Keynote address at the International Conference "Technology + Society = ? Future",
Montenegrin Academy of Sciences and Arts, Podgorica, 19-20 May, 2016.

Science-Based Technology and Society: *Arrows to the Future*

Professor Loucas G. Christophorou
Academy of Athens
28 Panepistimiou street, Athens 10679

ASTRACT: ***Science-based technological frontiers*** in biomedicine and energy, and their possible impact on society and on man himself are discussed. The frontiers in biology and medicine will give humanity new powers to treat, prevent and cure diseases and to effect beneficial genetic modifications of plants and animals vital for society's future (for instance, increase of food production). Simultaneously, these same powers will give rise to new ethical and social issues and "fears of the worst kind". Indeed, some argue that emerging scientific and technological frontiers in biomedicine, will determine, in the non-too-distant future, the ultimate fate of humanity. Similarly, frontier science-based energy technology promises abundant, "clean" energy, intelligently conditioned to the needs of modern technology; energy will impact all future functions of society and its availability and affordability will be considered a human right. Simultaneously, energy production and use will continue to raise fundamental challenges and serious concerns about its adverse impact on the environment and climate change.

Undoubtedly, there will be many new future avenues to knowledge and its use and misuse, and hence enormous shared responsibility by both scientists and non-scientists. This responsibility must be grounded on basic human values and the mutual accommodation of science and society through enhanced dialogue and trust. In our view, the *ultimate future challenge of civilization will be the protection of humanity and the respect of human dignity.*

Key words: science-based technological frontiers; biomedicine; energy; materials; dual impact on society.

1 SCIENCE-BASED TECHNOLOGICAL FRONTIERS AND THE DUAL ASPECTS OF THEIR IMPACT ON SOCIETY

Science and science-based technology have accelerated the pace of change and innovation and have unified the world; there is no "them" anymore; the boundaries of national civilizations and cultural-value-systems are being blurred. Science and science-based technology enabled the formation of societal infrastructures vital for the survival and well-being of humanity; they helped humanity achieve social justice, freedom and emancipation in many parts of the world and made possible the penetration and the breakup of the "iron curtains" of totalitarian states, liberating oppressed peoples.

Yet, injustice and suffering abide the world over, totalitarian states still enslave their people, and basic human needs for food, energy and shelter are still not satisfied for billions of people especially in the rural areas of impoverished countries. Terrorism and extremism still inflict pain and misery on a grand scale the world over, and uncontrolled capitalism and failed government policies lead to unprecedented world-wide economic crises setting humanity back on a slower pace, homogenizing people in their degradation. An unrestrained consumer society lives beyond its means and strains resources and the planet.

The *dual aspects of the impact of science-based technology on society and on man himself* will continue and can, in fact, be anticipated to intensify in the future. In this paper the impact of science-based technological frontiers is exemplified in three areas: (1) *Biology and medicine (foremost molecular genetics and molecular medicine) and biotechnology*, (2) *Energy (new sources, carriers and transformations of energy), and* (3) *New materials (nanomaterials and superconductors).*

1.1 Biology, medicine and biotechnology

In the previous century, we have seen the merger of chemistry with physics and gradually the merger of biology with both physics and chemistry. By the end of the 20th century we have begun to see the gradual reduction of parts of medicine to atoms, molecules and genes, and the beginning of the remarkable explosion in molecular and genomic medicine, driven in part, by *bioinformatics* (the use of computers to rapidly scan and analyze the genomes of organisms). Basic elements of these emerging technologies are the next generation of genome sequencing, genetic engineering, and big-data driven medicine. In the manipulation of the very small lies new fundamental knowledge for understanding the behavior of the very large, which will undoubtedly lead to new technological frontiers in biology, medicine and biotechnology giving humanity new powers to treat, prevent and cure diseases, and to effect beneficial genetic modifications of plants and animals vital for society's future. Concomitantly, these same powers have the potential to change us: the way we are, the way we live, the way we think about ourselves, and the way we relate to the rest of life and nature. Indeed, some argue that emerging scientific and technological frontiers in biomedicine, will determine, in the non-too-distant future, the ultimate fate of humanity.

Examples of the new frontiers in these fields are the following:

- *Molecular and genetic roots of cancer.* The processes leading to the development of cancer are extraordinarily complex and there are many different types of cancer. If the uncontrolled growth of cells is caused by genetic abnormalities in cells, then hitting cancer at its molecular origin is of utmost importance. It is generally believed that in the near future it would be possible to cure many genetic diseases that are caused by the mutation of a single gene. In the case of cancer one is likely to be dealing *with multigene processes* [1, 2].
- *Stem cell technology.* Stem cells can change into any type of cell in the body, and embryonic stem cells retain this ability to re-grow any type of cell throughout their life. Stem cells have the potential to cure diseases such as diabetes, heart disease, Alzheimer's, and Parkinson's. They are, however, controversial and they raise ethical questions because an embryo has to be sacrificed to extract these cells.
- *Designer genes.* In time, it will be possible to go beyond just fixing "broken" genes to actually enhancing and improving them. Whether designer genes should be used to change the way we look, the way we feel, to make us healthier or something else, we are faced with profound ethical issues.
- *Germline gene modification.* Here one alters the genes of the sex cells and the resultant genes are passed on to the next generation. A frontier field, full of promise and peril, and replete with scientific, ethical and social concerns [3].
- *Synthetic biology.* This new field began to surface at the turn of the previous century; it has been described as "the application of science, technology and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms"; "to create life from non-living materials .. to design living things that meet the specific needs and wishes of humans" [4]. Synthetic biology is defined as "the application of science and engineering to facilitate and accelerate the design, manufacturing and/or modification of genetic materials in living organisms" [5]. "Synthetic genomics" according to Cho and Belman [6] refers to the laboratory synthesis and assembly of genomes and their expression to produce viruses or cellular life forms. From its beginning, synthetic biology has been steeped in controversy regarding its potential for societal benefit or harm. Opinions vary from praising synthetic biology for "engineered future life" to how it could lead to the devaluing of life. Unquestionably, the ethical issues raised are monumental [7].
- *Epigenetics*. This emerging science "describes changes in the regulation of gene expression that can be passed on to a cell's progeny, but are not due to changes to the nucleotide sequence of the gene" [8]; they are epigenetic (non-genetic) modifications to the genome "that crucially determine which genes are expressed by which cell type, and when" [8].
- *Human genetics.* The genetic changes that help separate humans from chimps are likely to be profound despite the oft-repeated statistic that only ~ 1.2% of our DNA differs from that of chimps. A complete understanding of uniquely human traits will, however, include more than DNA [8, 9]; it takes much more than genes to make the human. The *sequencing of the human genome* gives humanity new powers to treat, prevent and cure disease. At the same time the new developments in biotechnology, genetic engineering and synthetic biology raise profound new ethical and social issues mainly caused by the possibility of crossing boundaries between species. What changes in man? Will, for instance, man proceed and create synthetic forms of life and should he concede rights to non-human animals? Is man, as many have prophesized [10], *en route* to the creation of a post-human society? And by "what standards and on whose authority?" might one rightfully ask?
- *Prosthetics*. Molecular and genomic medicine will profoundly impact the health care and delivery systems. Future robotic prosthetics which mimic what the human body does naturally are being envisioned, and nano-robots might become a reality and might alter society profoundly [2].

- *Genetic modifications of plants and animals*. Genetically modified organisms (GMOs) have been applied to plant and animal food sources and genetically-modified foods (GMFs) are a reality. The benefits – real and potential – of transgenically-modified plants and animals include food supply, enhancement of nutrient security, targeted health such as diet-related chronic diseases, as well as improving herbicide or disease resistance, or drought tolerance, etc. Currently, commercialized GM crops include maize, soya beans, cotton, canola, squash, papaya, sugar beet, tomato and sweet pepper, which are grown primarily in North and South America, and South and East Asia. In efforts to boost agricultural productivity in the world's poor regions, attention has been drawn to Africa [11, 12]. Africa, many argue, needs to embrace technologies that enable production of more and better food, and GMOs may increase cereal production especially in Sub-Saharan Africa. However, coexisting with the benefits of genetic modification of plants and animals are known and unknown risks such as possible health risks and food safety, but also possible effects on the environment and socio-economic and ethical issues connected with control of agricultural biotechnologies and intellectual property rights [11-14]. Partly for these reasons, there still remains scepticism over GMFs and the issue still divides the EU [15]. In spite of these (and possibly other) concerns, humanity would likely take full benefit of the new age of molecular biology and biotechnology for food production and would explore further options involving highly polygenic traits [16].

In the fight against world hunger, another factor is of paramount significance, namely, ***energy***.

1.2 Energy (new sources, new carriers, and new transformations of energy)

Frontier science-based energy technology promises abundant, “clean” energy, intelligently conditioned to meet the needs of modern technology; safer electrical energy from nuclear fission and abundant clean energy from controlled nuclear fusion; more efficient, cheaper and larger scale renewable energy sources with storable energy and fuels capabilities; transmission of large amounts of electrical energy over long distances [17].

Energy is and will continue to be critical for society. An incessant flow of energy is the basis of modern civilization and of life itself. Technology may be limited by not just the amount of available energy for its use, but also by the forms of available energy. For instance, technology today (information technology in particular) is dependent on the availability of energy in especially conditioned forms. New ways to access known forms of energy and new sources of energy will be sought, and new energy transformations and energy carriers will be searched for. What will succeed electricity as an energy carrier? Would *photons replace electrons as energy carriers?* And would a better understanding of the pathways of energy flow in biological systems lead to a better understanding of biological mechanisms and relevant technologies?

Energy is the key in achieving stability of the planet’s climate. Energy production and use will continue to raise fundamental challenges and serious concerns regarding its adverse impact on the environment and climate change. The energy-climate era will thus continue unabated. Hence, up and until we obtain abundant “clean” energy, we need to slow-down the use of “unclean” energy and reduce our consumption of energy by conserving energy and by utilizing it more efficiently [17-19].

Energy raises moral issues as major factor of social well-being. Ethical questions are raised about the use of energy and about the access to energy. World poverty is essentially energy poverty; to eradicate poverty we must satisfy *the basic energy needs of poor people*. Countries where a large part of their population lives on less than $2 a day have little or no access to electricity [20]. Developed countries consume up to a thousand times more electricity per person per year than the underdeveloped. There is in fact a clear relationship between the consumption of electricity and the GDP of a country. The high-energy consumption by the developed countries today affords their citizens the greatest choice in human history; lack of energy means lack of choice. The future is thus clear: *Escape poverty through provision of energy and in particular electricity; access to affordable energy may be regarded a fundamental human right and a moral obligation of civilization* [17, 18].

Humanity must make its use of energy compatible with human survival, need and dignity, and its obligations to the planet. And because the consumption of electricity will continue its ascendant course, the challenge for the future remains the transition to carbon-free energy.

1.3 New materials

Frontier science-based technologies will rely heavily on new materials. Let us look, by way of example, at just two categories of materials: *nanomaterials and superconductors*. The potential uses of both types of materials are based on knowledge to handle atoms and molecules and to manipulate them in a targeted way, making use of structure-dependent atom-to-atom and molecule-to-molecule interaction and processing.

Nanomaterials are substances with dimensions less than ~100 nanometers (1 nanometer is one billionth of a meter). At these sizes, materials exhibit size-dependent properties. Nanomaterials are increasingly being used in bioscience, information science and technology, energy generation and storage, bio-physico-chemical processing and catalysis, diagnostic and therapeutic applications in medicine, and so on [21]. Nanomaterial research is rapidly expanding in the use of nanoparticles in medicine and cancer therapy, and nanomaterials and nano-devices are envisioned revolutionizing medicine whether through nano-machines or molecular robots.

Another most interesting application of nanomaterials is in the area of *nanophotonics,* the study of the interaction of light at the nanometer scale, which allows understanding of the flow of light at length scales far below the optical wavelength. As photons are “shrunk” to nanoscale dimensions ultimately approaching the scale of the wave function of electrons, fundamental new science is expected and important new technological advances are anticipated, for instance, dense integrated circuits and optical computing [22]. Nanomaterials are expected to impact light-based quantum technologies, which are driving forward the quantum information revolution [23]. Light plays a central role in these applications because it is the ideal medium for transmitting quantum information [24]. Quantum communications deal with the idea of transferring quantum states from one place to another. The underlying concept is that quantum states can share entanglement between several parties, and these correlations can encode information which is shared between the parties.

High-temperature superconductors. The development of high-temperature (T) superconductors will signal the “age of magnetism” and will impact technology most profoundly just as electricity and electromagnetism did in the previous century. The highest-temperature known superconducting materials are the cuprates, which have demonstrated superconductivity at atmospheric pressure at T as high as -135 ^{o}C (138K) [25, 26]. A room-temperature superconductor is a material that would exhibit superconductivity at 0 ^{o}C. While this is not strictly room temperature (~20-25 ^{o}C) it is the T at which ice forms and can easily be reached and maintained. Finding a room T superconductor would allow creation of huge magnetic fields that require little power and would have enormous multifaceted technological significance; for instance, in high-speed rail systems and other means of transportation, in health systems, and in energy where they would enable “an *energy superhighway* by supplanting copper electrical conductors with a ceramic superconducting alternative that has higher capacity while eliminating losses that typically occur during transmission” [27].

Explosive new developments lay ahead also in many other areas such as *information technologies and the Internet*. Newness in future computing and in computers themselves would allow *abundant avenues to knowledge and its use and misuse.* We shall all be changed whether by ubiquitous computing (by bringing the computer into the world) or by virtual reality (by putting us into the world of the computer). Through the Internet, developing nations will be able to take a shortcut to the future, taking advantage of the information revolution to build on intellectual capital. *Information technology and the Internet* with all their wonderful benefits, could be easily misused (e.g., forgery, fraud), and we could all be drowned in “unfiltered information” and stripped of our personal privacy. More powerful computers and more fundamental advances in computational methods, taking advantage of new (superconducting) materials, would lead one to assume that in the future “everything would have a tiny chip in it, making it *intelligent*” and we would then, as Kaku writes [2], be living in “a world populated by robots that have humanlike characteristics!” Technology will drive ethics and not the other way around [28].

2 SOCIETY

2.1 Societal complexity

Human society, history tells us, is moving toward higher levels of complexity: larger settlements supported by increasingly larger and more complicated infrastructures; more institutions, social needs and specialization; larger information and communications loads and more societal interconnections through an elaborate web of systems and technologies. Society increasingly becomes more organized, more sociopolitically controlled, and more dependent on powerful technologies to support the services demanded by its population traditional needs and new habits such as the explosive growth in consumer, business and government e-services. The cost of maintaining this societal complexity is increasingly becoming more difficult to afford principally because it requires: (1) processing enormous amounts of energy and information in an increasingly less efficient manner, and (2) technological infrastructure which grows increasingly more complex and becomes more difficult to understand and to control. Societal complexity and its maintenance, it is argued [29], destabilizes society's institutions and diminishes their adaptive capacity; it makes society operationally fragile and vulnerable. Once complex societies become unable to support their complexity, they crumble and unavoidably they collapse; in the present age of globalization, *they may not collapse in isolation.* Yet, all indications are that present complex societies will become more complex in the future. They will thus require more efficient infrastructure, new technology, and new information processing and energy supply systems.

Another most crucial element for the sustainability of modern civilization is the balance between availability and consumption of resources. It is unlikely that technology alone will be sufficient for society to achieve this balance; society *has to tame consumerism* through *cultural change* and *adaptation.*

2.2 Complexity in science and values

In the future, new scientific concepts and constructs will be needed to enable better understanding of higher levels of abstraction in basic science and the emergence of large-scale behavior of highly complex systems. New mathematics will be needed for the modeling of complex systems and for characterizing the behavior and properties of biological entities with huge numbers of degrees of freedom.

The increase in societal complexity and the accompanied increases in communication, information exchange and human interactions are accompanied by changes in human behavior and the emergence of new types of human relations, which challenge traditional human values and ethics. For instance, the relations between individual persons have been profoundly affected by the degree of their mutual reciprocity. As human reciprocity weakens, so does the value of the "the golden rule". On the other hand, human problems and events become instantaneously panhuman, and ethics assumes new time- and space-characteristics. Will the spectrum over which value judgment is effected become too large for any value to be effectively applied? Is societal complexity a challenge to values?

Similarly, the ethics of energy and the environment transcends locality and demands responsible global action over space and time [30]. Adaptability, it has been said, is an asset for survival. Yet, paradoxically, the greatest threat to the quality of life is that the human species is so immensely adaptable that it can survive under utterly objectionable conditions. Healthy adaptation whether in governments, businesses, or social organizations and institutions needs innovation, and almost all innovations can cause both benefit and harm. And how would we adapt to machines interacting with each other as algorithms, with little human involvement?

As noted earlier in this paper, powerful new realities challenge ethics in a most fundamental way: *man is getting ready to modify and to remake himself and all the rest.* We are headed for actions beyond "all former ethics" and we may wonder if we would care about our former ethics and values and the things we were! Truly, then, we might ask: who has the right to experiment with the future of humanity?

2.3 Science, science-based technology, and societal values

It is the mutual responsibility of scientists and society to curb the power of science to suppress and destruct, and to deploy scientists in this process. Since WWII, the frontiers of science and technology have increasingly become the frontiers of weaponry. Science and scientists are unquestionably responsible for the dangerous nature of modern weapons [31] – without modern science such weapons would not be possible. There is thus a pressing need for radical scientific change, a need for a paradigm shift in the functions of modern scientists. Science needs to reassess its deep involvement with the machinery of war [32].

It is the mutual responsibility of scientists and society to predict, prevent and manage the risk against the idea of man associated with the progress of science. There will be immense future challenges to science and human values arising from the influence of science and scientific technology on man and his image.

As it has been argued earlier [33], the road from *human to animal* has become wide open with the systematic insertion of human genes into animals, to beings who share human and animal cells and are potentially new forms of life, *chimeras*. Several such efforts are under way in a number of countries. How "human beings" are the chimeras made with human stem cells? At what point in the process animal beings with consciousness are being created? Does the road to better health through chimeras constitute the next step in the further diminution of man? Difficult questions challenging science and values alike.

Earlier in this paper, reference was made to *synthetic biology* as its purpose is to artificially design new biological and biochemical systems ("genetic material parts"), that could then be placed in living cells and their behaviour and new functions be studied. This knowledge is sought in order to design synthetic systems, which define the recipient organism's central genetic features and allow the artificial intervention in the basic operational mechanisms of life and the feasibility of creating "artificial life". Thus, synthetic biology becomes potentially capable to design with computers and compose with biochemical methods artificial genomes, to import them at will in the cells of organisms and to bring in their genome any changes sought by the designer researcher (or his employer); it creates *semi-synthetic,"chimeric" cells, and opens the way for artificial life.* The questions raised are many and fundamental. What information will be "written" in the synthetic DNA that will be *infused* into the cells? Who will intervene and plan artificially the operation of the organisms' cells? Who (and how) will prevent the design of genomes for the creation of dangerous synthetic forms of life? These are essential questions and great challenges to science and values.

It is the mutual responsibility of scientists and society to require that the application of scientific knowledge is compatible with the values of society. For this, scientists and society must achieve accommodation between their mutual value systems, enhance their mutual trust, and shift from confrontation to complementary acceptance. Obviously, the morality of modern man cannot be based on science, but neither can it be separated from it, nor can science claim to be amoral. Science and science-based technology have added new roles for knowledge in ethics. It is furthermore essential for society to recognize that virtually every major issue confronting it has a science and technology component requiring public understanding. This requirement will be magnified in the future. It is thus necessary for society to appreciate the value of freedom in the execution of scientific research and to secure conditions for science to maintain its integrity and thus diminish its dark side.

2.4 The scientist as policy advisor and as advocate

Today, enormous new scientific knowledge is generated across all fields of science, which is important for human well-being; this powerful scientific knowledge is easily accessible and can be quickly put into practical use. Thus, the view is prevalent that scientists have a responsibility to advise governments, decision makers, and the public of the possible benefits and risks of new scientific knowledge and technology, and to help them choose wisely between available options. There is a need to develop ways for "Science for Policy" activities, which will make possible the input of scientific evidence into the decision making process and aid the resolution of social issues and claims [34]. For instance,

- *To aid society and decision makers in crises with scientific dimensions* (e.g., earthquakes, tsunamis, hurricanes, floods, volcanic ash clouds, terrorism, etc.)
- *To clarify scientific claims on important controversial scientific-technological issues where answers are still not clear and claims not fully trusted* (e.g., GM crops, fracking, food safety and security, climate change, etc.)
- *To delineate proposed claims for or against a given issue* (help avoid interpretation of scientific facts beyond the truth they contain).
- *To choose wisely the mechanisms from which advice is gotten.* Today, it seems that everyone wants to have scientific advice (especially the government) and everyone wants to give scientific advice, foremost to the government! Thus, debates over structures and procedures necessary for sound scientific advice abound. Unquestionably, society needs broad-based, open, evidence-gathering mechanisms to act. Five structures commonly used are: *individual scientists, chief scientific advisors, advisory councils, advisory committees, organizations of national academies.*There has actually been a proliferation of Groups of Science Academies [International Council for Science (ICSU), InterAcademy Panel (IAP), InterAcademy Medical Panel (IAMP), Federation of European Academies of Medicine (FEAM), European Academies' Science Advisory Council (EASAC), All European Academies (ALLEA), European Council of Applied Sciences, Technology and Engineering (Euro-CASE), Academia Europaea (AE), and others] offering "independent" and "competent" scientific advice to governments and national and international organizations, which often moderates extreme views on key issues and balances advocacy.

-*To delineate the role of the scientist as a policy advisor and as an advocate.* The views of scientists (whether acting alone or as members of academies/organizations/committees) are respected because they are objective and independent experts in the particular field advice is sought, but when they act as advocates they are likely to be in conflict with the professional norms of science. Advocacy by scientists themselves on behalf of any issue be it the environment, global warming, shale gas extraction, GMFs, stem cells, or synthetic biology, may be a real or perceived attempt to affect the opinions of the general public or certain groups of population, or the decision making of politicians, legislators and governments. And yet scientific advice almost always contains shades of personal opinion not entirely scientific, and in many instances the available scientific knowledge is incomplete, trans-scientific [30, 35].

Clearly we are witnessing new paradigm shifts as to the role of scientists and their scientific societies.

3 GAZING AT THE FUTURE

When modern man gazes at the future he is heavily troubled; many questions torment him:

- Will humanity preserve and will science and science-based technology respect man?
- Will science become an integral part of civilization and will man be able to respond to the ethical issues raised by the progress of science and the needs of society?
- Will society protect the universal values of civilization and will it be able to reconcile the values of science, local cultures, and religions?
- Will civilization provide to future generations the necessary commons: energy, water, food, materials, health, etc., and will societies and nations share resources with all humanity?
- Will man be led to a superior civilization or will the complex globalized society collapse irretrievably under the weight of its problems?

Or, will man change to such a degree, that all these questions and many others, be no longer meaningful?

Obviously the past constrains the future because the future is prepared on the basis of the knowledge of the past. The future however *challenges* because it is unknown and because it repeatedly contradicts the predictions of the past. And if the future is accompanied by the memories of the fears of the past, the future is desired because of the hope it promises!

I therefore believe in a promising future grounded in science and human values and the ability of future generations to recognize the value of complementarity. In this promising future, *the ultimate challenge of civilization will, in my view, be the protection of humanity and the respect for human dignity.*

4 REFERENCS AND NOTES

[1] It is conjectured (Ref. [2], pp. 152-157) that cancer fundamentally involves mutations in four or more genes, and that the fact that it takes a sequence of four or more defective genes to cause cancer probably explains why it often kills decades after an original incident (e.g., radiation exposure).

[2] Michio Kaku, *Physics of the Future,* Anchor Books, New York, 2012.

[3] Nicolas Wade, The New York Times, March 19, 2015.

[4] EASAC, *Synthetic Biology: An Introduction,* January 2011.

[5] R. Breitling, E. Takano and T. S. Gardner, Science **347** (9 January 2015, Editorial), p. 107; http://ec.europa.eu/health/consultations/index_en.htm

[6] M. K. Cho and D. A. Belman, Science **329** (2 July 2010), pp. 38-39.

[7] There is an extensive bibliography on these issues (for example, in *Science, Nature, Proc.of the National Academy of Sciences, USA*). See also M. Schmidt, A. Kelle, A. Ganguli-Mitra and H. de Vriend (Eds.), *Synthetic Biology – The technoscience and its societal consequences,* Springer 2009; EASAC, *Realising European potential in synthetic biology: scientific opportunities and good governance,* December 2010, ISBN 978-3-8047-2866-0; E. Parens, J. Johnson, and J. Moses, *Ethical Issues in Synthetic Biology – An overview of the debates,* Woodrow Wilson International Center for Scholars, June 2009; S. Joyce et al., *Synthetic Biology,* The National Academies Press, Washington, D. C., 2013, ISBN 978-0-309-22583-0; EASAC, *Synthetic Biology: An Introduction,* January 2011; Volker ter Meulen, Nature **509** (08 May 2014), p.135; Jennifer Sills, Science **348** (17 April 2015), p. 296.

[8] Nature-Editorial **518,** 273 (19 February 2015); www.nature.com/encode/category/research-papers

[9] F. S. Collins, *The Language of God,* Free Press, New York, 2006.

[10] F. J. Dyson, *Infinite in All Directions,* Perennial, New York, 2004; M. Rees, in J. Brockman (Ed.), *Science in the Age of Certainty,* HarperCollins Publishers, New York, 2006.

[11] Uma Lele, Science **326** (26 March 2010), p. 1554.

[12] Brian Heap and David Bennett (Eds.), *Insights – Africa's future… can biosciences contribute?* Lavenham Press, U. K., 2013.

[13] EASAC policy report 21, *Planting the future: opportunities and challenges for using crop genetic improvement technologies for sustainable agriculture*, June 2013, ISBN: 978-3-8047-3181-3.
[14] http://www.csa.com/discoveryguides/gmfood/overview.php
[15] Cynthia Kroet 12.06.2014 ENVIRONMENT
[16] H. C. J. Godfray et al. Science **327** (12 February 2010), pp. 812-817.
[17] Loucas G. Christophorou, *Energy and Civilization*, Academy of Athens, Athens, 2011 (ISBN: 978-960-404-216-6).
[18] Loucas G. Christophorou, *Energy, Environment and Modern Civilization*, Proceedings of the International Conference on "Transition to a New Society", Montenegrin Academy of Sciences and Arts, 2014, pp. 257-269.
[19] EASAC policy report 22, *Trends in extreme weather events in Europe: implications for national and European Union adaptation strategies*, November 2013, ISBN: 978-3-8047-3239-1; *Climate Change, Evidence & Causes*, The Royal Society and the US National Academy of Sciences Publication, 2014 (see also http://nas-sites.org/americasclimatechoice/ http://royalsociety.org/policy/climate-change/).
[20] International Energy Agency (IEA), *Energy Poverty-How to make modern energy access universal?* OECD/IEA, 2010; The World Bank 2011, *One Goal, Two Paths: Achieving Universal Access to Modern Energy in East Asia and the Pacific*, The World Bank, Washington, D.C. 2011 (ISBN 978-0-8213-8837-2).
[21] Joint EASAC-JRC Report, September 2011 (EASAC Policy Report No. 15), "Impact of Engineered *Nanomaterials* on Health: Considerations for Benefit-Risk Assessment".
[22] A. F. Koenderink et al. Science **348** (1 May 2015), p. 516-521.
[23] I. A. Walmsley, Science **348** (1 May 2015), pp. 525-530.
[24] M. Raymer and K. Srinivasan, Physics Today, November 2012, pp. 32-37.
[25] https://en.wikipedia.org/wiki/High-temperature_superconductivity
[26] In 2015, hydrogen sulfite under extremely high pressure (~ 150 gigapascals) was found to undergo superconducting transition at ~ 203 K (-70 ^{o}C) [25]; E. Cartlidge, Nature **524** (20 August 2015), p. 277.
[27] www.oe.energy.gov
[28] Freeman J. Dyson, *The Sun, the Genome, and the Internet*, The New York Public Library, Oxford University Press 1999, p. 60.
[29] See, for example, Joseph A. Tainter, *The Collapse of Complex Societies*, Cambridge University Press, Cambridge, 1988; Robert M. May, *Stability and Complexity in Model Ecosystems*, Princeton University Press, 2001.
[30] Loucas G. Christophorou, *Place of Science in a World of Values and Facts,* Kluwer Academic/Plenum Press, New York, 2001.
[31] Recent reports (International New York Times, January 13, 2016) that the US shifts to smaller, less powerful nuclear bombs which have more precise targeting capabilities, could make nuclear weapons more tempting to use.
[32] Loucas G. Christophorou, "*Scientists and Society: Needs and Responsibilities*", Rendiconti Lincei, Vol. **23**, Supplement 1, September 2012, pp. S23-S27.
[33] Loucas G. Christophorou, *The Inductive Method of Physical Science (from Molecules to Man?),* Proceedings of the Academy of Athens, Vol. 82 A', 2007, pp. 5-30.
[34] James Wilsdon and Robert Doubleday (Eds.), *Future directions for scientific advice in Europe,* Published by the Centre for Science and Policy, April 2015, Cambridge, ISBN: 978-0-9932818-0-8.
[35] A. M. Weinberg, Minerva **10**, April 1972, p. 209; Science **177** (21 July 1972), p. 211.