European Commission

The Future of Europe is Science

A report of the President's Science and Technology Advisory Council (STAC)

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Foreword from the President

JOSÉ MANUEL BARROSO
President of the European Commission

Over the past seven years, the European Union has had to deal with the worst financial and economic crisis since the last century. We have managed to overcome the existential threat to the Euro area and we have developed our Europe 2020 strategy for smart, sustainable and inclusive growth, with a strong focus on science, research and innovation.

The European Union remains the largest knowledge factory in the world: it accounts for almost a third of global science and technology production. And despite the crisis, Europe and its Member States have managed to maintain this competitive knowledge position.

But we cannot simply generate knowledge; we must translate this knowledge advantage into new products and services and we must use that knowledge for the benefit of Europe and its citizens, to develop a knowledge-guided society.

That is why, for example, we managed to make the budget for ***Horizon 2020***, the European research and innovation framework programme, almost 30% larger than its predecessor, at a time when the European budget was slightly decreased overall. At 80 billion Euros over seven years, Horizon 2020 is one of the largest research and innovation programmes in the world. It is our flagship to strengthen Europe's innovation leadership, by fostering excellence in research and the development of new and future emerging technologies, as well as to address societal challenges.

I am a firm believer that science, engineering and technology are vital for the health of our society, economy and environment. We must look to the future, to anticipate and prepare for new developments rather than react to them.

That is why I welcome this second report of my Science and Technology Advisory Council entitled "The future of Europe is science". The report highlights some challenges and the immense opportunities that science, engineering and technology may bring us over the next 15 years. It also suggests how decision-makers and citizens can start preparing for the future and more importantly, how we can create our own future.

And I also welcome the debate on those issues in the conference on "The Future of Europe is science" in Lisbon on 6-7 October 2014, bringing together world-class scientists, business and civil society representatives, as well as political leaders, to underline the future opportunities that science, technology and innovation can bring to Europe, in terms of growth and jobs, business opportunities and societal well-being.

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Towards a knowledge-guided society: a new vision for Europe

Europe's past was shaped by science: the Greco-Roman Antiquity, the Renaissance and the Enlightenment all emerged from advanced European scholarship, arts, research and ingenuity. These were instrumental in creating "Western civilisation". Today, science, engineering and technology (SET) remain central to our competitive advantage in an increasingly tough global marketplace; but they are also part of our heritage, our culture and our identity as Europeans.

Yet we cannot afford to simply gaze upon this legacy with nostalgia and pride. We must look forward, and recognise that not only is science a part of our future, it must be central. SET is already embedded in nearly every aspect of our daily lives.

The waves of change will sweep over us with increasing frequency. We can either stay still, resisting the waves of change, or we can ride these waves into a future of our own creation.

Europe is uniquely positioned to meet the challenges of the modern world, where the use of knowledge not only provides competitive advantages but is the basis for choosing the future we want - a future that ensures a good life in a sustainable environment. These choices must not be made by small elites, but by citizens, using shared knowledge and evidence. Europe can initiate a major paradigm shift to citizen participation in SET – or citizen science. Thus the people of Europe can once more lead in the transition to a knowledge-guided society. Such a future could bring us:

- Personalised and preventive medical care for all who need it, based on better understanding of the human body;
- Improved living conditions with integrated services, based on intelligent ICT: smart cities and smart homes;
- New and innovative energy systems with renewables, improved energy efficiency, storage and transportation and environmentally friendly, highly functional materials; and
- A balanced process of economic, technological and social development that can provide employment and prosperity — and serve as a role model for transitions in other parts of the world.

However, these trends will not become reality without proper investment in science and technology, including significant public funding from Member States and the EU for fundamental research, the bedrock of future innovations.

To achieve this, it is necessary to engage in systematic foresight activities because policy-makers must anticipate potential opportunities as well as threats and manage risks prudently and effectively. Furthermore, Europe needs to ensure that transitions and technological opportunities will be equally accessible to all its citizens. Knowledge, in particular, will be an increasingly valuable commodity: a knowledge divide in society could have severe consequences. Major tasks that are part of prudent risk management and knowledge-sharing include:

- providing equal opportunities with respect to education, basic social services, access to technologies and services (including digital equality), and political participation;
- developing and implementing effective and efficient procedures for peaceful conflict resolution, financial stability, fair burden sharing and distribution of wealth; and
- reducing environmental pollution, unsustainable land use and resource depletion to a minimum.

Founded on the creative power of cultural diversity, commonly shared values and a dedication to peaceful development, Europe has the tradition, the resources and the vision to lead the transition towards a good future for all of its citizens.

Our vision for Europe is clear: we must avoid the path towards decadence and actively generate a new Renaissance. It is inconceivable that this vision can be reached without science, engineering and technology (SET) as a central element. The future of Europe is science.

"The future cannot be predicted, but futures can be invented"

Dennis Gabor (Hungarian physicist)

1. Introduction

1. Imagine you are living in Europe in the year 2030. What does your society look like, where do you live and what occupies your time? Over the next 15 years, change will not only continue; it will be accelerated by technological possibilities and the growing interconnections between science and society. For policy-makers in Europe, scientific, engineering and technological innovations offer opportunities to improve life for European citizens and provide benefits for sustainable development worldwide. Cross-disciplinary and integrated foresight thinking is essential to prepare for many of the possible futures we face and to manage the accompanying risks. We emphasise the plurality of possible futures, because it is important to remember that the future we get and the way we will be able to address tomorrow's challenges will be shaped by our actions today.

2. Europe is a world leader in producing knowledge, but evidence suggests that we are relatively weak at making the most of that knowledge and in translating it into economic and societal benefit. We intend our report to prompt European policy-makers, decision-makers and citizens to think about the future beyond the short term, so that we are all better prepared to make the most of opportunities offered by science, engineering and technology (SET) knowledge.

3. This report builds on our first report, published in 2013, which focused on science and society ([1]). In late 2013, the President of the European Commission asked us to produce a report about scientific foresight in Europe. As well as our own views, we have been informed by the development of the European Strategy and Policy Analysis System (ESPAS) project ([2]), the activities of the Commission's new Foresight Network ([3]) and a Eurobarometer survey of citizen's views on future priorities for SET ([4]). We have structured our report to reflect the priorities for science and technology innovation according to citizens as revealed by the Eurobarometer. The following sections cover: health and medical care; jobs, ICT and learning; and environment, climate and energy. Each section includes future challenges, SET opportunities and recommendations. Our report is intended to provoke both thought and action, rather than to be comprehensive. We have focused on Europe's future, but set in a global context where possible.

([1]) "Science for an informed, sustainable and inclusive knowledge society", *President's Science and Technology Advisory Council* (2013), European Commission

([2]) European Strategy and Policy Analysis System, *europa.eu/espas*

([3]) See Annex for information on supplementary documents to this report

([4]) "Public perceptions of science, research and innovation", *Special Eurobarometer 419* (2014), European Commission

2. Health and medical care

Future challenges

4. In the 2014 Eurobarometer survey of "Public perceptions of science, research and innovation", 55% of EU citizens identified health and medical care as the top priority for science and technology innovation over the next 15 years ([1]).

5. **Although our understanding of the human mind and body will increase and medicine will become more advanced, we will still face major challenges such as the health of ageing societies and antimicrobial resistance**. In a few years, 20% of the European population will be over 65 years old ([2]), with a resulting increase in diseases such as dementia, diabetes, arthritis and cancer ([3]). The challenge is not how to live longer, but how to live an independent, healthy life for longer. While the provision and cost of medical care will be a major concern, an ageing society can also stimulate innovation in health services, products and urban planning, with appropriate investment ([4]).

6. **The rapid evolution of antibiotic resistant bacteria means that simple bacterial infections that are now treated with common antibiotics, will again become life-threatening.** This already causes a large number of deaths amongst those whose immune systems are compromised ([5]). The apparent lack of interest of pharmaceutical companies to develop new antibiotics is a matter of concern that needs to be addressed through sustained public funding on fundamental research on the issue ([6]).

7. **Medicine offers great opportunities, but this must be complemented by preventative action**. The health of tomorrow's Europe will depend on the physical and mental integrity of its youth, which is threatened by a growing culture of sedentary behaviour ([7]). This is linked to the pervasiveness of information and communication technologies (ICT), whose long-term effects on health and the brain are relatively unknown. We need to counteract trends toward unhealthy fat to muscle ratios (i.e. obesity) in order to reduce disease.

Opportunities offered by science, engineering and technology

8. **Science, engineering and technology will create opportunities to improve the quality of human life as well as its length.** Regenerative medicine based on stem cells will rejuvenate our tissues and restore failing sensory organs. For those who are irreparably infirm (e.g. paraplegics or those with advanced degenerative disease), non-invasively captured brain signals will drive robots and artificial limbs to overcome many of the limitations imposed by an infirm body ([8]).

9. **Performance-enhancing technologies are likely to redefine what is meant by a state of health.** Future enhancements could include anything from new limbs and improved hearing, to exceptional eye sight or enhanced logical thinking. Dramatic advances are being made in human organ culture, and the reconstitution of tissues and bones. Peripheral sensory stimuli can already help to "fix" new memories in the mind, by reinforcing and consolidating memory during sleep ([9]). Chemicals may also help us suppress psychologically disturbing experiences.

([1]) "Public perceptions of science, research and innovation", *Special Eurobarometer 419* (2014), European Commission

([2]) "The future of longevity in Switzerland: backgrounds and perspectives", *Institute of Social and Preventive Medicine Lausanne* (2008)

([3]) The frequency of cancer increases exponentially with age, see for example: *"Cancer incidence by age"*, Cancer Research UK, www.cancerresearchuk.org, page updated 14 January

([4]) Raphael C., Ahrens J. and Fowler N., (2001), Financing end-of-life care in the USA, *J R Soc Med, 94*, pp. 458-461; Longevity may also bring other benefits, see: Healy J., (2004), The benefits of an ageing population, *Australian Nat. Univ. Disc. Pap. 63*; pp. 1-49

([5]) For example, cancer and AIDS patients

([6]) "Race against time to develop new antibiotics", *Bulletin of the World Health Organization* (2011), pp 88–89

([7]) Vainshtein A., Grumati P., Sandri M. and Bonaldo P., (2014), Skeletal muscle, autophagy, and physical activity: the ménage à trois of metabolic regulation in health and disease, *J Mol Med (Berl)*, 92(2), pp 127-37

([8]) Velliste M., Perel S., Spalding M.C., Whitford A.S. and Schwartz A.B., (2008), Cortical control of a prosthetic arm for self-feeding, *Nature, Vol 453 issue 7198*, pp 1098-1101; Taylor D.M., Tillery S.I., Schwartz A.B., (2003), Information conveyed through brain-control: cursor versus robot, *IEEE Trans Neural Syst Rehabil Eng., 11(2)*, pp 195-9

([9]) Rasch B., Buechel C., Gais S. and Born J., (2007), Odor cues during slow-wave sleep prompt declarative memory consolidation, *Science Vol 315 no. 5817*, pp 1426-1429; Rolls E.T., (2004), The functions of the orbitofrontal cortex, *Brain Cogn., 55(1)*, pp 11-29

How the brain works

Oscillatory electric signals from the human brain were first recorded in 1924 in Germany. Research in Great Britain in the 1970s contributed to the development of nuclear magnetic resonance as a method to produce images of the brain and body. In 1992, the first whole-head system for mapping electromagnetic activity in the human brain became operational in Finland.

Today, electroencephalography, magneto-encephalography (MEG) and structural and functional magnetic resonance imaging (MRI) are powerful clinical tools that help save lives by diagnosing diseases such as cancer, epilepsy or stroke. Using these non-invasive measures of brain activity, we are improving our understanding of how humans move, interact, comprehend and remember, and how knowledge is organised in the brain. MEG and MRI technologies rely on large, heavy and costly devices, but spintronics promises miniaturised, mobile systems that could bring these techniques into everyday life, to support personalised health, learning and training ([1]).

10. **Interpreting the human body as a complex zoo of microorganisms will change the way we produce and deliver medicines.** Traditionally, pharmaceuticals have been targeted towards specific enzymes or pathways. But the impact of our microbiome – the microbes that live symbiotically with us in our bodies – is a key, multi-tiered determinant of human health. Diseases ranging from obesity to depression can be linked to this complex microbiome ([2]), and in the future we may increasingly treat disease by modifying our intestinal microbes. Instead of traditional pill-based medicines, synthetic biology will produce microorganisms to sense body malfunction and respond to it by synthesising medicines inside the same body ([3]). Microbes can also help ensure localised drug delivery. The growing popularity of medicine-through-nutrition and the use of live agents to prevent and treat disease will change the concept and the production of medication ([4]).

([1]) See also paragraph 36 for spintronics

([2]) Kinross J. M., Darzi A.W. and Nicholson J.K., (2011), Gut microbiome-host interactions in health and disease, *Genome Medicine Vol 3 No. 14*; Bakker G.C., van Erk M.J., Pellis L., Wopereis S., Rubingh C.M., Cnubben N.H., Kooistra T., van Ommen B., Hendriks H.F., (2010), An anti-inflammatory dietary mix modulates inflammation and oxidative and metabolic stress in overweight men: a nutrigenomics approach, *Am J Clin Nutr, Vol 91 Issue 4*, pp 1044-1059; Quinones, M.P. and Kaddurah-Daouk R., (2009), Metabolomics tools for identifying biomarkers for neuropsychiatric diseases, *Neurobiol Dis, Vol 35 Issue 2*, pp 165-176

([3]) Qin J., Li R., Raes J. et al, (2010), A human gut microbial gene catalogue established by metagenomic sequencing, *Nature Vol 464 Issue 7285*, pp 59-65; Round J.L and Mazmanian S.K., (2009), The gut microbiota shapes intestinal immune responses during health and disease, *Nature Reviews Immunology Vol 9 Issue 5*, pp 313-323

([4]) Round J.L and Mazmanian S.K., (2009), The gut microbiota shapes intestinal immune responses during health and disease, *Nature Reviews Immunology Vol 9 Issue 5*, pp 313-323; Turnbaugh P.J., Ridaura V.K., Fait J.J. et al, (2009), The Effect of Diet on the Human Gut Microbiome: A Metagenomic Analysis in Humanized Gnotobiotic Mice, *Sci Transl Med Vol 1 Issue 6*; Kau A.L., Ahern P.P. et al., (2011), Human nutrition, the gut microbiome and the immune system, *Nature Vol 474 Issue 7351*, pp 327-336

11. **Personalised medicine and the "omics" that accompany it will generate large data sets that describe an individual's physiology ([1]).** These will surely be available on small, mobile instruments ([2]). The development of novel algorithms that can use this information with proven predictive value for medical prognosis is a major area of growth ([3]). Early detection and the identification of predisposing factors will allow accurate preventative medical practice, perhaps to the point that even lifestyle-related ailments, like diabetes and heart disease, can be avoided.

Recommendations

12. Unbalanced diets, lack of physical exercise and the use of recreational drugs, are major causes of premature death in Europe. **Alongside the advance of medical care, the EU and Member States should implement educational and communication programmes to support Europeans to have a healthier lifestyle and thus take preventive measures to ensure future health.**

13. **Future medical advances will continue to raise questions of ethics and fairness**, such as how can society ensure fair distribution of performance-enhancing prosthetics to those who need them? We will need approved criteria for what constitutes a defensible human enhancement or organ replacement. **Governments should commission the development of ethical guidelines with input from scientifically and medically trained professionals as well as ethics experts and citizens. These should then be offered to all European and Member State health agencies to implement.**

([1]) His/her genome, metabolome, epigenome, phosphoproteome etc. See paragraph 14 for explanation of "omics"

([2]) Snyder M. and Chen R., (2013), Promise of personalized omics to precision medicine, *Wiley Interdiscip Rev Syst Biol Med*; "Top 10 medical uses of the iPhone", *internetmedicine.com*, page updated December 2012

([3]) For example, Gottesman O. et al, (2013), The Electronic Medical Records and Genomics (eMERGE) Network: past, present, and future, *Genet Med 15:10*, pp 761-771

14. **Increasing generation of medical data raises questions about how data is used.** With quantitative information on patients' "omes" ([4]), diagnosing disease will no longer be the realm of the experienced practitioner, but the work of a committee of experts in quantitative analysis. There are enormous opportunities for Europe-wide studies to develop reliable algorithms that accurately predict diagnoses and prognoses. Secure databases and "biobanks" ([5]) could be shared anonymously across Europe, to reach the numbers necessary for reliable predictions based on human genetics. **Member State medical training programmes should be revised to better train doctors in the basics of statistics, genetics and epigenetics, so that they can handle data and advise patients appropriately. Disease definitions and diagnostics should also be modernised to take account of molecular causes of disease ([6]).** As well as improving patient treatment, an increase in personalised medical data could result in data misuse. Effective methods of data and privacy protection are essential to prevent commercial, political or social abuses of their citizens' personal data. **The EU will need legislation and ethical guidelines on the use of personal data and access by third parties (such as employers).**

([4]) "omes" are comprehensive data sets of a quantitative digital nature, that describe various molecular characteristics of a particular cell or tissue or organism. A genome is the comprehensive sequence information of all the heritable DNA of an organism, the transcriptome, is the comprehensive pattern of RNAs synthesised using the genome as template (transcription), epigenome is the comprehensive data set of histone and DNA modifications related to a genome in a particular cell (this varies from cell to cell in a given individual) and proteome is the comprehensive set of proteins expressed from the Messenger RNA that is transcribed (since protein levels differ and some RNAs are not translated, the proteome is not identical to the predicted set of proteins based on the transcriptome). Finally the microbiome is the complex set of genetic information from the bacteria hosted in an individual's gut.

([5]) Biobanks are systematic tissue samples that are fixed or frozen and stored along with patient data and history – often sampled during the course of a disease or treatment. These reservoirs of information and samples are necessary for systematic studies of human response to treatments.

([6]) Schrodi S.J., Mukherjee S., Shan Y., Tromp G. et al, (2014), Genetic-based prediction of disease traits: prediction is very difficult, especially about the future, *Front Genet 2;5:162;* Snyder M. and Chen R., (2013), Promise of personalized omics to precision medicine, *Wiley Interdiscip Rev Syst Biol Med*; Manolio T.A., (2010), Genomewide association studies and assessment of the risk of disease, *N Engl J Med 8;363(2)*, pp 166-176

15. **Citizens have ever-increasing access to internet sites addressing health and medical issues**. However, data does not equate to knowledge. The obvious risks that will need to be tackled are the rise of misinformed self-diagnosis and a proliferation of false medical information. **Sources of validated, scientifically correct information must be made available to citizens, as otherwise trust in qualified medical establishments could be eroded. Governments are responsible for providing registers/directories of health websites that can be trusted ([1]).**

16. **The problem of antimicrobial resistance is drawing international attention.** The European Commission proposed a 5-year Action Plan where the development of effective antimicrobials for treatment of human and animal infections has a pivotal role. Similar initiatives have also occurred in Member States and in the USA ([2]). However, the pursuit of new antibiotics also calls for a better scientific understanding of the inherent evolutionary drive of microorganisms to conquer new chemical environments ([3]). **The European Commission and Member States must work together to strictly regulate the human and animal use of antibiotics.**

What if...?

We could marry medical science and digital data to make medicine more predictive? This would reduce, premature death, pain and suffering and medical errors based on ignorance. Antibiotic-resistant bacteria and mutating viruses will continue to pose new challenges, but with predictive medical analyses perhaps even bacterial variation will become manageable.

([1]) In our first report we endorsed the establishment of a science information website that provides balanced and comprehensible information based on evidence and the best available knowledge: "Science for an informed, sustainable and inclusive knowledge society", *President's Science and Technology Advisory Council* (2013), European Commission; See also "Direct-to-consumer genetic testing for health-related purposes in the European Union: the view from EASAC and FEAM", (2012), *European Academies Science Advisory Council and Federation of European Academies of Medicine*

([2]) For example, in June 2013, G8 science ministers focused on antimicrobial drug resistance as a major health risk and decided to act concertedly to address it

([3]) de Lorenzo V., (2014), From the selfish gene to selfish metabolism: revisiting the central dogma, *Bioessays*, pp 226-235.

3. Jobs, ICT and learning

Future challenges

17. When asked about the top priorities for science and technology innovation over the next 15 years, 49% of European Union citizens identified "job creation" and 33% identified "education and skills" ([1]).

18. **Advanced robotics and automation will continue the trend of replacing workers or some of their tasks.** Some work is less easily automated, such as low skilled professions (e.g. cleaning, catering) and high skilled professions (e.g. creative industries). This could mean that Europe's middle classes will face greater job insecurity. It is therefore crucial that we train and educate our citizens to flexibly adapt to the jobs of tomorrow, and not the jobs of today.

19. **The rapidly expanding quantity of information is setting challenges for learning**. The ease of obtaining information anytime and anywhere could decrease quality and selectivity in information gathering (see also paragraph 15). While it is possible to enhance learning capacity, for example with behavioural training or pharmacological agents, we will need to identify learning methods and knowledge structures that would best support basic education and lifelong learning.

20. **Moore´s law (which predicts that the number of transistors on a computer microprocessor will double every two years or so, leading to regular leaps in computing power) is coming to an end ([2]).** Therefore the cost of computing devices might increase and not, as was the case in the past, decrease. This might slow down the rate at which productivity can increase. However, currently evolving technologies such as quantum computing may provide new opportunities.

21. **Due to the high level of education in Europe we are productive in high technology manufacturing, where the cost of manpower is less influential and the cost of the process can be optimised.** In low cost commodity manufacturing, in services and where the cost of raw materials (including energy) are dominant, Europe is generally considered to be unappealing to foreign businesses and investors. This is because of: (i) the lack of natural energy sources and raw materials in Europe; (ii) the perception that care for the environment is a cost rather than an investment; and (iii) the international relocation of companies being socially unpalatable.

Opportunities offered by science, engineering and technology

22. **Developments in ICT will lead to the integration of services** addressing energy conservation, mobility (including virtual trips and meetings), sanitation, communication, security, health care and consumption. Advanced interaction technology such as virtual-reality interactions and novel collaboration tools may help us to reach conclusions faster, more effectively and more efficiently. Enhanced mobile technologies will provide personal services according to lifestyles, without limitations of time and space. People will not have to use specific input devices anymore: based on their movements and their communications, computing systems will be able to determine their service needs ([3]). This will lead to more resource efficiency, more comfort and more individualisation.

23. **The growth of online activities and connected devices (for example smartphones) has created huge volumes of data, and this trend is set to continue.** A key question is what to do with all the data. Mining and modelling big data can improve our understanding of the world. For example, new discoveries could be made through

([1]) "Public perceptions on science, research and innovation", *Special Eurobarometer 419* (2014), European Commission

([2]) Yardi M.Y., (2014), Moore's Law and the sand-heap paradox, *Communications of the ACM Vol 57 Issue 5*, p 5

([3]) Chung K.Y., Yoo J. and Kim K.J., (2013), Recent trends on mobile computing and future networks, *Personal and Ubiquitous Computing Vol 18 Issue 3*, pp 489-491

What if...?

Microbes could move us from a petroleum-based economy towards sustainable and environmentally-friendly industry? They could also change the way we handle drug delivery and help us to develop new and efficacious therapies for a suite of thus far intractable health problems.


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the analysis of huge data sets collected by satellites. Massive Online Open Courses (MOOCs) and other interactive learning tools generate data about their users: mining this data could improve teaching. But the impact of mining large data sets is not limited to science and learning; there are also numerous economic applications. For example, in online advertising the advertiser can collect valuable information about the buyers of a product, such as gender, age or keywords used on web search engines.

24. **Although most collaborative systems and advanced mobile technologies are currently in the research stage they are expected to influence or enable development of new products and services**. An example is gamification; the use of online games to achieve a serious goal such as engaging citizens on health awareness or teaching and training. Other examples are improved user interfaces and visualisation to make online interactions more enjoyable, as well as improved machine translation techniques.

25. **The way Europe produces goods will continue to develop.** Additive manufacturing—also known as 3D printing—will enable us to print more complex objects, from aircraft engines to body parts. The widespread use and increasing complexity of 3D-printing is also likely to have disruptive impacts on consumption behaviour and retail businesses. Furthermore, the decentralisation of typical industrial procedures could foster locally-based (if not home-based) waste disposal and energy production. Other key developments will include: energy storage and innovative technologies to make renewables better able to respond to energy needs through the day ([1]); and advanced robotics able to make responsive decisions and improve inspection technology (e.g. drones), replacing activities currently carried out by workers.

Recommendations

26. **Education is the great equaliser.** Knowledge is becoming an ever more valuable currency. As the world changes, citizens will need to build continually on a solid foundation of knowledge, to find effective ways of acquiring knowledge throughout their lives and to develop critical thinking. This can be thought of as personalised learning, or the shift to a lifelong learning society, which will be particularly important for helping citizens adapt to changing job markets. Behavioural and neuroscientific research will help in this endeavour. In addition, Europe, with its long and strong history of widely accessible high-level education, is in a unique position to initiate the next, major paradigm shift to a real, extensive and inclusive citizen participation in SET ("citizen science"). **Education in Member States must focus on training young and old alike "how to learn"; learning how to use information is more important than gathering it. The EU and Member States should strive to maintain everyone's interest in learning and to provide the opportunities to learn e.g. as a standard part of the workplace or recreational facilities. This is the surest and most democratic way to strengthen societal unity, equality and fairness. Equally, citizens must rise to the challenge of a knowledge-guided society.**

([1]) For example, energy storage and combination with high yield thermal gas combustion or similar innovative technology such as gas-to-power

27. **Online interactions will increase and become more pervasive, so it is crucial that they are secure and that the privacy of users is preserved.** Contrary to our expectations, citizens do not consider the protection of personal data to be a high priority for SET in the next 15 years (11%) but this might change in the future if citizens are confronted with serious security problems ([1]). Additionally, we have concerns over whether the future ICT-based Europe will increase or decrease social equity. **To reduce digital inequality, European policy makers must enable all parts of society to have access to IT (including broadband access) and to empower citizens to use IT services for serving their own needs. As well as investing in research to improve the security of online interactions, European policy-makers must ensure that citizens are aware of their responsibilities to protect their own personal information.**

28. **There are many unresolved privacy and security issues with the way large data sets are currently stored**, for example in the "cloud". However, responsible use of this data might also lead to future business opportunities ([2]). **It is the responsibility of governments to: (i) organise the procedures for identifying, verifying and securing reliable sources of data that can be fed into dedicated databases; and (ii) to allow restricted access to these databases for businesses.**

29. **Designing products for reuse will improve environmental sustainability and mark the start of a new economic sector** focused on salvaging high-quality parts and materials to produce new goods without compromising on appeal and reliability. Design is also vital for aesthetics; the eco-oriented desires of society will bring back into focus the diverse but ultimately shared European quest for aesthetics and attractive design. **Design should be protected as an essential part of educational curricula in Member States.**

30. **Future developments will help to replace off-shoring with near-shoring aimed at shortening the supply chain and decreasing response time to customer requirements.** Industry may transition from being a product supplier to being an individualised solution provider. There is thus a need to develop smart factories. **To make European manufacturing competitive, new smart industries must meet increasingly variable customer requirements, including new schemes of production by demand and individualisation of services.**

([1]) "Public perceptions of science, research and innovation", *Special Eurobarometer 419* (2014), European Commission

([2]) At the EU level, a cloud computing strategy was introduced in 2012, see "Unleashing the Potential of Cloud Computing in Europe", *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*, (2012), COM(2012) 529

4. Environment, climate and energy

Future challenges

31. Europe's commitment to sustainable development means "meeting the needs of present generations without jeopardising the ability of future generations to meet their own needs" ([1]). When surveyed, European citizens picked protection of the environment (30%), energy supply (25%) and the fight against climate change (22%) as priorities ([2]).

32. **The age of plentiful, accessible and relatively inexpensive oil may be coming to an end ([3]).** Although alternative fossil fuels are being currently explored (e.g. shale gas), environmental concerns need to be taken into account. Additionally, we depend on oil as the major source of chemicals and materials (e.g. plastics). Future challenges include: (i) developing clean and renewable energy sources to reduce Europe's dependence on imported fuels and curb environmental damage; (ii) finding new construction materials and alternatives to critical raw materials such as rare earth metals; and (iii) managing fossil fuels in line with commitments to reduce carbon emissions.

33. **Future worldwide settlements will be affected by demographic change and environmental conditions**. Globally, more than 50% of people live in cities and the UN predicts that around two thirds of the global population will be urbanised by 2050 ([4]). In contrast, in certain parts of the industrialised world (such as in former East Germany), cities are shrinking due to a population decline or migrations caused by economic recession, challenging the economic viability of public infrastructures ([5]). Mega-cities with more than 10 million inhabitants will compete with each other on a global scale and consume and emit on a massive scale; shaping such cities to reduce their ecological impact will be a challenge. Anthropogenic global warming, intensified land use, significant sea-level rise, extreme weather and reduced precipitation in the subtropics will render many settlements unsustainable, and eventually uninhabitable.

What if...?

Our roads could provide solar power, by using photovoltaic panels as multifunctional replacements for concrete and asphalt? This could potentially produce decentralised energy, directly and wirelessly power electric vehicles via magnetic induction on their way along "intelligent highways" and serve as a traffic management system. Solar heat energy might even be stored underground in summers and used to de-ice roads in winters.

([1]) "Sustainable development", European Commission, *ec.europa.eu*, page updated June 2014

([2]) "Public perceptions of science, research and innovation", *Special Eurobarometer 419* (2014), European Commission

([3]) Rogner H., Aguilera R. F., Archer C., Bertani R., Bhattacharya S. C. et al, (2012), Chapter 7 - Energy Resources and Potentials. In Global Energy Assessment - Toward a Sustainable Future, *Cambridge University Press, and the International Institute for Applied Systems Analysis*, pp. 423-512

([4]) "World Urbanization Prospects: The 2014 Revision", (2014), *United Nations*

([5]) Schetke S. and Haase D., (2008), Multi-criteria assessment of socio-environmental aspects in shrinking cities: Experiences from eastern Germany, *Environmental Impact Assessment Review Vol 28*, pp 483-503

The "internet of things"

Future "smart" cities will balance sustainable infrastructure with the provision of services and goods to citizens. ICT links will enable an integrated supply and demand structure that provides energy, security, mobility and communication more efficiently. The internet of things means that your building could be more energy efficient by sensing the movements of occupants and adjusting lighting and heating accordingly. Your refrigerator could order food or warn you about items close to their expiry date, helping to reduce food waste. Today your car has sensors to tell you if something is wrong with the engine, but in future your car could also tell you where the nearest garage is and inform the garage when you would arrive. Physical transport may be heavily reduced by advanced methods of commuting, especially intelligent and flexible schemes based on electric transport.

This integration is not without potential risks, for example, lack of personal agency, violation of privacy and reduced resilience. In addition, the practicalities of connecting different operating systems need to be addressed. However, creative network designers are working on these issues. As well as increasing the quality and sustainability of services, the freeing up of time previously spent on tasks such as travelling will provide opportunities for productivity and leisure.

Opportunities offered by science, engineering and technology

34. **Our industrial European society will need to exploit biomass and organic matter (often waste) as an alternative raw material, thus creating a new type of bio-based industry.** We need raw materials as well as new catalysts to perform synthesis and degradation reactions in an environmentally friendly, low-energy manner. To tackle this challenge we rely on the microbial world as the largest reservoir of biological activities in the biosphere. But, like the European explorers of the 16th and 17th century, microbiologists today find themselves at the edge of an unknown territory. It is estimated that only 0.1–1% of microorganisms can be cultivated using current techniques; therefore the enormity of microbial lifestyles, molecules and activities remains to be discovered. A major challenge is the development and implementation of screens for new microbiological activities ([1]). Some benefits stemming from environmental bacteria have been in place for a long time (e.g. antibiotics), but the number of new genes that are discovered every year as a result of massive sequencing projects has not yet reached a plateau ([2]). The shift to bio-based industries could be facilitated by systems biology and synthetic biology, which allow a fast translation of biological data into useful information and then into valuable products and processes ([3]).

([1]) Streit W.R. and Schmitz R.A., (2004), Metagenomics – the key to the uncultured microbes, *Current Opinion in Microbiology 7*, pp 492–498; Riesenfeld C.S., Schloss P.D. and Handelsman J., (2004), METAGENOMICS: Genomic Analysis of Microbial Communities, *Annual Review of Genetics 38*, pp 525-552

([2]) Yooseph S., Sutton G., Rusch D.B., Halpern A.L., Williamson S.J. et al., (2007), The *Sorcerer II* Global Ocean Sampling Expedition: Expanding the Universe of Protein Families, *PLoS Biol 5(3): e16*

([3]) Schmidt M. (Ed), (2012), Synthetic Biology: Industrial and Environmental applications, *Wiley-Blackwell*, ISBN 978-3527331833

35. **Europe is already investing heavily in new nano-materials such as graphene**, which has the potential to replace other scarce resources ([1]). However, numerous other technological possibilities for finding resources are being investigated. These include: (i) access to the ocean floor for mineral extraction; (ii) creating artificial or floating "islands" ([2]); and (iii) harvesting expensive scarce metals (such as platinum, iridium and tungsten) by mining asteroids in space; or drilling to gigadepths on Earth ([3]). These options raise important questions and need to be carefully studied.

36. **To address increasing urbanisation in the future, cities in developed countries with older populations will place emphasis on sustainability and quality of life.** Since cities will have to rely more and more on renewable energy sources, modern technologies (organic photovoltaics, micro-wind turbines, solar active tarmac and building surfaces etc.) will help to tap the potential of buildings and infrastructures. Novel materials such as graphene and carbon fibre will significantly enhance resource efficiency within urban environments ([4]). Spintronics (using the spin of the electrons in addition to their charge) could significantly reduce the energy consumption of electronic devices (for example, lighting).

37. **Food security and quality will remain vital concerns for Europe**. With increasing urbanisation, urban farming (e.g. converting multi-storey buildings to vegetable farms) will contribute increasingly to local and regional food production.

Recommendations

38. **Europe's main challenge is how to combine social justice and environmental sustainability with the realities of the free market in an extremely competitive world**. Tackling this challenge will require us to: (i) use what we already have more efficiently; (ii) develop a truly circular economy where resources are continuously reused; and (iii) look beyond the horizon and prepare for new technical possibilities and challenges that are not known to us at present (i.e. foresight). **The European Commission and Member States should increase support for technologies and initiatives (financial and regulatory) that can reduce consumption levels without sacrificing quality of life, and that contribute to absolute decoupling (where growth in income occurs while use of resources and/or environmental impacts decline).**

39. **The EU should develop a coordinated strategy and prioritise work on developing new technology systems, infrastructure and procedures to adapt to climate change and sea-level rise.** For example, Amsterdam's Schiphol airport operates effectively at 1.5 metres below sea level.

40. **Europe can and must take the lead in the exploration of microbial biodiversity to find "bioactives".** These should be integrated into microbiology, chemistry and biochemistry disciplines to create coordinated pipelines for discovery and commercial development ([5]). Funding of such pipelines must come not only from already overstretched national research budgets, but also from sustained EU resources (Horizon 2020 and beyond).

([1]) "Graphene Flagship", European Commission, *graphene-flagship.eu*

([2]) Artificial islands are already common worldwide as urban extensions of overcrowded frontline cities, harbouring stores, airports, hotels, and various industrial facilities. Floating islands already serve as bases for extensive drilling facilities and hotels

([3]) "The Kola Superdeep Borehole", EnglishRussia, *englishrussia.com*, page posted July 2009; Kozlovsky Y.A. (Ed.), Lavrushko, I.P. (translator) et al, (1987), The Superdeep Well of the Kola Peninsula; Series: Exploration of the Deep Continental Crust, Springer; *Softcover reprint of the original 1st ed. 1987 edition*

([4]) Novoselov K.S., Fal'ko V. I., Colombo L., Gellert P. R. et al, (2012), A roadmap for graphene, *Nature 490(7419)*, pp 192–200; Chand S., (2000), Review Carbon fibers for composites, Journal of Materials Science, 35(6), pp 1303–1313

([5]) Timmis K. et al, (2014), Pipelines for New Chemicals: a strategy to create new value chains and stimulate innovation-based economic revival in Southern European countries, *Environ Microbiol 16*, pp 9-18

What if...?

Available solar energy could completely cover the EU's energy needs? We could invent technologies to acquire, store and use solar energy in eco-friendly ways using innovative, intensive "bio-solar plantations" including algae tanks and extensive forestation. Europeans would benefit from having natural fuel, healthy forests and abundant food.

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41. **Europe's largely linear production systems and waste disposal are not compatible with the goals of sustainability and efficiency.** Although changes in policy, management, and consumer behaviour all play important roles, it is still necessary to develop technology applications that will make the reuse of resources possible and economically affordable, with minimal loss or "downcycling" in terms of quality. **While European programmes to advance efficiency and the circular economy already exist (e.g. Resource Efficient Europe ([1])), the EU and Member States should also implement programmes for: (i) recycling systems to reclaim raw materials from common wastes, such as sewage; (ii) methods for reclaiming critical raw materials such as rare earth metals; and (iii) reuse of urban and municipal solid wastes.**

42. Many initiatives for resource exploitation (as described in paragraph 35 for example) are attracting investment and often developing without any serious consideration of the systemic sustainability implications and impacts ([2]). **There should be a coherent European strategy covering public and private investment in resource exploration that weighs options according to their sustainability.**

([1]) "A resource-efficient Europe – Flagship initiative of the Europe 2020 Strategy", *European Commission*, ec.europa.eu, page updated February 2014

([2]) For example, if ocean bottom mining is developed then there will be a need to construct giant floating islands above the mineral reserves field; Donges J.B., (2011), The Economics of Deep-Sea Mining, Springer London, ISBN 978-3642702549; Mahmoudi S., (1987), The Law of Deep Sea-Bed Mining: A Study of the Progressive Development of International Law Concerning the Management of the Polymetallic Nodules of the Deep Sea-Bed, Almqvist & Wiksell International, ISBN 9122011560

5. Achieving the best future for Europe: Final conclusions

Foreground

43. **Foresight activities will never be able to predict the future, but they will help Europe to cope with the implications of changes and future surprises.** Traditional approaches to scientific foresight were based on linear projections of present practices and needs into the future ([1]). However, the political, social and natural environment constantly changes, producing new opportunities and threats. Foresight activities are necessary to identify those opportunities and threats and the complex relationships between nature and human society, so that we can be better prepared. **The Commission needs multidisciplinary foresight activities, including modelling and simulation. The creation of a foresight network, linking foresight activities in Directorates-General, is a good start and should be built upon in the new Commission. In addition, Member States should better link their foresight activities. Ethical foresight should also be a priority ([2]). Foresight functions with regard to accelerating technology development need to be linked to policy development: Europe should already be preparing for the future beyond the Horizon 2020 research programme.**

44. **Citizens need scientific literacy and good understanding of statistical probability while politicians and scientists need to incorporate citizens' views into scientific and technological policies.** Assessment of opportunities and risks is accompanied by public perceptions that often amplify the potential risks and underestimate the positive changes that may materialise if new technologies are implemented. Previous examples are chemical factories, power plants, genetically modified organisms or nanotechnologies ([3]). Sceptical attitudes towards new technological developments should not be seen only as a problem; in democratic societies, citizens need to be involved in decisions that will affect them. **A genuine two-way communication process should be the default in all future SET policy development to ensure that citizens can embrace the positive effects of change while knowing that their needs and concerns have been heard and acted upon.**

Investment in research and development

45. **Scientific collaboration creates vital international links for knowledge sharing and problem-solving.** Making Europe healthy, productive and competitive in future should not be the only ambition for European science and policy. We live in a global environment and we have a responsibility to help meet challenges in the developing world, such as alleviating poverty, disease and hunger. There must also be willingness to conquer new frontiers (such as space and the deep ocean) and to accept inherent risks. Science should capture people's imagination and mobilise support for new human endeavours.

([1]) Höjer M. and Mattsson L.G., (2000), Determinism and backcasting in future studies, *Futures, 32(7)*, pp 613–634

([2]) "Science for an informed, sustainable and inclusive knowledge society", *President's Science and Technology Advisory Council* (2013), European Commission; see also "European Group on Ethics in Science and New Technologies", *European Commission*, ec.europa.eu, page updated August 2014

([3]) Gregory R., Flynn J., Slovic P. and Kunreuther H., (2001), Risk, media and stigma: understanding public challenges to modern science and technology, *Routledge*, pp. 3-8; Frewer L.J., Fischer A.R.H., Gupta N., (2012), Socio-psychological determinants of public acceptance of technologies: a review, *Public Understanding of Science 21 (7)*, pp 782-795

46. **The research base in Europe, where many ground-breaking ideas come from, must continue to be excellent in order for opportunities to materialise in the first place.** Fundamental, exploratory science that is not necessarily linked to obvious or predictable material benefits in the short term still holds great value for Europe, which is a world leader in this type of research. As well as social and economic benefits, science has a value for the realisation of our potential as a species. However, there are huge differences in science investment across Europe, resulting in regional inequalities. **The Commission and Member States should think of science as a European resource and a shared, strategic good that must meet some common standards and thus involve a binding common policy. Member States must benchmark their domestic science and research systems to a European touchstone, and this should extend beyond the Framework Programmes. An excellent, pan-European, harmonised R&D system must include a shared educational counterpart and a consistent roadmap for academic careers.**

47. **While private funding is essential for bringing innovation closer to the market, the investment of public resources in fundamental research has led to the birth and expansion of key economic sectors**. Prioritisation of strategic, top-down funding schemes for short-term problem-solving may appear attractive to decision-makers in today's challenging financial situation. Nevertheless, the healthy Europe of tomorrow needs fundamental, researcher-initiated science to uncover new paths to explore and establish platforms of reference before the impact desired by industry is identified. This requires public research investment. **For Europe to have an innovative future beyond 2030, Member States (and not only the EU) must commit to domestic long-term support for fundamental, researcher-initiated science and technology.**

Looking Forward

48. The extraordinary trends and possibilities that are briefly described in this report are merely the "tip of the iceberg". Europe is known globally today for large-scale science and technology programmes and infrastructures such as CERN and its Large Hadron Collider (where the Higgs boson was discovered), or the missions of the European Space Agency. Europe is where the Nobel Prizes in science and medicine are awarded each year. Horizon 2020 provides a very strong foundation for European science in the coming years. But Europe, and indeed all Europeans, must do more. To achieve the future that we all want, we need to put our historic scientific legacy to even better use, deepen and enrich the relationship between science and society, and embrace a new era of European exploration and innovation.

The future of Europe is science… let us all play our part in delivering the vision.

List of STAC members

The President's Science & Technology Advisory Council (STAC) is an independent and informal group of science and technology experts from academia and business, covering a broad range of disciplines and uniting expertise from across the European Research Area. Established in January 2013, the task of the Council is to examine areas where research and innovation can contribute to Europe's growth — with a particular focus on benefits and risks of advances in science and technology and how to address and communicate these.

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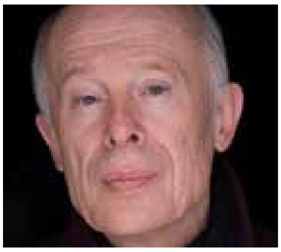

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Supplementary materials

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- Foresight workshops organised by the European Commission, attended by external experts, STAC members and Commission staff from several DGs.
- SET fiches (files) produced by the European Commission's foresight network.
- A Eurobarometer survey on Public perceptions of science, research and innovation *Special Eurobarometer 419.*

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