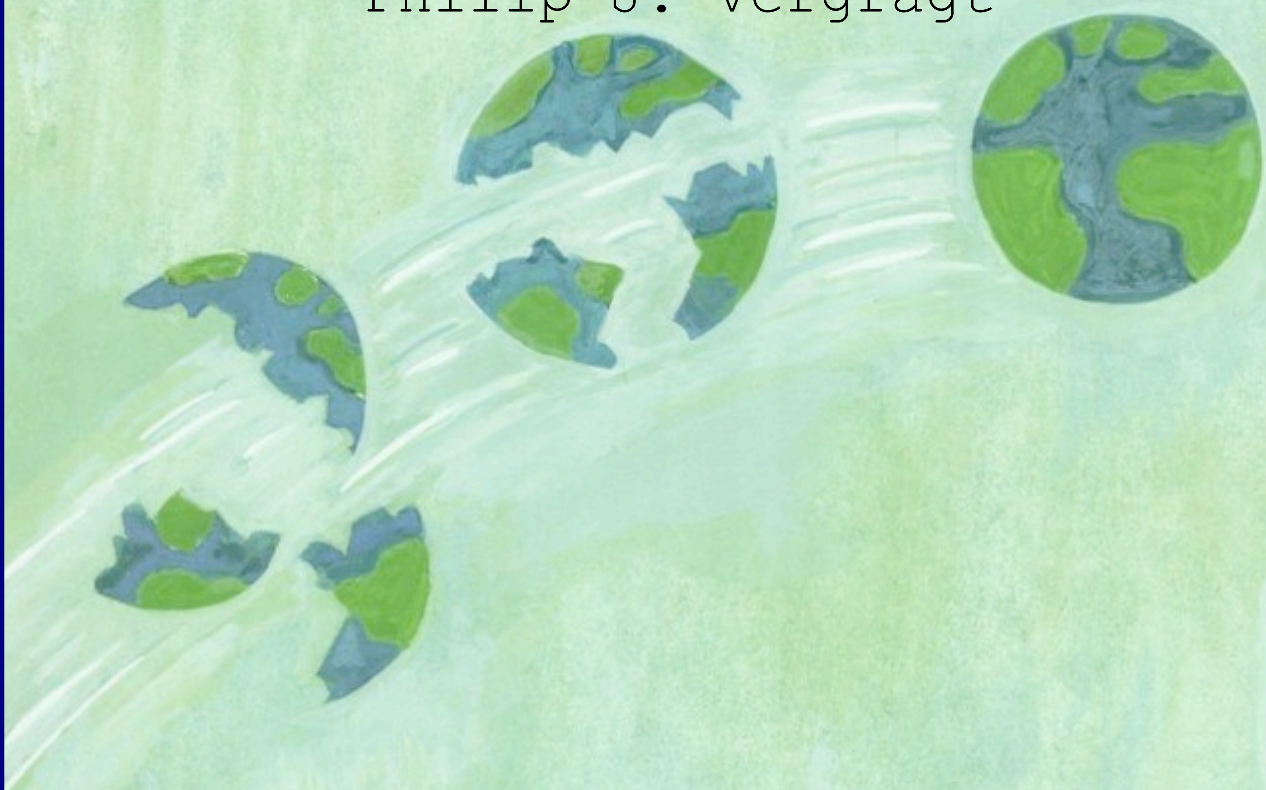
How Technology Could Contribute to a Sustainable World

Philip J. Vergragt



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Introduction

The paradoxes of technological development

The effects of technology underlie early twenty-first century global challenges. On the one hand, since the Enlightenment, technology, especially science-based technology, has offered the promise of a better world through the elimination of disease and material improvements to standards of living. On the other hand, resource extraction, emissions of dangerous materials, and pollution of air, water, and soil have created conditions for unprecedented environmental catastrophe and have already caused irreversible damage to the biosphere. While the future might promise a vast acceleration of technological innovation, the scale and impact of environmental degradation may reflect this vast acceleration as well.

A related painful paradox is that, despite the ongoing technological revolution, the majority of the world population still lives in abject poverty with inadequate food, housing, and energy, plagued by illnesses that could be easily cured if clean water and simple drugs were made available. Fortunately a significant number of former "developing" countries are now on the threshold of development, helped by technology transfer and technological innovations that have benefited large parts of their populations. Some countries, such as China, India, Korea, Taiwan, Singapore, and, to a certain extent, Brazil, have followed their own technological trajectories. However, for large populations in Africa, Asia, and Latin America the benefits of technology remain a dream, even if new technologies like photovoltaic cells, cellular phones, and the Internet could help them "leap-frog" towards the twenty-first century.

The persisting contradictions between a better life created and supported by technology for the wealthy few, and increasing environmental degradation and persistent poverty for the vast majority call for a deeper exploration and understanding of the nature of technology and its relationship to society, especially to a sustainable society. In the context of the effort to catalyze a *Great Transition* to a sustainable global society, in which deep changes in culture, values, consumption patterns, governance, business, and institutions are envisaged (Raskin et al., 2002), questions about the role of technology become even more pressing. For example, would a *Great Transition* society require an intensive use of technology to abate the environmental degradation of the ecosphere, or might technology play a much more modest role in such a society? Would that society essentially return to the time before the first industrial revolution when technology offered a limited, incremental extension of human capacity to transform nature? In either of these visions, we must ask how to imagine the development of technologically and economically underdeveloped countries.

Aim of this essay

The aim of this essay is to envision a sustainable and equitable global society through reflection on the role of technology during the transition to such a society and in that society's future. In a *Great Transition* society, technology will support and enhance a "good life" for all of its citizens, in both rich and presently poor countries, without compromising the Earth's ecosystem or the prospects of later generations. A good life requires essentially that basic human needs are met and aspirations for freedom, belonging, and self-realization are fulfilled as much as possible (see Stutz, 2006). It does not necessarily mean the maximization of material production and consumption.

Thus, we consider technological innovation in the context of the good life and how it can be supported or threatened, depending on the way technological innovations are influenced and steered by human decisions and institutions.

Meanings of "technology"

The word "technology" encompasses essentially three meanings: *tools and instruments* to enhance human ability to shape nature and solve problems (such as a hammer and nail), *knowledge* of how to create things or how to solve problems (such as to brew beer or to make an atomic bomb), and *culture* (our understanding of the world, our value-systems). Historically, the emergence of human civilization has been closely connected to the development of tools for hunting, agriculture, irrigation and water management, and navigation. In the second meaning, knowledge, technology becomes reflexive in that understanding of how to make and use tools and instruments becomes encoded and transmissible as technological knowledge and know-how. Related to this second meaning of technology is the development of modern scientific knowledge, based on empirical observations, hypotheses, and generalizations on the natural laws concerning the behavior of materials and the living environment.

In the third sense, culture, technology has permeated society to such an extent that separation between technology and culture is no longer meaningful. All human activities, like housing, nutrition, transportation, work, leisure, even art and imagination, become heavily enmeshed with technology. We "own" products of technology by a process of "cultural appropriation", in which the use of technologies is learned, interpreted, and given meaning in everyday life. (Hard and Jamison, 2005). We are living in a "culture technique" in the sense that our deepest and most private knowledge and emotions are permeated by technology.

The transition from technology as tool use to knowledge began around the emergence of the first industrial revolution more than two centuries ago. The transition to technology as culture accelerated after the Second World War and is closely related to the rise of information and communication technologies, biotechnology, computers, and the Internet.

In contrast to technology, science is seen as an organized search for "truth" and "objective knowledge" about reality and the laws of nature. Science can be characterized by a rigorous methodology exemplified by Popper's claim that science is an unending process of conjecture and falsification. In practice, the boundaries between modern science and technology have become blurred; moreover, modern philosophy of science treats scientific knowledge to a certain extent as "socially constructed" (see also the section on decision-making and new technologies below). In this paper, we focus primarily on technology, but science is relevant as one of the pillars of technological knowledge.

In the literature, technological innovation is generally understood as bringing a new product, process, or service successfully to the market, meaning that it can be sold for a profit (Freeman, 1997). Technological innovation thus goes beyond invention, which depicts the elaboration and prototyping of a new technological principle; it is related to diffusion, which refers to the spread of new technology into the wider society. Of course, innovation is by no means identical with creating the physical conditions for a "good life" as defined above. Because of companies' profit motives, as well as unintended and unforeseen consequences, the contribution can be both positive and negative. In a *Great Transition* society, the definition of technological innovation will be changed (See Section 4, "How did we get there").

Societal consequences of technological developments

Seventeenth-century thinkers such as Descartes and Bacon thought that science and technology unlocked the keys to mankind's mastery over nature, which they saw as synonymous with human progress. Since the Enlightenment, the development of modern science and technology has been associated with the triumph of reason and science over superstition and religion. Knowledge based on empirical observations and rational thinking has been the basis on which technological innovation has thrived. Modernization and modernity have been synonymous with technological innovation.

The idea that science reflects reality or even absolute truth has been challenged in many ways, from critics of its reductionism to critics who emphasize that scientific facts are as much socially constructed as a reflection of natural laws (Latour and Woolgar, 1979). In *The Structure of Scientific Revolutions*, in which he argued that theories and facts have only meaning within a dominant "paradigm", Kuhn (1962) laid the groundwork for challenging logical positivism. Latour and Woolgar (1979) followed by showing in an anthropological study of the modern scientific lab, how scientific facts are "socially constructed" through interpretations by scientists of scientific measurements. Thus, the myth of the "objective scientific fact" was challenged and demystified. This work was followed by the demystification of technology by the SCOT (Social Construction of Technology) theory (Pinch and Bijker, 1987; Bijker, 1995)

The idea that technology could have unwanted or unintended consequences is also relatively new. Although the Luddities of the early nineteenth century smashed the machines that were seen as a threat to their employment, and the Romantics decried the dehumanizing march of industrialization, more widespread anxiety about and resistance to technology did not emerge until the mid-1900s. The unprecedented destruction unleashed by the atomic bombing of Hiroshima and Nagasaki spurred many people to question the nature of the individual scientist's ethical responsibility. To what extent is the scientist accountable and responsible for unwanted and often unforeseen consequences of his/her work? From that moment, the assumption of a self-evident linkage between societal progress and technological innovation has been questioned (Carson, 1962).

Technology came under increasing scrutiny as a result of the use of Agent Orange during the Vietnam War and the persistence of dioxin contamination and birth defects among U.S. service members and the Vietnamese thereafter. Next came the protests against nuclear energy and the possible health consequences of low doses of radiation from nuclear testing, uranium mining, and nuclear waste. Other environmental and health problems followed: the consequences of air pollution, soil pollution, and water pollution on health, safety, and the environment; the accumulation of DDT, heavy metals, and PCBs in the food chain and in the reproductive organs of animals and humans. With the increase of biochemical knowledge—the possibilities of manipulation of the DNA of microbes, plants, and animals—new hazards were created: man-made mutations and pathogens that created new risks for health, safety, and the environment. The nuclear, biological, and chemical arms race of course contributed to these anxieties.

Early questions addressed not only the individual social and ethical responsibility of scientists, but also the structural and even cultural connections between modern science and technology and the economic and political systems. President Eisenhower coined the term "military-industrial complex" to describe the close relationship between the Pentagon and the corporate defense industries and the Cold War ideology, which was used to increase demand for new weapons systems and armaments—a perpetual wartime economy. But the basic alliance between corporations and technology emerged much earlier, in the late nineteenth century when the large chemical, electrical, and automobile companies were created, mainly in the USA and Germany.

Technology and the military merged on a large scale in the Manhattan Project and in the nuclear arms race after the Second World War. Since then, information, communication, biotechnology, energy technology, and medical technology have all developed in "complexes" consisting of universities, large industrial firms and their R&D laboratories, small spin-off firms, and military research and development facilities. Financing is provided by a combination of military and business funding. At least in the "developed" world, citizens benefited from this unprecedented acceleration of innovation, which produced a surge of new products such as radio and color TV, microwave ovens and innovative cars, new medicines and medical technologies, computers and the Internet, and airplanes to take affluent consumers to holiday resorts.

At the same time, social critics continued to voice concerns about the pace of change and increasing fragmentation of modern life. For these critics, new products and services came at a price. Not only did environmental and health effects become problematic, but the increasing rationalization of all aspects of life through technology also led to a deeper feeling of alienation and dislocation. Jobs were lost to automation and to outsourcing of production to low-wage countries. The globalization of production itself was made possible by new transportation, information, and communication technologies. People in the USA found themselves working harder and longer hours, and families suffered as often both parents worked full-time to pay the mortgages on their houses. Many people felt that they were no longer masters of their own lives, locked into a lifestyle determined by a demand to keep pace with new technologies. A present example of such "lock-in" is that of suburban residents being trapped in traffic jams and congestions due to urban sprawl. Decisions made on the individual level by consumers, in this case purchasing readily available cars and suburban homes, often do not work out well when aggregated to the societal level.

Decision-making on new technologies

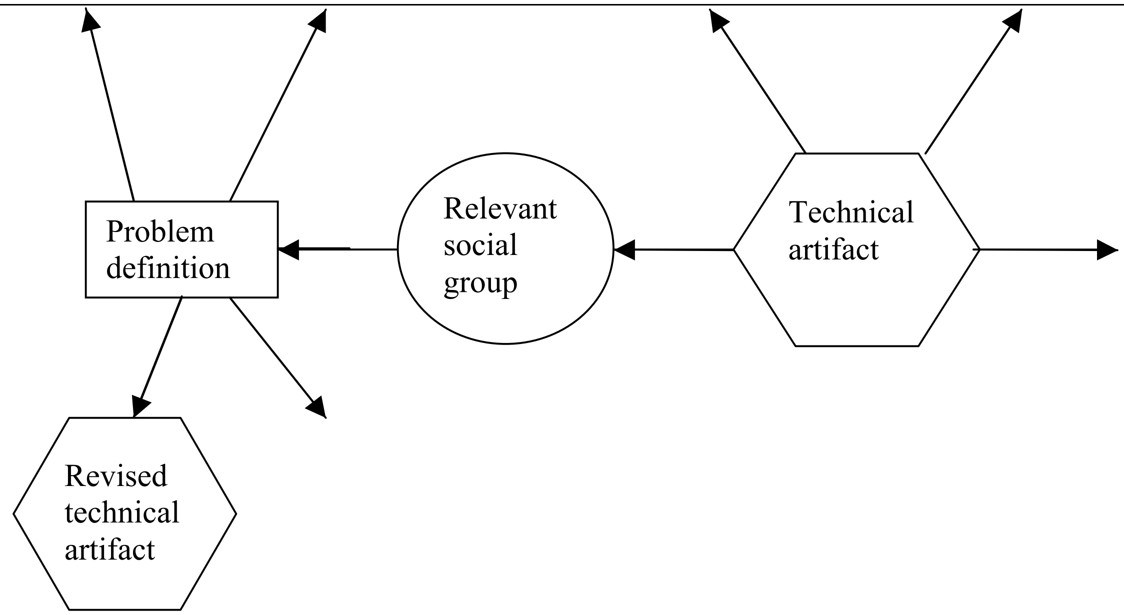
Technologies co-evolve with societies (Saviotti, 2005); technological developments influence society and vice versa. The questions about who makes decisions about the development and direction of new technologies have seldom been asked and even less often answered. In academic circles in the 1960s and 1970s, questions were increasingly voiced about wanted and unwanted consequences, both foreseen and unforeseen, and the direction and steering of new technologies in science, technology, and society studies, technological forecasting, technology assessment (Smits and Leyten, 1988), technology policy, and appropriate technology (Vergragt, 2003). Some of these studies were used by the military and corporate planners to better forecast and assess the optimal directions of future technologies; others were used to warn against possible catastrophes. A well known example is the 1972 Club of Rome forecast about a looming energy crisis and the possibility of the exhaustion of fossil fuels.

Apparently, the development of science and technology from tools to an encompassing culture obscured questions about their helmsmanship, especially the possibility of democratic decision-making directing them. Such questions were obscured as well by the dominant philosophy and history of science and technology that emerged in the 1930s (empiricism and logical positivism), which posited that scientific invention is driven by innate human curiosity and that scientific discovery eventually leads “automatically” to technological application and commercial deployment. This approach, generally called the “linear model” of technological innovation, in which “science invents”, “technology applies”, and the “markets select”, suggests that some inexorable laws of nature, rather than human choices, are directing this endeavor (Fig. 1).

Figure 1: The linear model of technological innovation

The linear model, also called “technological determinism”, is no longer supported by many academics, but is still widely believed in general society. Research into the processes of scientific and technological discovery has shown that the linear model is not valid, disguising the role of human choice and values in shaping technology, as well as the social and economic interests guiding scientific inventions and technological innovations. It has been replaced by models like Social Construction of Technology (SCOT) (Pinch and Bijker, 1987; Bijker 1995) and Actor Network Theory (Callon, 1986; 1987). These theories include social actors, problem definitions (Vergragt, 1988), and social networks. For example, in the SCOT theory, technological innovation is steered by the meaning that “relevant social groups” give to a technological artifact, generating problem definitions that lead in turn to adjusted technological artifacts, a process highly contingent on the particular context (Bijker, 1995; see Fig. 2).

Figure 2: Social Construction of Technology



A technical artifact creates problems for several "relevant social groups", which results in one or more problem definitions. These problem definitions lead to a revised technical artifact. The process is highly contingent on contextual factors (after Bijker, 1995).

Because of persistent broad acceptance in society of the myth of the linear model, the question of democratically determined guidance of science and technology seems like an oxymoron in the minds of most, even well-educated, citizens. Even when the linear model is understood to be false, a second myth holds that market forces are so strong that democratic decision-making about science and technology is unthinkable in a market economy (and, of course, science and technology in a totalitarian society are hampered by limits on the free flow of information). Research has demonstrated that defense interests in most market economies dominate the research community to such a degree that, in a "free society", "market forces" do not determine the development of science and technology. Even one of the most "democratic" developments of the late twentieth century, the Internet, was originally designed and developed by DARPA, the Pentagon's military research establishment.

A third myth is "technological fix" thinking, which is the belief that technical means alone can solve most problems, including the unanticipated consequences of technological innovation itself. Examples are the belief that the problem of hunger can be solved by biotechnology or that health problems can be solved by more drugs (instead of improving water and sanitation). Other examples include the belief in hydrogen to solve energy problems (Vergragt, 2006) or carbon capture and storage as a solution to the climate problem. Related are the ideas that terrorism can be solved by a technological "war" or by technical safety and vigilance measures.

Each of those myths obscures seeing the possibilities of democratic decision-making regarding technology. Of course, to see the possibilities is not to claim that democratic decision-making about technology would be easy. Indeed, there are many inherent problems: science and technology are difficult to understand for most people (Loka Institute, 2006), the consequences of decisions are hard to foresee, and scientific communities have their own systems of quality control that should not be criticized or superseded. On the other hand, it certainly makes a difference if society directs funding to the development of renewable energy rather than nuclear energy, or to eradicating the world's most prominent diseases, such as malaria and tuberculosis, rather than drugs for prosperity diseases and high-technology medical equipment. It also would make a difference if we could change the laws and the institutions regarding accessibility of scientific information—the patenting laws—that regulate intellectual property and the related profits.

Lay-out of this paper

So, how could technology (and what technologies could) contribute to a sustainable society as envisioned in the *Great Transition* scenario? In order to explore this question, we will develop a broad-brush picture of future technological developments and some of their societal consequences (Section 2). We then will develop a vision of a *Great Transition* world with a focus on technological aspects (Section 3). Finally, we look back from the future and explore events, pathways, mechanisms, and choices that contributed to the realization of that vision (Section 4).

Technological Developments and Future Studies

Two approaches

In this section, we follow two lines of thought. The first considers some of the dominant developments in so-called high-tech: information and communication technologies, biotechnology and health technology, and new materials and nanotechnology. The second line explores the so-called "alternative" technological developments, such as appropriate technology and traditional health and medicine. Although these latter technologies have been developed from a different perspective than modern industrial technology, they are relevant for developing a more holistic view of science and the sustainability challenge.

Technological forecasting and its pitfalls

Forecasting the development of innovative, especially entirely new technologies is, of course, very difficult. The history of past efforts is full of false predictions and disappointments. Some of the most impressive technological developments, like the personal computer and the Internet, were not anticipated by anyone. Most forecasts turn out to be too optimistic about the short-term introduction and too conservative about the societal consequences in the long term.

Technological forecasting has developed into a scientific discipline of its own, with distinctive methodologies such as scenario building and Delphi studies (based on questioning experts), trend extrapolation, and system dynamics. The motivations and goals of technological forecasting are quite divergent: they range from fundraising for present R&D projects by raising expectations about future benign applications (Van

Lente, 1993) to the stimulation of a broad societal debate about unwanted consequences of new technologies. Technological forecasting is closely related to Technology Assessment, namely the systematic evaluation of possible societal effects of new and emerging technologies. Technology Assessment itself has become closely associated with technology policy, through which government stimulates socially desirable technologies by using policy instruments. These include R&D subsidies, public-private cooperative projects, and regulation to avoid unwanted consequences such as environmental degradation and health issues as well as to encourage desired technological innovations (Smits and Leyten, 1988).

One of the problems with technological forecasting is that it necessarily focuses on technologies rather than on the functions they may fulfill in society. In this essay, our goal is to consider the possibilities for sustainable housing, transportation, water management, and, in general, for the fulfillment of human needs rather than the specific technologies that may enable these needs to be met (Weaver et al., 2000; Max-Neef, 1989). We will address the broader issues in Section 3, but here we shall focus first on the forecasting of current technological trends.

Based on the limitations discussed above, the technological forecasts described below need to be read with considerable care. On the one hand, they reflect the current scientific literature and are thus credible to a certain extent. They cannot be dismissed as “hype” or “spin” as many critics may be inclined to do. They could become true. They certainly reflect what could happen if technological developments continue mostly unchecked as they have done in the last fifty to one hundred years. On the other hand, the scope of this essay is to lay out possibilities for alternative directions in technological innovation, reflecting the SCOT (Social Construction of Technology) model of technological innovation, where technologies are to a certain extent shaped and influenced by societal forces.

Prospective and normative scenarios: a digression

The differences between technological forecasting and the future fulfillment of sustainable function mirror the difference between prospective and normative scenarios. In a prospective scenario, present trends and developments are projected into a story about what the future might look like and how we might get there. Of course, a wide range of possible futures can be projected, depending on how different drivers develop and unforeseen incidents like calamities, war, unexpected discoveries, and the impact of social movements.

In a normative scenario (Raskin et al., 2002; Vergragt, 2005), a vision is sketched of a desirable future that is thought to be at least possible, if perhaps not probable. A sustainability scenario is thus a normative scenario of a future sustainable society. Of course, a normative, like a prospective, scenario contains a narrative about how to get there, which by definition encompasses “deep change” processes in individuals, institutions, society, values, and very likely also technological developments. We return to normative sustainability scenarios in Section 3.

Biotechnology and health technology

Perhaps the most challenging developments in technology are taking place in the realm of biotechnology. Genetic modification of crops has already made it possible to increase their yield, protect them from insects and pests, and enable them to grow in brackish water, among many other unprecedented alterations. We are at the beginning of a vast trajectory of modifying plants and possibly animals and other living organisms. While some writers endorse these developments in order to address the problems of feeding an increasing world population, others, especially in Europe, find these developments highly suspect (Krimsky, 2005). Some critiques highlight contamination of seeds, access to non-modified food, reduction of biodiversity, and especially patenting of living organisms. A more general issue is the control wielded by big multinational biotech corporations, such as Monsanto, over farmers and the farming enterprise.

Developments in the field of health technology have also been spectacular. Since Nixon in 1971 declared a "war on cancer", the USA has spent between fifty and 200 billion dollars for basic research related to understanding and treating cancer. The result was a great advancement in the fields of molecular genetics, developmental and cell biology, and immunology. Although the universal "cure" for cancer has not been found, the advances in medical biotechnology have been impressive. Nonetheless, critics see an imbalance between the promises of modern health technology and the lack of progress in eradication of common third-world diseases like malaria and tuberculosis.

The mapping of the human genome opens up the possibility of targeting hereditary diseases in a much more fundamental way than has been possible in the past and the development of drugs that are more pinpointed on specific illnesses and even specific persons. Genetic manipulation of human hereditary material—likely to become possible in the future—initially will be pursued for the elimination of hereditary diseases, but not so far beyond that phase, the possibilities of "improving" human beings will take shape in ways we cannot foresee now. In a related vein, the cloning of human cells opens the door to the creation of factories where human organs can be grown and harvested from brain-dead organisms, to replace faulty organs without the problems of tissue rejection that we experience now.

Kurzweil (2005) discusses the possibility of injecting human stem cells into the blood stream to rejuvenate human organs and thereby far extend longevity. We can glimpse a future in which humans could be tailor-made from specifications (Ishiguro, 2006), people live much longer than they do now, and illnesses could be targeted by very specific drugs designed according to the patient's individual genetic make-up.

For the time being, such possible developments are highly speculative. As they do arise, they will be as controversial as GMOs (genetically modified organisms) and the patenting of living material are at present. Unfortunately, these debates often take place after the discoveries are made, and the social consequences become clear (the famous "Collingridge dilemma"[*]). These developments will again generate normative and ethical questions about where the boundaries lie in human interference with nature. A special

[*] In an early stage of technology development, forecasting its consequences is very difficult. Once the technology is further developed, steering away from undesirable consequences may have become impossible (Collingridge, 1981).

area of concern is the possible development of next generation biological weapons which may be much more targeted on specific human characteristics.

Nanotechnology

Another fast-emerging technology is nanotechnology, basically the design of technology at the molecular level. A Greenpeace report (Arnall, 2003) identified two broad classes of nanotechnology production technologies: top-down and bottom-up. Top-down includes optical techniques, lithographics, and the "scanning probe microscope", which are used to create elaborate surface patterns on a nanometer scale. Bottom-up processes are molecular engineering and may include self-organization and self-assembly of molecules. Perhaps the most well known examples of nanomaterials are "buckyballs", or fullerenes, and "buckytubes", or nanotubes, which are curved carbon-carbon surfaces wrapped into a sphere or a tube, respectively, with remarkable properties, especially for absorption and lubrication.

Some current and near-future applications of nanomaterials include catalysts, dry lubrication, coatings, clothing, and materials. The most important current applications, as measured by the number of patents, are in micro-electronics: massive storage devices, flat panel displays, electronic paper, extended semiconductor approaches, and information processing, transmission, and storage devices. Beyond this, there are more far-reaching ideas about "DNA-computing" and computational self-assembly. The main drivers for these developments are computing, telecommunications, consumer electronics, and military applications.

In chemistry and pharmaceuticals, nanotechnology promises new forms of drug development and delivery, medical diagnosis, and cancer treatment. Nanotechnology in combination with biotechnology underpins rapid advances in genomics, combinatorial chemistry, high throughput robotic screening, drug discovery, gene sequencing, and bio-informatics and their applications. Targeted drug delivery (delivering a drug to a specific place in a body) is a very promising area. The size of the market is the main driving force.

For the energy sector, lighting technologies based on nanotechnology could reduce the energy demand for lighting. In photovoltaics, nanotechnology could raise efficiency and lower costs. In the military sector, nanotechnology may contribute to surveillance, sensors and barrier systems, small anti-tank weapons, and smart munitions. Nanotechnology may also contribute to virtual reality systems; automation and robotics; chemical, biological, and nuclear sensing; and aerospace, food processing, and construction industries. One of the most evocative possible applications could be "nanobots", or robots on a nanoscale, which could be introduced into the bloodstream to clean unwanted substances from blood cells or veins.

As with many other new technologies, nanotechnology may have wide and pervasive implications, especially in combination with other emerging technologies such as genetic engineering and information and communication technologies (Fleisher et al., 2004; Merkerk et al., 2005; Royal Society, 2004). There are obviously environmental and health concerns about nanotechnologies (Glenn, 2006): the effects of infiltration in humans (through tanning creams among other possibilities), the possible attachment of high concentrations of toxic substances, the effects on living systems, the possibility of slipping past the immune system, the potential damage to lungs by nanotubes. More frightening potential dangers are runaway self-replication in nature and a nanotech arms race. Many writers stress the need for more attention to ethical issues, even for a moratorium on research in order to first create better regulation (ETC, 2003).

Information and communication technologies; Artificial Intelligence

Information and communication technologies will continue to rapidly develop. It seems certain that economically privileged people everywhere will be in more or less constant communication and interaction with each other through mobile phone, Internet, teleconferencing, and GPS technology. The Internet and its successors will enable unprecedented exchange of information and knowledge across the globe. The Internet already is bringing together like-minded people from different cultural and economic environments. Computers will become smaller and more ubiquitous, growing from their current deployment in housing and transportation to new applications like clothing and food wrappings. In the realm of technological innovation, it is expected that the miniaturization of memory chips and microprocessors will continue to proceed at the same high speed (Moore's law). The implications of these and other developments are highly uncertain. Kurzweil (2005) speculates about the possibility within the next twenty to thirty years of a human-machine "singularity": the merger of human and machine computational intelligence to create something that goes far beyond human intelligence. Kurzweil bases his speculation upon the likelihood that computation will increase exponentially. Similarly, our understanding of how the human brain works is growing very fast. It is foreseeable that we will be able to implant computers in parts of the human brain to improve its functioning. We might even be able to "upload" the human brain function to macro computers. So we might be able to enhance biological intelligence with non-biological and vice-versa. In 2030 we may have computer entities that seem to be conscious and claim to have feelings.

Kurzweil's projections exemplify the technological determinism approach and tech-fix thinking. He even claims that hunger and poverty may be eliminated by these new technologies. His overarching view sees technology itself as an exponential, evolutionary process, the continuation of the biological evolution that created humanity.

These speculations (some say extrapolations) raise provocative questions about the nature of Artificial Intelligence (AI). Recent literature has documented a renewed interest in AI. Anderson (2005) cites Thomas Georges' "Digital Soul" (2003), in which he investigates the implications of intelligent machines outside human control. He not only asks the obvious questions, such as "What does it mean to be intelligent?" and "How different will machine intelligence be from human intelligence?" but also less obvious ones such as "Will it be morally allowable to make intelligent, autonomous machines work for us?"

Of course AI raises questions about human intelligence, human identity, human consciousness, and ultimately, what constitutes a human being. If we understand the human brain well enough to replicate its functions and combine cells from separate brains, we might ultimately be able to speed up human intelligence processes. This is Kurzweil's speculative prediction. Questions remain: Will this really be possible and what would we achieve by doing it? Would we be able to control its development and would it be desirable to do so? Might the value of such unbound intelligence be that human beings do not control it?

Interactions and mutual reinforcements

It is compelling to speculate about the mutual interactions and combinations of AI, information and communication technologies, nanotechnology, medical technology, biotechnology, and energy technologies. Mutual reinforcements between and among these technologies seem probable. Early examples include the interface of information and biotechnology in the human genome project and the possibility of targeted drug delivery by nanotechnology. Such interfaces and reinforcements are likely to lead to greater acceleration of growth and development in these technologies.

The forces driving the technologies may also change in the future. In the past, military, space, and health technologies have been driving forces, with spin-offs to the consumer market. In the future, the scarcity and high prices of energy, the pressure of environmental deterioration, and new threats of terrorism may create new drivers. In this context, while the combinations of new technologies may have benign social applications, they could combine to undermine sustainability, e.g., through use in a new arms race or for terrorism. These uncertainties provide the new context for re-visiting old questions about forecasting and assessments, decision-making and control of new technologies (MIT, 2006).

Appropriate technologies

In contrast to the areas of so-called high-tech innovation and development we have considered so far, there is a very different strand of technologies, often called intermediate (Schumacher, 1973) or appropriate technologies. At present, these are found primarily in the rural third world, but also in pockets of the "developed" countries (Vergragt, 2003). Appropriate technology is small scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community. The breadth of the paradigm of appropriate technology is suggested by the many terms used to describe it: *intermediate, progressive, alternative, light-capital, labor-intensive, indigenous, low-cost, community, soft, radical, liberatory, and convivial* (Akubue, 2000). Schumacher envisioned a technology for the third world that was midway between, for example, a hand hoe and a tractor. As Schumacher described it, "such an intermediate technology would be immensely more productive than the indigenous technology…but it would be immensely cheaper than the sophisticated, highly capital-intensive technology of modern industry" (Schumacher, 1973, p. 180).

Appropriate technology has been advocated as a solution for rural development problems, but has also gained support as a direction for sustainable technologies. However, it has often been identified as "cheap", "second hand", or second best by adherents of massive Western technology transfer to developing countries and by ideologues who believe in modernization by technological innovation.

Many features of intermediate or appropriate technologies could be used in the development of technologies for a sustainable society, especially when used in synergy with high-tech developments. These include their orientation toward human needs, control by and empowerment of local communities, and small-scale distributed energy that is high in efficiency and labor intensiveness and low in cost and environmental impact. The renewable energy movement in the USA and Western Europe emphasizes some of these elements. The challenge going forward is to learn from past mistakes and to combine elements of appropriate technology with some aspects of high-technology into a new paradigm of sustainable technology.

*Health care in Asian societies**

There is a close relationship between appropriate technology and traditional or "indigenous" knowledge. Health care in Asian societies is a good example. In Asian societies, and perhaps increasingly even in societies in developed Western countries like Australia and the United States, the organization of health care services has been characterized by a pluralism that is not reflected in the *official* policy-making institutions. Health care, where it is driven by *official* policy-making institutions, is dominated by "modern" medicine developed largely in the West. This modern medical system was transposed to the colonies during the earlier part of the last century. In many Asian societies, the introduction of modern medicine through the hospitals and other institutions established by colonial administrations meant the marginalization and even erasure of indigenous medical traditions that had been in use for hundreds if not thousands of years.

The persistence of the practice of Chinese medicine and other medical traditions is not surprising once the status of colonial health care and other social provision is understood. While colonial forces disparaged Asian medical traditions, they did not succeed in making their Western alternatives widely available. Traditional health care providers continued to provide migrant groups with their only source of health care.

Chinese medicine is an example of a medical tradition that has seen fast changing fortunes in the colonies of Southeast Asia and in China as well, particularly in the earlier period of the twentieth century. Medical traditions like Chinese medicine have continued to thrive and actively contribute to modern health care in Southeast Asian countries like Malaysia, Singapore, and Thailand. Certainly in China, traditional medicine has been strongly endorsed as part of the communist ideology of "walking on two legs" —Eastern and Western, or modern and traditional. In societies in Southeast Asia, Chinese medicine is supported solely by the private sector, since it receives little endorsement from the state. Patients who consult with the practitioners of Chinese medicine may pay more than if they had gone to a doctor trained in modern medicine, yet Chinese medicine continues to draw patients who trust this tradition and its practitioners. To a large extent, health care beliefs are handed down through the generations.

The continued patronage of traditional medicine in spite of the existence of a well-developed modern health care infrastructure strongly argues against a single perspective of health and medicine dominated by modern medicine. Health care pluralism can prove to be sustainable in the long term if the delivery of services is organized to be far more inclusive than it has been of established medical traditions with which people are familiar, particularly in developing countries.

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* Contributed by Dr. Ling Giok Ooi.

Summing up

In this section, we described possible future developments of high technology and some alternative models. We started with a note of caution about the value of technological forecasting and trend extrapolation. Exploring the future is full of risks and uncertainties. On the other hand, scientific and technological developments are occurring fast, while human institutions to control and direct them are virtually undeveloped. We may well experience some technological surprises before we know how to react to them. Although contemporary theory depicts technological innovation as a highly socially embedded phenomenon, in practice it is steered by the dominant societal interests and difficult to influence through democratic institutions. Technology could help us to develop and take steps towards the realization of a vision of a sustainable *Great Transition* world, but only if the “right” decisions on technological innovations have been made in an early stage of their development.

Visions of Technology in a Sustainable Society

Introduction

In this section, we develop three visions for a possible sustainable society in which technology plays a significant role. These visions are not based on technological forecasting, but rather take into account the possibilities that modern and future technologies offer if they are steered in the “right” direction. The “right direction” is of course not a priori. Its elements will be a “good life” and “well-being” for all now and in the future, sustaining the Earth’s ecosystem, banning poverty and related health and housing issues, a sustainable agricultural and food system, and employment and leisure for all. Technologies could help achieve that, if actively directed by the right drivers, institutions, and steering mechanisms. In the next and final part of this essay, we will further explore questions about “how to get there” and what mechanisms might help society develop the “right” technologies. Here we concentrate on three broad areas, energy, health, and agriculture, all of which are crucial for sustainable development and to which technology could contribute significantly.

Recently, Paul Raskin wrote a compelling vision in *The Great Transition Today: A Report from the Future* (2006), in which he elaborated the sustainability scenario first developed in the *Great Transition* (Raskin et al., 2002). He introduced a society characterized by new values of sustainability: quality of life, human solidarity, and ecological sensibility. Quality of life refers to a deep change in lifestyles for the rich and a steep increase in need fulfillment for the poor. It means that needs are fulfilled by less material and energy throughput—human fulfillment is improved by a lifestyle that acknowledges non-material needs as being as important as material needs. Human solidarity means that in a globalizing world the barriers between rich and poor, between North and South, and between different religions and cultures have been diminished to a level at which each human being truly understands him/herself as a “global citizen”, with responsibility for “global neighbors” and future generations. Ecological sensibility of course refers to a preservation of ecological capital by a combination of careful environmental management and the deployment of cutting-edge technologies to fulfill material functions.

In accordance with *The Great Transition Today*, we will explore energy, health, and agriculture in three different "archetypal" societies in a *Great Transition* world: Agoria, Ecodemia, and Arcadia. Each of these archetypal societies has created a different approach to living and sustainably addressing human needs. These archetypes will help us create a sense of the diversity of technological solutions available for present problems of unsustainability and poverty.

Energy, health, and agriculture

Recently, a panel of scientists reported that the three most important global problems were the provision of sustainable energy and avoiding serious climate change, the provision of affordable medicines and health delivery systems, and water scarcity and the improvement of water efficiency in agriculture (Glenn and Gordon, 2005). Correspondingly, we underscore the dimensions of energy, health, and agriculture in discussing the *Great Transition* vision.

Energy is a key aspect of sustainable development. The present energy system is mainly based on fossil fuels. This trend is unsustainable for a number of reasons: threats of man-made climate change by greenhouse gas emissions, the rapid depletion of fossil fuels, rising energy prices due to increasing demand, geopolitical uncertainty, and threat of instability in oil-rich countries. Solutions will be found in massive energy efficiency; development of renewable energy based on sun, wind, biomass, and tides; and improvements in energy storage technologies, such as batteries and flywheels. Carbon capture and storage is not yet proven feasible but could help to mitigate increasing CO_2 emissions (Stephens and Zwaan, 2005). Hydrogen is an option, but only if it can be efficiently generated by use of renewable energy (Vergragt, 2006).

Health care is obviously of central importance for every person on the planet, and takes quite different forms in so-called "developing" and "developed" countries. In the South, health care will concentrate on the eradication of poverty-related diseases such as malaria, TBC, diarrhea, typhus, and HIV. This can be accomplished through a combination of poverty alleviation, sanitation, safe drinking water, prophylaxis, vaccination, and Western and traditional medicines. In the North, health care will concentrate on lifestyle issues, such as achieving balance between work and relaxation, stress reduction by meditation and exercise, healthy nutrition, as well as new drug and medical treatment development.

Agriculture in a sustainable society will provide plentiful food supplies at prices local populations can afford, at a level of quality that promotes health, and without damage to the environment or reduction of biodiversity. To achieve this goal will require a prudent combination of new technologies and ecological sensitivity. Thus, after extensive discussions and controls, some GMO crops would be admitted, but others would not be allowed (Vergragt and Brown, 2006). Ecological agriculture would be accepted and practiced as standard throughout the world, taking different forms in different places depending on tradition, local circumstances, and specific opportunities.

Regions in a Great Transition World*

The fabric of planetary society is woven with hundreds of regions astonishingly diverse in character and size. Some correspond to the national boundaries of a century ago and others are federations of earlier states. Still others are parts of former states, forging a common identity around the boundaries of river basins and other ecosystems (so-called “bio-regions”), urban centers, and cultural traditions. Nevertheless, most regions can be clustered crudely into one of three major types, called *Agoria*, *Ecodemia*, and *Arcadia*, although few regions are pure cases.

Agoria

These regions would be most recognizable to a visitor from the year 2000. Some critics call *Agoria* “Sweden Supreme”, with its more conventional consumer patterns, lifestyles, and institutions. Its economies are dominated by large shareholder corporations. However, when compared to even the most outstanding examples of social democratic models of the last century, the commitment to social equality, the environment, and democratic engagement from the level of the firm to the globe is of a different order. The key is a vast array of policies and regulations, supported by popular values, that align corporate behavior with social goals, stimulate sustainable technology, and moderate material consumption in order to maintain highly equitable, responsible, and environmental societies.

Ecodemia

The distinguishing feature of *Ecodemia* is its fundamental departure from the capitalist economic system. The new system, often referred to as “economic democracy”, banishes the capitalist from two key arenas of economic life. First, the model of the firm as comprised of private owners and hired workers has been replaced by worker ownership in large-scale enterprises, complemented by non-profits and highly regulated small businesses. Second, private capitalist markets have given way to socialized investment processes. Worker ownership and workplace democracy has reduced the expansionary tendency of the traditional capitalist firm. Instead the focus is on profit per worker (rather than absolute profit) and the popular goal of “time affluence”, which shortens work weeks. Publicly-controlled regional and community investment banks, supported by participatory regulatory processes, re-cycle social savings and tax-generated capital funds. Their mandate is to ensure that successful applications from capital-seeking entrepreneurs satisfy social and environmental criteria, as well as traditional financial criteria.

Arcadia

Relative to other regions, the bias in *Arcadia* is toward self-reliant economies, small enterprises, face-to-face democracy (at least in cyberspace), community engagement, and love of nature. Lifestyles tend to emphasize material sufficiency, folk crafts, and reverence for tradition. While the local is emphasized, most people are highly connected with cosmopolitan culture and world affairs through advanced communication technology and transportation systems. *Arcadia* has centers of innovation in some technologies (organic agriculture, modular solar devices, human-scale transport devices, etc.) and arts (new music, craft products, etc.). Exports of these products and services, along with eco-tourism, supports the modest trade requirements of these relatively time-rich and slow-moving societies.

This discussion of differences should be balanced by a reminder that the regions also have much in common. Relative to the nations of a century ago, contemporary regions enjoy a high degree of political participation, healthy environments, universal education and healthcare, high social cohesion, no absolute poverty, and more fulfilling lives. Finally, people the world over share the historically novel attribute of citizenship in a world community.

* Summarized from Raskin (2006).

Agoria

Agoria is a sustainable society that bears some remote resemblance to the present social democracies in Scandinavia.

In the highly urbanized Agorian societies, possibilities for sustainable and ecological agriculture are somewhat limited, but urban gardens, rooftop gardens, and agricultural developments between suburbs (green lungs) create a steady supply of produce for the urban market. Farmers markets are highly popular, with distributions of produce directly from farmers to consumers. Conservation technology and some genetic modification have created the possibilities for longer produce storage, thus reducing energy needs from deep-freeze storage. Appropriate drying technologies by solar energy also enable longer storage possibilities with less energy expense. Meat-like products are produced predominantly without using animals; through improved and new technologies, it has become possible to grow highly sophisticated meat-like products from proteins (Weaver et al., 2000).

Energy is predominantly generated by highly sophisticated renewable sources, including wind parks, solar panels on all roofs, and biomass. Transit-oriented development reduces transportation energy demand. Car sharing, public transit, transit on demand, and transportation services by employers further reduce individual car transport. Vehicles are fueled by hydrogen fuel cells and solar cells integrated in vehicle bodies (Partidario, 2002); they are small and made of ultra-light recyclable materials. Electric bikes and scooters have replaced many private cars; in addition, self-powered cycling has been made more attractive by many covered tunnels with backwind generated through ventilators.

Houses are completely prefab and recyclable, with high isolation and natural ventilation, solar systems, heat and cold storage, solar lighting aided by heliostats, and highly isolating windows and shutters (Brown and Vergragt, 2006). Building densely reduces heat losses and improves energy efficiency. Existing housing is refurbished, insulated, and provided with cutting-edge energy technologies, generating a large number of jobs. In land-use planning, housing development is integrated with transportation planning.

Industrial sites are conceived according to the principles of industrial ecology, where waste materials and energy are used to fuel other processes. The principles of green chemistry (Woodhouse, 1998) are applied in the production of chemical materials. Dematerialization, reuse, and recycling of products and services ensure a massive reduction of materials throughput.

Health problems in Agoria have largely been solved by advanced biotechnologies and health technologies. An advanced combination of traditional and alternative medical knowledge with advanced biotechnology has resulted in healthier people. There is a certain amount of highly regulated genetic screening in order to eliminate genetic disorders as much as possible. In addition to and in combination with permitted screening, advanced forms of in vitro-fertilization (IVF) enable parents to optimize the selection of their offspring to certain extent; again, the state has set strict limits as to how far this selection can go. For instance, parents are not allowed to choose the gender of the new baby, in order to protect gender equilibrium.

For the most part, diarrhea, infectious diseases, and AIDS have been eradicated by clean water supply and sanitation, poverty alleviation, wider access to medicines and treatment, health education, general education (especially for women), better housing and nutrition, and a highly increased standard of living. Through intensive education and putting reins on unbridled capitalism, recently developed Agorian regions have been able to avoid many of the "well-being" illnesses of the past, such as obesity and heart and coronary diseases.

Ecodemia

In Ecodemia, economic democracy is established mainly through cooperative production facilities and non-profit business. There is less emphasis on profit making, and the standard work week is shorter, resulting in more free time for leisure and voluntary work and activities. Advanced information and communication technology (ICT) plays an important role in Ecodemian societies, enabling direct participation of workers in decisions about production processes, technological innovations, and diffusion of goods and services in the market. Similarly, ICT facilitates more complex sharing of living arrangements such as co-housing and household tasks, community services, and material goods such as vehicles, appliances, and tools.

Health care is based on the principles of cooperative ownership and direct democracy. It means that patients, their families, and potential and future patients all have a stake in the organization of health care services. Health care services are aimed first at fostering a healthy lifestyle through exercise and nutritious diet. To this end, health care providers and planners cooperate with schools and workplaces to ensure that such food is served and that collective forms of exercise are encouraged. Second, they ensure that everyone has access to first-line general practitioners. In formerly so-called developing countries, this approach has vastly contributed to the eradication and prevention of formerly endemic diseases like diarrhea, malaria, and TBC. It has also enormously helped contain the HIV epidemic and the bird flu pandemic of the early twenty-first century.

Health technology innovation is tightly controlled by means of the democratic cooperative institutions enabled by ICT. It means that all the relevant social groups such as patients, doctors, nurses, scientists, technology developers, insurance companies, and government agencies all participate in a facilitated discussion about how to allocate research money, set goals, monitor progress, identify unintended consequences, control costs, and distribute costs and benefits. This activity also encompasses neighboring fields such as biotechnology and bio-informatics.

Advanced information and communication technologies (ICT) ensure a high level of citizen participation in decisions about local, regional, and supra-regional issues. Significant developments in Artificial Intelligence and robotics make work and household tasks more interesting and fulfilling than previously imagined possible. Collaboration among workers is stimulated and rewarded by advanced monitoring systems, and human-machine interactions are optimized to the extent that they facilitate human-group interactions. Thus job satisfaction markedly increases. Similar technologies facilitate interactions at home between parents and children, among children, and among parents, increasing the quality of life. Technology also facilitates interactions between citizens, politicians, and bureaucracies, enabling a much more transparent form of governance and administration.

Energy conservation and renewable energy are fostered through public participatory processes ensuring that energy use is monitored and discussed, new technologies installed and optimized, and obsolete technologies and programs curtailed. Transparency through ICT ensures that, for example, driving gas-guzzlers is frowned upon as anti-social, and refusal to refurbish a house is easily disclosed. While some deplore this as increased social control, others argue it reflects a successful value change whereby social responsibility is now valued as much as individual entrepreneurship. Under the intense and general impacts of climate change and continued global precariousness, personal energy budget and trading system for personal emission rights have not only become socially accepted, but also a source of joy and excitement similar to sports games and video games. Competitions in energy conservation and energy efficiency create a source of pride.

Agriculture in Ecodemia is organized through cooperatives in production and processing, transportation and storage, and retail distribution. In many cases, small groups of users collectively own a farm or a production unit close to the city where they live, thus ensuring fresh produce on a daily basis. In other organizational forms, collectively owned farmers markets bring together buyers and sellers. Here, as everywhere, information and communication technologies play a great role.

Arcadia

Arcadia is in essence the advanced future form of a rural society. Economies are mainly self-reliant, enterprises are small and locally owned, direct democracy and community engagement are the norm, and the love of nature is one of the dominant values. In such a society, ecological agriculture and permaculture (Holmgren, 2002) are predominant, with a close relationship between consumers and producers through local cooperative organizations, as well as strong linkages with academic and business research institutes that follow ecological agricultural principles and methods. ICT also enables bonds with other communities, both local and at great distances, which share similar values. New conservation methods vastly enhance trade in agricultural products. While Arcadia accepts some Agorian innovations, GMOs are firmly rejected. Arcadians stick to more traditional methods of breeding. Meat consumption is infrequent, and animals are raised with humane practices—Arcadians prefer more “natural” meat to processed proteins.

Energy in Arcadia is generated by means of widespread applications of solar photovoltaic, wind, water, and biomass gasification technology. Through interaction with research institutes and other communities, the newest energy technologies are imported and tried out on the small-scale level. Houses may be larger than in the other regions, but highly insulated by the newest materials and technologies. Highly efficient hybrid and fuel cell technologies power most forms of transportation and agricultural machinery; in sparsely populated areas, the car as individual means of transportation is dominant, contrary to the more densely populated areas.

Health care in Arcadia is mainly decentralized; small health posts are most important for first-line care and prevention. Participation of patients and other stakeholders in management of these centers is common. Research is predominantly aimed at identifying local and traditional indigenous knowledge about herbs, indigenous plants, and local ecosystems. Because of the more relaxed lifestyles, the rural environment, and the proximity of nature, modern stress is less prevalent; moreover, the improvement of sanitation, clean water availability, and hygiene has vastly reduced common illnesses. In Arcadia, there is close communication with R&D centers in Agoria and Ecodemia; Arcadian values, however, tend to be more traditional and holistic than high-tech oriented.

Arcadia supports new forms of sustainable tourism, where tourists can partake of an Arcadian country life, closer to nature but facilitated by high technology. By this means, Arcadians contribute not only to a healthier lifestyle for people from Agoria and Ecodemia, but also to an education in a different approach to life, more rooted in nature.

To conclude

In this section, we have developed some future visions of sustainable and more equitable *Great Transition* societies in which technology plays an important, but not dominant, role. We have assumed that technological developments have been fast, but well-monitored and controlled, and that during their development, the "right" decisions have been made as to the direction of their development. The three regional types, or archetypal visions, allow some diversity in the future visions. Of course, these descriptions are highly eclectic and only meant to stimulate imagination and debate; they are by no means meant as blueprints. Such visioning exercises in multi-stakeholder settings could contribute greatly to the richness and depth of these visions.

How Did We Get There?

In this final section, we discuss in broad brushstrokes how we made the transition from early-twenty-first century society and technologies to the future late-twenty-first century societies like Agoria, Ecodemia, and Arcadia. First, we discuss some of the drivers and mechanisms that led to technological and societal change. Then, we discuss some of the choices made in the development of technology itself.

Drivers of technological change

The present dominant drivers of technological change are business interests and state- and military-driven innovations. In Section 2, we illustrated how some present technological forecasts sketch technological futures that are not very sustainable and probably not very desirable either. In Section 3, in contrast, we looked at three different sustainability visions in which technology plays an important, but not dominant, role. The chance that these visions will be realized depends on societal developments as well as decision-making on technological innovations. The main actors that drive technological change are delineated below.

Governments

Governments at all levels rank high among the most important drivers of technological change. We assume a transition in the twenty-first century towards a truly democratic governance system, which is not captured by business, military, or bureaucratic interests (Rajan, 2006). Such a governance system will operate on all levels of society, from global to local, in accordance with the subsidiarity principle. Information and communication technologies (ICT) will be instrumental to make governments more transparent and less prone to corruption, truly balancing long- and short-term interests of all sections of the population. Governments will play important roles by regulating adverse technological consequences, investing in research and development (R&D) and in new technological innovative forms, purchasing sustainable products and services in order to pave the way for broad market introduction, setting criteria that foster sustainable and appropriate technologies, curbing excessive private interests-driven research, setting long-term goals, and communicating about science and technology issues with the public at large.

Citizen-consumers

The second most important drivers of technological change are the citizen-consumers. A strong Global Citizens Movement (GCM) and a progressive change in dominant societal values (Kates et al., 2006) has raised awareness among consumers that their lifestyles were not only unsustainable, but also unhealthy and stressful, which prevents them from feeling happy and fulfilled. Shorter working weeks, more walking, biking, and playing, that is to say, less stress and more exercise, have become broadly accepted as desirable consumer products. Consumers became less interested in consuming as such to fulfill their needs (Stutz, 2006) and more in participating in decision-making about issues that are relevant for their own and their children's lives. In this way, they have become citizen-consumers. Citizen-consumers have been empowered to express their demands for products and services in such a way that they reach a balance between personal interests and the public good. For instance, a citizen-consumer expresses his/her need for transportation in a form that is not immediately met by buying a new car, but instead by supporting a sustainable transportation system. Again, ICT plays an important role in realizing such forms of demand articulation.

Citizens' Self-organizing Groups (SOGs) and NGOs

Citizen-consumers organize themselves in ways that foster the public good. These organizations and institutions, formerly known as non-governmental organizations (NGOs), have been aptly renamed citizens' self-organizing groups (SOGs), or in some places in the world, like India, as self-help groups (SHGs). SOGs are organized around each and every issue for which a demand exists, from transportation and housing, to sustainable food and shopping, to health and medical care, to environmental issues. The Internet and ICTs are again very instrumental in forming and developing these groups. Early forerunners could be seen in early twenty-first century as eBay and a host of chat groups and email lists. Even earlier, in the 1970s, science shops had been formed to translate societal wishes into scientific research. Other early expressions were science courts as organized in Europe and the USA around controversial technological developments such as nuclear energy and genetically modified foods. Governments and existing NGOs also have been instrumental in helping form and organize such groups. SOGs have a strong influence on R&D and technological innovation by expressing desires and making demands in such a way that governments, existing business, and emerging new business take notice and act accordingly. In addition, they have established their own research organizations, funded by foundations and private investors, which have become powerful centers of research and innovation for the public good.

Business

Business can be divided into big multinational corporations (MNCs), small and medium-seized enterprises (SMEs), and emerging new firms (mainly science-based or service-oriented). Large MNCs were curbed because a world government emerged that enforces the rule of law. The World Trade Organization, in combination with the World Court and some parts of the UN have jointly developed into a much more socially oriented world government system that is committed to sustainable development, equity, and justice. This global government system has developed enough strength to force MNCs to adopt global standards of labor, environmental and social sustainability, and reasonable rather than excessive profits. The world governance system has also curbed the financial markets, applied a Tobin tax on worldwide financial transactions, and tamed unbridled financial speculation to an extent that is within the bounds of what is considered socially beneficial. Because of this, companies are able to look further ahead and develop truly long-term sustainable strategies for their products, services, and labor operations. Technological innovation is redefined as successfully bringing products and processes on the market that fulfill sustainability needs by citizen-consumers, as well as generate a modest profit for the business. Business decisions on R&D and technological innovations are heavily influenced by citizens' self-organizing groups (SOGs), governments on all levels ranging from local to world government, trade unions, environmental groups, and human right groups.

Intellectual property rights (IPRs) and the patent law system are reformed so that companies can no longer be prevented from reaping the fruits of others' innovations elsewhere. A commitment to reward innovative research into new products and production processes remains, but again within bounds and with due regard to societal benefits. Through this reform alone, global technological innovation is enhanced dramatically and new technological firms have sprung up to reap the fruit. Less money is spent on patent litigation, which makes it easier to enter the market with a new product or process. Patenting of living materials has been forbidden, and GMO research has been confined to those areas which have clear benefits to the population at large (such as health).

Education and Communication

Deep changes are needed in high school and college education on science, technology, and sustainability. The history of technology, the differences among technologies in various cultures, the social shaping of technological artifacts, the societal processes and decision structures that shape technological innovations, and the consequences of technology for society should be taught in ways that engage students in a deeper understanding of technological change processes. Similarly, sustainability needs to be taught in a holistic way, connecting technology with institutions and values, ecology with economy and society, consumers with producers and governments, short term with long term, well-being with equity, and differences between cultures with global values.

Nowadays, communication media are dominated by commercial advertisements promoting the fruits of technological innovation in the form of desirable consumer products that are absolutely necessary for a good life and for "well-being". The media could become another driver for a transition to sustainability, if it could address issues of sustainability in an integrated and holistic way, understanding the mass culture, but trying to strengthen its sustainability. Communication about really sustainable forms of need fulfillments would be the way to do it. Although how mass communication could be disentangled from the grip of powerful corporations is unclear, the key is probably to reform business itself (White, 2006) to create a better balance between business and other actors in society.

The "right" choices in technology development

Technology development has been the result of interplay of many factors:

- scientific discoveries,
- changing business self-image and interests,
- changing consumer demand,
- government regulation,
- the global citizens movement,
- emerging institutions and paradigms, and
- ultimately changing dominant values.

Developing the “right” technology depends both on far-sighted and entrepreneurial individuals and on a deep insight in technological opportunities and societal consequences. None of this is easy or self-evident.

Appropriate technologies and traditional and indigenous technologies have proved to be of enormous value for the development of a new technological paradigm. The combination of early twenty-first century high-tech developments with the principles embodied in appropriate technology and the knowledge and wisdom of traditional technologies and medicine has inspired many developments which we now (in the late twenty-first century) take for granted. Examples can be found in sustainable laundry services, where high-tech washing machines are combined with the traditional laundry service, or in sustainable health services, where high-tech medical technologies are combined with traditional Indian, Chinese, and African holistic practices.

Energy conservation is practiced everywhere from production technologies to transportation, housing, agriculture, and consumption. Driving forces are government policies, rising prices, experiments with alternative energies and energy conservation, innovation by large MNCs and SMEs, NGO and SOG research, experiments, and development. Unforeseen and sometimes sudden events also helped: after the sudden spike in energy prices during the Arab and Venezuelan oil boycott in 2007 and the intense heat waves between 2006 and 2015, a strong public awareness pushed for technological innovation and strong government regulation. New, lighter, and stronger materials, improved land-use planning, Internet conferencing, and e-shopping all contributed to a reduction in energy use materials. Bio-feedback, the immediate feedback on one’s energy use, first deployed in cars, is now everywhere, raising awareness and stimulus for energy saving. Energy is now mostly generated by solar panels on roofs and on road surfaces, biomass, and wind turbines big and small, all integrated in buildings. Buildings themselves are naturally ventilated; air conditioning units have become museum pieces.

Health care has become more holistic, focusing on well-being of the body and soul as an integrated system. Drivers have been spiking health costs, dissatisfaction with the dominance of modern technologies in medicine, dissatisfaction with the dominance and behavior of large drug companies, the emerging awareness of traditional medicine by citizen-consumers, small-scale experimentation with new combinations of traditional and modern medicine, and, last but not least, growing awareness of the risks of genetic recombination and screening. Especially after the shock of the discovery of a human cloning factory in North Korea in 2010, where human organs were produced to fulfill the worlds' needs for transplant organs, and to fulfill North Korea's need for foreign currency, tight international regulations and ethical guidelines were drafted by 2015. Genetic manipulation of humans, animals, and plants came under the control of international standards and multi-stakeholder citizens' committees, with R&D closely monitored by bio-information technologies and satellites. Biotechnology now works closely with indigenous medicine experts to produce smart combinations of new drugs and prevention, aimed at early monitoring and treatment of diseases without compromising fragile ecologies as well as citizens' privacy concerns and their freedom to procreate as they wish. Many of the common illnesses of the early twenty-first century have now disappeared, and humans around the globe live generally healthily into their nineties or longer; costs of health care are tightly under control, and there is a limit to the number of treatments humans can claim.

Information and communication technologies are now oriented mainly to fostering transparency and democratization in governance and business, to citizen participation in decision-making in all aspects of life, to communicating widely the results of modern science and technology among the population, and to diffuse widely sustainable practices, services, and technologies. These transformations were mainly gradual but sometimes unexpected shocks helped accelerate transitions in the "right" directions and transition processes to a more sustainable use. For instance, the shocking history of a highly intelligent robot that escaped from the lab in 2023 boosted awareness of the dangers of the information society and the imminent danger of the "singularity". The robot was able to manipulate information and communication around the globe for days, and managed to create enough havoc in energy, water, nutrition supply, and waste collection to create a huge economic pandemic. Eventually brought under control, the robot's rampage sparked a global discussion about Artificial Intelligence. As a result, the developments of ICT are now tightly controlled, both by ethical and technical committees on all levels of society. As the Global Citizens Movement surged in the first decades of the twenty-first century, it forced a more gradual and reflective agenda for high-tech developments. The new consensus was that technological prowess was already sufficient for the transition to a sustainable society that could provide the necessary services to mankind for the foreseeable future, and that any additional development should proceed with great caution in view of the potential dangers.

In agriculture, the transformation towards ecological agriculture that started in the 1990s is now nearly complete. In combination with home and rural gardens, agriculture now produces more than enough to feed the world population, especially because meat has become a scarce, luxury product, mainly available in Arcadia but hardly in Ecodemia or Agoria. Multi-functional land use makes it possible to combine food and energy production, water management, and recreation in such a way that farmers make a good living even if the part resulting from agriculture is relatively low. Pesticides and herbicides have disappeared in their present chemical forms; intelligent breeding vastly helped by ICT and nanotechnology, but hardly by genetic recombination technologies, have proved to be quite successful.

Conclusion

We have tried to show that social helmsmanship of technological innovation in the direction of sustainability is a very challenging task and to suggest what is required to take it on. It calls for changes in attitude in the scientific community, increased awareness in the general population, the development of better methods of monitoring and forecasting in academia and government, and, most importantly, more value placed on ethics and social responsibility. It calls, above all, for changes in the forces that drive scientific and technological innovations—the funding systems, the military and business interests, and consumers. It calls for greater transparency of scientific and technological enterprises, enabling societal actors to better monitor, assess, forecast, and influence developments at an early stage. It calls for new and comprehensive visions of the scientific and technological foundations of a society of the future, one which is sustainable and attractive and which fulfills human needs and aspirations. It calls for backcasting and social experimentation and for new forms of governance.

In this essay, we have sketched some credible forecasts of how technologies may develop in directions that might be neither sustainable nor socially acceptable. These forecasts are the results of strong current drivers of science and technology, mainly dominant economic forces and military interests. Our intention has been to create eye-openers for some unpleasant surprises ahead if we are not careful and vigilant about technological innovations. Of course we have also cautioned against too much confidence in technological forecasting. The main aim here has been to create awareness that technology will not automatically lead us into a sustainable future and that it is very hard to influence dominant technological trajectories.

At the same time, we have sketched some archetypal sustainable societies in which technologies play an important, if not decisive, role. Specifically, ICT, new materials, energy technologies, and biotechnologies are all key players. Thus we must emphasize that these technologies will not be developed or become wide-spread and dominant without socio-political, economic, and cultural mechanisms to steer innovation in the "right" or most desirable direction. We have argued that information and communication technologies themselves could be instrumental to create more transparency and openness in decision-making processes and create the conditions for more direct participation of stakeholders in these processes. However, the transition to a stronger participation by citizen-consumers, the formation of new institutions (Self-Organizing Groups, SOGs), and ultimately a change in dominant values are some of the conditions necessary for change.

Cultivating these conditions could be a starting point for developing strategies and actions, on the local, regional, and global scale, directed at specific audiences from science, business, governments, and NGOs. The next logical step could be a call for an agenda for research and action, endorsed by a committed group of academics, researchers, and activists.

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