue. An entire jawbone, a nose, and an ear have been built and transplanted into patients. Livers, pancreases, breasts, hearts, and fingers are taking shape in the lab. Researchers have discovered the gene that allows stem cells to remain pluripotent, i.e., able to grow into any cell of the body.

Some scientists claim a veritable body shop of laboratory-grown organs will be available to patients in about 10 to 20 years, while TechCast estimates mainstream use at 2017 and a market of $120 billion. The challenges are Herculean, so this estimate may easily prove optimistic. Our best forecast suggests mainstream use by 2025.

Life extension: Opinions are controversial, but the evidence seems to be accumulating that life extension is possible. Discoveries are being made in extending the life of cells, repairing damage to the body, replacing organs, curing major illnesses, and improving lifestyles. Some authorities claim that human life spans are fixed and are expected to top out at an average of 85 years for genetic reasons. However, a study noted that such claims have consistently been proven wrong, so it is more likely that gains in life span lie ahead.[414] The social consequences would be enormous, but the bulk of evidence and the views of most authorities suggest the problem can be solved to a large extent.

Researchers have developed telomerase, an enzyme that causes human cells to replicate hundreds of times beyond what was thought to be the limit of cell reproduction, the "Hayflick Limit."[415] Northeastern University has developed a drug that reverses the damage of aging by promoting the growth of natural antioxidants with profound effects. Harvard scientists have found that enzymes called sirtuins are "universal regulators of aging in virtually all living organisms." Genes are being identified that seem to prolong life. Nanotechnology may permit fleets of computer controlled molecular tools smaller than a cell to remove obstructions in arteries, kill cancer cells, and repair the human body.

The World Health Organization estimates that 30% of the global population will be over 80 by 2025, and trends suggest that life span could average 120 to 150 years about the middle of this century.[416] TechCast estimates average life span could reach 100 years in 2044, which may be more realistic.

Personalized medicine: Like most things in life, people vary enormously in their genetic susceptibility to illness, drugs, and other factors, making one-size-fits-all health care often ineffective and at times highly damaging. With the human genome now analyzed carefully, researchers are moving toward genetic tests to determine these differences and thereby permit precise medical treatments that are more effective and produce fewer side effects.

The complexity is staggering. Minute genetic differences must be identified and related causally to specific outcomes from a wide range of drugs. People of different social classes and races have different genetic reactions which could provoke issues involving discrimination. Knowing the genetic susceptibility of people to various ills raises a host of disturbing issues, such as finding insurance coverage and employment, but the prevailing generalized approach is only 40–50% effective and often produces serious side effects. More than 100,000 people die each year in the US from the side effects of drugs, and another 2 million become seriously ill.[417]

Drug companies are developing tests to identify differences in drug response, making genetic testing cheap and convenient, creating computerized information systems to manage this complex array of data on each patient, and developing protocols for individualized treatment.[418] TechCast estimates these advances could enter the mainstream about 2015 to 2020, saving hundreds of billions of dollars and greatly improving health care.

Telemedicine: Medicine is the least-computerized industry in the world with 90% of medical care conducted by paper and telephone suggesting enormous possibilities for improvement. The problem is that health care is a very complex field, and institutional obstacles also hamper it. Hospital administrators are often not interested in telemedicine, insurance does not cover it, many physicians resist computers, and patients are fearful about loss of privacy.

With the advent of out-of-control medical costs in the US and more powerful IT systems, however, conditions in this leading market for medical services are now right for progressive hospitals to embrace new approaches. Kaiser Permanente, the biggest health maintenance organization in the US, is automating its entire chain of hospitals with sophisticated technology. "Point of care" systems manage all patient information, and "virtual care" systems treat them at a distance. Medical records are stored and retrieved electronically. Physician training is now increasingly IT-intensive. Telemedicine could eliminate 80% of the 100,000 deaths per year caused by medical errors, and hospitals should be able to reduce costs by 30–40% while improving service. A recent survey found that 70% of hospitals in the US are planning to adopt telemedicine, and the field is growing by 30–50% per year.[419]

TechCast finds that expert opinion forecasts telemedicine to enter mainstream use by 2013, while the CEO of Waterford Telemedicine Inc. expects it to cover 15% of all health care by 2015.[420] Our best forecast is that the field will grow quickly in the US due to the desperate need to control spiraling health costs, and so the TechCast forecast is more credible. Trends in the US should quickly carry-over into other parts of the world due to the cost savings. Telemedicine thus is likely to prove one of the largest applications of IT, creating a new industry worth approximately $1 trillion–$3 trillion globally.

Environmental Implications of Advances in Medicine and Biogenetics

The main concerns over this field are social, but they have strong environmental implications due to demographics. If millions of poor people are denied access to even basic medicine, but affluent people in developed countries have easy access to artificial organs, gene therapy, grown organs, and personalized medicine, social tensions between rich and poor nations will surely intensify. If developed-country affluent populations can extend their lives to 120 or 150 years, while life expectancy in some developing countries continues to decline because of HIV/AIDS or other epidemics, then difficult moral and ethical questions will need to be answered. The global consumption consequences of longer developed world populations are of environmental concern as well. On the other hand, many medical advances are likely to extend lifespans in the developing world too. If telemedicine saves $800 billion per year in health care costs by 2007, will these savings be diverted to increased private consumption or to improvements in health care in developing countries? If human life can be extended by 40–80 years, the social issues of working lives, retirement ages, and pension schemes will need to be addressed. Insurance companies and actuarial firms will need to change their basic assumptions. Clearly, these moral, ethical, social, and environmental dilemmas, will intensify with time, but the debate to resolve them needs to start urgently.

As noted, the main impact of these technological advances will be indirect, related to increased energy and physical consumption of the developed and developing world, as each person increases their lifespan. Already much of the world's entertainment, tourism, and leisure industry is supported by retired persons from the developed world. As the period of healthy years in retirement increases, then one can expect this age group to considerably expand their consumption. Driven by this demand, the environmental impacts of production processes to meet the needs of the retiree community will also expand.

Institutional Change

This field represents a different type of technology, the "social technology" that executives use to channel behavior into more successful organizations. This is a large field, but our interest is in the historic changes that major social institutions are experiencing today. "Institutional change" goes beyond "organizational change" to focus on entire classes of organizations serving various societal functions: business, government, education, military, and the like. Unlike the management aspects of organizational change—teamwork, leadership, etc.—institutional change concerns the underlying social rules or norms that define how societal functions are structured.[421]

Today, revolutionary information technologies, globalization, and an increasingly knowledge-based economy are transforming all institutions from the mechanistic systems of the Industrial Age to organic systems for the Knowledge Age, and the biggest hurdles lie ahead. The "Stakeholder Collaboration" described below form the central features of this emerging model of institutions for the Knowledge Age.[422]

E-organization: This concept represents the technological dimension of institution change. It defines the movement of information processing from paper and telephone within a hierarchical chain-of-command toward fully integrated information systems operating in real time—"telework" among "virtual teams," automation of the entire supply chain, "e-tailing" directly with clients via the Internet, and "real-time management." A recent survey of executives found a strongly held consensus that the relentless advance of more powerful information systems seems destined to automate virtually all routine tasks, accelerate the pace of change to approach real time, and create a new organizational transparency.[423] Organizational life in modern nations is rapidly being transformed into integrated IT networks with organizations of all types forming and reforming as self-organizing nodes in this global system.

For example, two thirds of professional workers in the US today report that they work in virtual teams, and 90% think it is more productive and satisfying. About 24% telework full time from home, in the field, at client sites, and elsewhere while 70% telework part time. E-tailing systems help customers place orders directly to factories, automatically updating financial accounts, reducing labor costs and inventory, eliminating retail outlets and salespeople, and delivering cheaper but customized high-quality goods in days. Some companies use a "digital dashboard" or "corporate cockpit" providing real-time strategic information to allow instantaneous organizational control like a flight simulator.

Forecasts show that the main components of an e-organization—B2B, e-tailing, teleworking, etc.—are likely to enter the commercial mainstream during the second half of this decade. Other studies, although preliminary, confirm this time frame.[424] Our best forecast, therefore, is that the e-organization is likely to enter mainstream use during 2006–2010. Because this will amount to a crucial change in the way societies function at the basic organizational level, the economic and social impact is likely to be phenomenal.

Self-organizing systems: This represents the economic dimension of institutional change. The traditional hierarchy can be best understood as a "planned economy" controlled by executives while there is a general move toward "internal market economies" of many small, self-managed units that are better able to harness employee knowledge to manage a new era of exploding complexity and change. The growth of organizational networks, self-managed teams, performance pay, entrepreneurship, internal enterprises, and other trends all point in this direction.

Progressive corporations are increasingly organized as a self-organizing system of countless small entrepreneurial business units held accountable for performance and left free to manage their own operations. Subjective performance appraisals are being replaced by incentive systems, bonuses, and stock plans. The greatest needs of employees today focus on gaining flexibility to better manage time and balance the demands of work and personal lives. A recent survey in the US found that 60% of managers think employee flexibility is more productive. One manager said, "The focus is on whether we produce, not how, when, and where we do it."[425]

Stakeholder collaboration: This can be thought of as the political dimension of the knowledge institution. Organizations are essentially political in that they must form a working coalition of investors, employees, clients, and other stakeholders to succeed. All of these groups should be engaged in collaborative policy decisions to gain their unique resources, support, and knowledge. If carried to its conclusion, the organization can become a "corporate community" that strives to ensure all members share a common vision, a unifying sense of purpose, rights and obligations, acceptable norms of behavior, and sanctions.

One company was struggling with labor unions, environmental groups, local governments, and consumers until it started to work with these critics. The CEO described the change this way: "We viewed outsiders as a nuisance. Now we find that our adversaries help us find creative solutions to intractable problems." WSSD in Johannesburg led to similar partnerships, many involving the private sector.[426] The best examples are provided by the traditional approach of Japanese corporations, which have long focused on collaboration among employees, suppliers, investors, and other constituencies to serve the broader needs of society. Studies indicate that "stakeholder collaboration shows a direct correlation between financial results, customer satisfaction, and employee well-being," and that 80% or more of managers accept the concept because it is clear that support of various groups is essential.[427]

Many corporations around the world cling to the Industrial Age tradition that profit is the main goal of business. This clash between the reigning focus on money versus the escalating social needs of an interconnected world struggling with poverty, congestion, environmental decay, and other massive ills is largely responsible for the predictable backlash against globalization referred to in Chapter 2. It is hard to anticipate when or how this dilemma will be resolved, but there clearly exists a great opportunity for enlightened executives and governments to take the lead.

Environmental Implications of Institutional Change

Generally, the breakthroughs posited for this field should have no significant adverse environmental impacts that would distinguish them from current institutional models. Some environmental benefits can be expected from telecommuting (especially in reduction of transportation impacts), but increased waste also may be generated from a proliferation of "home" offices. In general, however, the new corporate management models incorporate a wider range of concerns in decision making, and engaging more positively with all stakeholders should bode well for the environment.

THE TECHNOLOGICAL FUTURE OF ASIA AND THE PACIFIC

A few cautionary notes are needed to temper the often extravagant promises of technological breakthroughs. Obviously, some of these 44 technologies may not develop successfully due to sheer technical limitations. They could be delayed beyond the time horizons estimated here, or they could play a far smaller role. The hopes for a hydrogen economy, for instance, hinge on finding as yet undeveloped energy-efficient, cost-effective, and environmentally sound methods for extracting hydrogen which could turn out to be exceedingly difficult. Social and political values also are likely to pose obstacles to the profound changes implicit in many of these fields. For example, bioengineering could easily flounder on social barriers, as seen with GMOs in Europe. Further, technical advances almost always introduce some form of environmental damage—often unanticipated. Technology is a two-edged sword, exacting costs and perils as well as great benefits.

Almost all new technologies engender fear of the unknown. For example, before 1896 in the UK, all mechanically propelled vehicles had to be preceded by a man carrying a red flag, 60 meters in front of the vehicle, limiting their pace to walking speed. It is not surprising that emerging technologies today sometimes engender extreme scenarios for our planet's future. What is surprising is that some very technology-savvy observers are predicting not only environmental damage from some of these technologies but nothing short of the total demise of the human race. Although the authors do not share this pessimistic view of the future, it is important for the reader to be aware of these extreme views, if only to put the environmental concerns regarding new technologies into context. Ultimately, all technology involves choice, and choice is best guided by complete information.

In 1992, 1,700 of the world's top scientists issued a "Warning to Humanity" which includes, "Human beings and the natural world are on a collision course…that may so alter the living world that it will be unable to sustain life in the manner that we know it… No more than one or a few decades remain before the chance to avert the threats we now confront will be lost."[428] Reflecting on the critical issue of biodiversity loss, a renowned ecologist said, "So important are insects and other land-dwelling arthropods that if all were to disappear, humanity probably could not last more than a few months…. The land surface would literally rot."[429] As this graphic description did not reverse the disturbing trends, he repeated his warning with even greater urgency in 1996. "Dominant as no other species has been in the history of life on Earth, Homo sapiens is in the throes of causing a major biological crisis, a mass extinction, the sixth such event to have occurred in the past half billion years. And we, Homo sapiens, may also be among the living dead…not only the agent of the sixth extinction, but also one of its victims. Our species retains hereditary traits that add greatly to our destructive impact. We are tribal and aggressively territorial, intent on private space beyond minimal requirements, and oriented by selfish sexual and reproductive drives. It is possible that intelligence in the wrong kind of species was foreordained to be a fatal combination for the biosphere. Perhaps a law of evolution is that intelligence usually extinguishes itself."[430]

The use of new technologies in the hands of terrorists also worries those concerned about global security. "The 21st-century technologies—genetics, nanotechnology, and robotics—are so powerful that they could spawn whole new classes of accidents and abuses. Most dangerously, for the first time, these forces are widely within the reach of individuals or small groups. They will not require large facilities or rare raw materials. Knowledge alone will enable their use. Thus, we have the possibility not just of weapons of mass destruction but of knowledge-enabled mass destruction, its destructiveness, "…hugely amplified by the power of self-replication…it is no exaggeration to say we are on the cusp of the further perfection of extreme evil, an evil whose possibility spreads well beyond that which weapons of mass destruction bequeathed to the nation-states, on to a surprising and terrible empowerment of extreme individuals."[431]

While some of these concerns will certainly prove parts of our forecasts in error, the greater sweep of this Technological Revolution is almost certain to alter the social order around the globe over the next 20 years or so. As noted earlier, IT is now one of the most powerful forces on Earth, relentlessly transforming business, government, education, public awareness, and other institutions. It is also advancing the growth of knowledge at an unprecedented rate, driving the breakthroughs reviewed above. Some analysts observe an unusual pattern of "double exponential" growth in computer power, genetic coding, and other indices of scientific progress, suggesting that normal expectations of technological change could prove quite conservative in the face of such accelerating rates.[432]

Climate experts are worried that sudden changes due to global warming may result from positive feedback loops that cause runaway climate systems beyond human control.[433] For example, as the frozen tundra melts, methane gas may be released, which is also a potent GHG, adding to the concentration of GHGs in the atmosphere and accelerating global warming. Melting ice caps and glaciers could change the salinity of the oceans and change the global mechanisms exchanging heated water from the tropics with colder water from the poles (the so-called conveyor belt)—disrupting global climate patterns and perhaps sending parts of Europe into a mini Ice Age. As one leading observer puts it, "The present climate pattern is very delicately poised. This system could snap suddenly between very different conditions with an abruptness that is scary."[434]

While the details may be wrong, the broad technological profiles sketched out in this report are very likely to affect Asia and the Pacific dramatically over the next few decades. Drawing on the capabilities of nanotechnology, robotics, mass-customization, and other new fields, manufacturers will soon be able to deliver almost any conceivable product online, quickly, cheaply, and to order. Biogenetics should allow medicine to treat a far greater range of human ills in a decade or two with the efficiency of online systems. The internal combustion engine is likely to yield to hybrids and fuel cell cars along with various other transportation modes, all largely powered by alternative fuels that ease the economic and environmental problems of carbon-based energy. In addition, IT systems are almost certain to improve by another factor of roughly one million over the next 20 years, integrating all of this activity into a seamless web of communicating, computing, learning, working, and shopping that unifies entire societies and the globe.

Thus, there is little doubt that a Technological Revolution roughly along the lines outlined here will play a major role in the transformation of Asia and the Pacific over the next two to three decades. So the main question that requires long and hard thought is simply: Which of these technologies would be most beneficial for the region, and what is the best strategy for developing their capabilities? Only leaders and citizens of the region can answer these questions, but we offer three general guides to thinking on this huge challenge.

First, nations in Asia and the Pacific should reconsider the functioning of their universities, think tanks, and other research institutions. The source of this coming wave of technological innovation is, as always, scientific knowledge, and an entire discipline has risen recently offering powerful insights into the management of knowledge.[435] This report does not examine how research institutions should be redesigned, but it would be useful to ensure that all scientific knowledge is published, discussed, and accessed online conveniently by scholars of the region. It is also urgent that scientists have the resources, freedom, and support needed to collaborate with their peers. It is of the greatest importance that this intellectual energy be guided effectively toward research offering the greatest strategic opportunities for the people of the region. Many scientists and engineers have migrated from the region seeking greater freedom and employment opportunities elsewhere; they need to be encouraged to return home.

Second, corporations from the region should reconsider how effectively they work together in developing commercial products. The era of isolated companies locked in battle with one another over limited markets has yielded to a new ethic of "coopetition," in which alliances offer great strategic advantages. Almost all large corporations today have hundreds of strategic alliances, often with their competitors. The Chinese family capital and investment networks of the region provide an interesting model from which to build. How can corporations from the region work together to develop a regional network that facilitates alliances? Is there a role for trade associations or governments in developing systems designed to match optimal strategic partners with each other? Could this system in time be extended to include collaboration with European and American corporations?

Finally, economic systems themselves are evolving under the imperatives of a knowledge-based world, raising interesting questions about the "Asian economic model." An unusual opportunity may exist for Asia and the Pacific to take the lead in moving the world toward a more sustainable model of economic development.

A decade or so ago, Japan led the world with its commitment to a form of business stressing employee participation and job security, working closely with suppliers for continuous improvement, and supportive alliances with keiretsu partners, all guided by government leadership. These practices highlight the power of a "social technology" described above as stakeholder collaboration. Meanwhile, other companies from the region gained notoriety for developing a "distributed" enterprise system in which small business units were allowed the autonomy to be innovative. This prestaged the powerful social technology of "self-organizing systems." It seems that the region has a strong cultural predisposition for the application of both of these "new" approaches described above as the dominant global trends in today's rapidly changing institutions.

The people from Asia and the Pacific are vastly diverse, of course, but it would be useful to have corporations and governments engage in a regional dialogue to more systematically define the unique principles that have made the region a formidable player in the global economy. Americans are committed to a more extreme form of capitalism that is dynamic and creative but harsh. Europeans have developed a more socially oriented market system that is reasonably productive and supports the highest quality of life in the world. Can Asia and the Pacific embrace a model combining these two poles of entrepreneurial creativity and social harmony?

A large body of research suggests the two approaches can be unified into far more powerful economic systems. An honored scholarly tradition has studied alternative economic models operating around the globe and consistently finds them superior to conventional systems.[436] Furthermore, the absence of an improved, 21st century model of the large public corporation seems to be one of the greatest obstacles to a sustainable form of globalization. For lack of political initiative, no major nation has successfully moved these creative practices into the economic mainstream. An empty niche persists in the global economy for a synthesis that could be called "democratic enterprise," "markets with a human face," or "entrepreneurial community."

The challenges of adopting some type of hybrid economic system are enormous, but so are the potential gains. It is precisely such unresolved differences that drive growth of any type. Different energy levels are needed to power any mechanical engine, and price differences energize an economy. Likewise, synthesizing the powers of both entrepreneurship and community in corporations and the economy could unleash far greater financial wealth as well as tremendous social progress.

From this brief exploration of emerging technologies and their environmental implications, it should be obvious that there is no "silver bullet" waiting in the wings to solve all of humanity's economic or environmental problems. Any suggestion that technology will provide simple solutions is misleading and misguided. Almost all new technology needs to be treated with some skepticism on (i) how rapidly it will become mainstreamed in commercial markets, (ii) the ease of adoption in developing countries, and (iii) its contribution toward environmental and social improvement. The dual-edged sword characteristic of technology appears to be a generally applicable rule.

A change in mindset is needed to ensure that (i) research is devoted to the most promising technologies, (ii) inventors and innovators are rewarded for environmentally beneficial advances, (iii) companies are provided with incentives to develop such technologies, and (iv) barriers are removed from diffusion of the best technologies to developing countries. A broad coalition of stakeholders needs to work together to ensure that maximum pressure is applied to all decision makers to make choices in favor of environmentally beneficial technologies and to penalize choices that go in the opposite direction.

"Markets and technologies are merely tools that serve the goals, the ethics, and the time horizons of the society as a whole. If a society's goals are to exploit nature, enrich the elites, and ignore the long term, then that society will develop technologies and markets that destroy the environment, widen the gap between the rich and the poor, and optimize for short-term gains."[437] The need is to change the feedback structure or information links in our society so that a common set of ideas, goals, incentives, costs, and feedback all point in the same direction to a shared vision of sustainable development. "The trick is to choose the best (technology) for any given situation, in terms of both solving a particular problem and avoiding the creation of a whole new set of problems."[438]

We need to decide how to (i) increase expenditure on new environmental technology, infrastructure, goods, and services; (ii) help lagging countries and corporations to leapfrog over dirty, outdated technologies and policies; (iii) examine thoroughly the environmental and social implications of emerging technologies before they are introduced; and (iv) ensure that solid, traditional values that could underpin sustainability are not lost in the process of globalization. How do we ensure that business, governments, and civil society turn away from the currently dominant paradigm of economic growth at all costs and focus on patterns of development and technology application that will aid and abet a transition to a sustainable future rather than dreaming up new ways to consume the Earth's resources? Here too, the emerging technologies reviewed offer insights to a vision of companies that are making profits and protecting the planet.