

UK non-paper on thematic priorities for Horizon 2020

Introduction

In May 2011, the UK Government published its overall policy position on funding for EU research and innovation from 2014¹. This official-level non-paper sets out the UK's current thinking² on key themes and topics which should feature in Horizon 2020, with particular focus on the Challenges and key enabling technologies planned for the new framework.

Research and innovation are vital to promoting smart, sustainable and inclusive growth in Europe in line with Europe 2020 and should continue to receive a high – and ideally increased – proportion of the 2014-2020 EU Budget which is re-prioritised to focus on sustainable growth. Both challenge “pull” and technology/knowledge “push” research will be needed to deliver the twin objectives of sustainable growth and addressing global challenges.

The FP7 Cooperation Specific Programme has shown the benefits of investing in key enabling technologies such as ICT, nanotechnology, biotechnology and specific technologies for space, aerospace, the environment, energy and future transport needs. Such technologies, and the fundamental research that underpins their development, should continue to be supported as they provide the technological push that can potentially address future challenges and build the research capability of key industry sectors.

Technological/thematic support needs to be linked to strategic planning. The SET plan has shown how an EU initiative can address a major challenge whilst building competitiveness and sustainable economic growth, and demonstrating genuine EU added value.

This support also needs to be provided as part of a broad approach to innovation, including social innovation and new business models. Grand challenges are complex; multidisciplinary approaches will be relevant to addressing all the global challenges. The social sciences and humanities should play an instrumental – and in some cases leading – role in addressing issues relating to societal change and should be embedded in all aspects of future programmes.

Public engagement with science is important to maximising the benefit of research to society. Decision makers in research must be able to understand and respond to the hopes and concerns of the public. The principles of Responsible Research and Innovation, including the promotion of public engagement activities, should be mainstreamed across all the challenges proposed for Horizon 2020.

To maximise the benefit from these efforts there needs to be improved sharing of results together with a greater focus on exploitation to realise real economic and social benefits. Real and rapid return on investment in research will depend on improved dissemination of results to and uptake by those who can make use of and add value to the results.

Some UK priorities for each of the grand challenges are outlined below; however we recognise that further work is needed to develop the multi-disciplinary perspectives of all these challenges. Developing this takes time and we strongly encourage the Commission to embed a multi-disciplinary approach across all grand challenges. Such an approach should occur from the very first stages of formulation rather than being an ‘add-on’.

¹ <http://www.bis.gov.uk/assets/biscore/science/docs/f/11-901-funding-eu-research-innovation-from-2014>

² NB the content of this paper is without prejudice to the UK Government's position in the forthcoming negotiations on the Horizon 2020 legislative package

Thematic options

These represent current BIS thinking on the challenges and technologies that could be addressed as part of the Horizon 2020 programme. This is not a comprehensive summary: we believe that the EU must have a mechanism in place to agree challenges as they emerge and remove others if appropriate.

1. Meeting societal challenges

1.1. Health, Demographic Change and Wellbeing

Europe's health challenges arise from a changing health demographic at the same time as we see the rapid advance of new medical interventions. Our population is staying healthier and living longer than ever before. It is estimated that by 2050 one third of Europe's population will be over 60 and just 13% under 16. This change leads to an increase in chronic diseases, particularly the 'big killers' cardiovascular diseases and cancer, as well as increases in obesity, metabolic syndrome and mental health disorders, all of which impact on health expenditure. Advances in high throughput sequencing and genome analysis are making it possible to consider ways of tailoring treatment to individual patient needs. Regenerative medicine is providing new technologies to repair and replace damaged tissues or cells, and information technology is underpinning new imaging and diagnostic techniques. These new challenges necessitate an evidence-based approach to improving health care systems and to promoting preventive public health measures. To ensure that new interventions can meet the health challenge it is necessary to support the full innovation cycle (including innovation in services) from research to market uptake, including technology transfer and commercialisation, and research on ethical and cultural dimensions of health should be embedded within this holistic approach. This needs to be accompanied at European level by support for market frameworks, appropriate development of regulation and health policy guidelines.

The following areas need to be addressed.

1.1.1. *Aetiology of disease, treatment and health*

- (1) **Stratified medicine:** will lead to the development of treatments that are particularly effective within defined groups of patients. Targeting of specific disease pathways coupled with new diagnostics will lead to better interventions with fewer side effects and higher success rates. Implementation will require new taxonomies of disease classification, accelerated therapeutic discovery through close collaboration with industry, better characterised patient cohorts, linking of biomedical data to clinical data sets, clinical trial designs that permit subgroup analysis and mechanisms to promote uptake of therapies within existing health services.
- (2) **Regenerative medicine:** is an emerging field of research and clinical applications requiring a multidisciplinary approach. It includes tissue engineering, developmental and stem cell biology, gene therapy, cellular therapeutics, biomaterials (scaffolds and matrices), nanoscience, bioengineering and chemical biology.
- (3) **Systems medicine:** requires a computational approach to understanding how the control of gene expression, self organisation of macromolecular assemblies, signalling pathways and other cellular components affect whole biological systems (renal, hepatic, immune etc) and ultimately the health of the individual. It includes gene expression, macromolecular assemblies, signalling pathways, self-organisation within cells, understanding disease and ageing effects at a whole-system level, applying whole-pathway understanding to the design and use of new therapies.

Key priority areas include: Neurosciences and mental health (biology of the brain and its

disorders including neurodegenerations, depression, addiction, prevention of mental illness, biological and social determinants of mental illness, rehabilitation and recovery), chronic diseases (diabetes, cardiovascular, musculoskeletal disorders, cancer) rare diseases (including working through international partnerships), infectious diseases (including pandemic preparedness, vaccine development, drug resistance, immune response. Evidence to support the introduction of new treatments, including repurposing of drugs, or behavioural interventions should be provided through support for clinical trials

1.1.2. Prevention research, healthy lifestyles and healthy environments

- (1) **Healthy ageing:** starts at conception and the early life determinants of healthy ageing need to be properly explored. Reducing the burden of age related conditions will need to take account of increased dependency that accompanies ageing and which may require changes to the physical environment. It needs to address issues of health inequalities and inclusion, arrangements for social care and increase understanding of how to improve wellbeing through cultural and social participation.
- (2) **Environmental change and health:** As well as the broader issues associated with global climate change the programme should address issues such as exposure to allergens, pollution and chemicals in the food and water supply.
- (3) **Population health sciences:** Population cohort studies are essential for studying the association between social, biological, environmental and lifestyle factors in health and disease. There is a need to ensure effective European disease registries and to support cross-sectional population surveillance and biomarker discovery
- (4) **Public health and the impact of lifestyle and behaviour:** A key challenge for a healthy Europe is to improve our record on disease prevention. This requires better methods of delivering behavioural interventions and education programmes but also developing our understanding of the impact of factors such as diet, transport, exercise and occupational risk on healthy living.

1.1.3. Management of health systems and social care

- (1) **e-Health:** The wealth of data in health records is poorly utilised for research and innovation but if appropriately exploited would underpin many of the areas described above. There is a need to develop new methodologies, particularly in data management, analysis and statistics. Research into the regulation and governance of e-Health are essential if Europe is to benefit fully from this initiative.
- (2) **Health Systems research:** Improved health care research and health systems research for delivery are required to ensure uptake of evidence based medicine and development of best practice across Europe. Similarly, improved knowledge about social care systems, based on rigorous research, is a key to spreading best practice.

1.1.4. Global health research

Europe needs to take a lead in global health research, building on existing programmes such as EDCTP but also developing new partnerships to tackle new challenges. It is appropriate to continue to target global infections including neglected tropical diseases, but there is an increasing need to engage with international approaches to tackling chronic diseases, maternal and child health and health inequalities. Nutrition research in developing countries should also be supported. Health systems research in developing countries is urgently required to ensure an effective infrastructure for implementation of the outcomes of research into drug resistance amongst current infections. The programme will need to undertake research for pandemic

preparedness, drug resistance and vaccine development. New vaccine discovery will also need continued studies on the immune response to infection.

1.2. Food security and sustainable bio-resources

The challenge is to deliver sustainable, nutritious, safe and affordable food for all, tackle waste and to exploit non-food bio-resources sustainably, and to do this in the face of an anticipated increase of 70% in food demand by 2050 for a global population of over 9 billion, increasing demands on water, land and other finite resources, and the need to mitigate and adapt to the impacts of climate change.

Investment in research and innovation will support **sustainable intensification** and '**climate smart**' **food systems** to improve food security for Europe and globally, and help systems adapt to and mitigate against climate change. Increasing productivity and resource efficiency, and understanding and promoting sustainable consumption, will help reduce environmental footprints of food and improve competitiveness. Research to help make diets healthier and foods safer for all will reduce health and economic impacts of poor nutrition and food-borne illness in the EU.

Europe's green economic growth depends on innovation and sustainable development of bio-renewable energy, bio-fuels and bio-materials, delivering sustainable forestry in a multifunctional landscape, and managing competing demands for land use to maintain ecosystem services. Bio-resources are the only viable alternatives to fuels and materials derived from fossil carbon.

These challenges are inter-related. Significant added value can be delivered by taking an holistic view at EU level to understand trade-offs and synergies between different aspects of food security and bio-resources and to deliver the most effective package of actions for Europe to achieve its objectives. This will need co-ordination with other themes and enabling technologies to avoid gaps and overlaps and ensure synergies. Specific areas that need to be addressed include:

1.2.1. Economic resilience

- (1) **Food supply, trade and prices:** improved understanding of the critical factors controlling world trade and the global food supply. More rapid, reliable, cost-effective methods to underpin traceability and food authenticity and detect adulteration throughout the supply chain.
- (2) **Sustainable rural communities:** Better understanding of rural communities and economies, including community structure, rural demographic changes and the nature of social exclusion will be needed to enhance economic and social regeneration in rural communities and provide the basis for resilient food (and non-food) production within an ecosystem services approach.

1.2.2. Resource efficiency

In items 1–6 below there is scope for research to improve understanding of behavioural change which can lead to complementing technical advances by, for example, influencing the demand for resources.

- (1) **Greenhouse gases:** new technologies, management systems, and evaluation tools to reduce GHGs emissions from the food system including primary production, food manufacturing, retail, service and domestic consumption and related sources such as transport and refrigeration.

- (2) **Waste:** prevention, re-use, recycling and disposal of agricultural and food waste and by-products; reducing storage losses; sustainable food processing; smarter packaging.
- (3) **Energy:** on-farm and off-farm energy from renewable bio-sources (farm waste digestion, poultry litter, meat and bone combustion, straw, energy crops, paper/packaging); reduction of energy consumption in primary production, processing, transport, storage and retail.
- (4) **Water:** sustainable water management strategies for European and global ecosystems; reducing water usage through new technologies (including plant and animal genetics) and practices; better evaluation of water footprints in all sectors.
- (5) **Nutrients:** Sourcing and use of fertiliser (organic and inorganic), other chemical inputs and critical nutrients; minimising losses of nutrients to the environment.
- (6) **Soils:** Sustainable use and management of soils as a finite resource, including contribution to carbon release/sequestration, competing land uses, analysing soil loss, risk and impact.
- (7) **Farming systems:** whole systems approaches to enhance biodiversity conservation, maintain natural resources and ecosystem services, manage competition for farm land, and better reflect regional or local conditions. Understanding drivers behind decisions by producers and consumers, to inform effective policy to encourage behaviour changes.

1.2.3. Sustainable food production and supply

- (1) **Crop production:** sustainable intensification, increasing productivity while optimising resource use and enhancing nutritional quality; better monitoring of and protection against pests, diseases and weeds (responding to tighter regulation of agrichemicals); improving quality of seeds and propagation material and tolerance to abiotic stresses; advanced breeding using genomics, genetic markers and biotechnology, as appropriate; nitrogen fixation by non-legumes and improved efficiency of photosynthesis; plant genomics and genetic diversity.
- (2) **Soil:** understanding soil processes; rhizosphere and plant-soil-microbe interactions, effects on plant health, soil microbes; carbon and nitrogen fluxes, structural properties of soil, and the interactions with organic matter and inorganic nutrients.
- (3) **Livestock production:** breeding for improved yield, quality and welfare; genetic diversity and use of rare breeds; vaccines for endemic and exotic diseases (EU and global); improved diets and management to improve feed conversion; better detection, monitoring and management of exotic and endemic diseases; reduced impact of GHG emissions; lower-intensity farming especially in marginal areas; safe, sustainable sources/uses of feed, including novel products.
- (4) **Aquaculture and fisheries:** sustainable management of wild and farmed fish for key species; safe, sustainable solutions (e.g. plant technologies, novel protein sources) for fish feed; understanding nutritional and environmental impacts of different farmed fish species including responses to disease and sea lice; innovative approaches to wild fisheries management to conserve fish stocks by tackling discards, harvesting fish at maximum sustainable yield, and moving towards an ecosystems approach; and research into greater utilization of food material caught as part of fishing process but not currently marketed.
- (5) **Ecosystem services:** Understanding trade-offs/synergies between maintaining ecosystem services and other aspects of food security.

1.2.4. Sustainable, healthy, safe foods and diets

- (1) **Healthier diets and nutrition:** improved understanding of how foods and diets affect health including chronic diseases and obesity; developing and testing interventions to improve diet and health; micronutrient requirements and nutritional needs of specific groups; personalised nutrition; new/improved foods acceptable to consumers; optimising product (re)formulation through new uses or sources of ingredients and nanotechnology.
- (2) **Sustainable consumption and healthy eating:** understanding relationships/trade-offs between production, consumption, safety, healthy eating and affordability and cultural significance; what a healthy low-impact diet might comprise; how best to help people achieve this in a sustainable food system; understanding the cultural relevance of food and how that influences sustainable consumption in different contexts.
- (3) **Consumer attitudes and behaviours:** an integrated approach (social, economic and biological knowledge) to improve understanding of what shapes consumers' attitudes and behaviours, including cultural aspects and interest in the convenience, taste, quality and origin; understanding issues that affect food availability and affordability and barriers to healthy eating.
- (4) **Food safety:** food safety in a global whole food system; better understanding and management of risks from known, new and emerging food-borne pathogens, chemicals and external factors, including climate change, demographics, waste, globalisation; understanding causes and mechanisms of food allergy; increasing shelf-life and maintaining food safety; effective methods to support regulation; evidence to underpin effective risk-based controls for the whole chain; challenges and opportunities from emerging technologies and novel foods.

1.2.5. Sustainable use of non-food bio-resources and industrial biotechnology

- (1) **Forestry:** understanding how to maximise benefits from sustainable forestry in a multifunctional landscape; climate change impact, adaptation and mitigation; water quality/flood mitigation; ecosystem services; renewable energy; sustainable food production; land regeneration and urban greening; wider benefits to society. Prevention and control of damage from pests and diseases, enhancing tolerance to abiotic stresses; solutions for sustainable management and intensification; tree improvement and forest genetics.
- (2) **New sources of biomass and bio-products:** non-food use of crops/by-products/wastes and marine/aquatic bio-resources. Sustainable feedstocks for bulk biofuels, biochemicals and other products, addressing land use pressures. Breeding for increased yields, adaptation to marginal areas, and for selected traits and uses in industry. Modelling, simulation and prediction to explore control of pathways and develop opportunities for synthetic biology.
- (3) **Industrial biotechnology:** developing renewable bio-fuels, products and processes to replace petroleum-based systems. Understanding and manipulation of process conditions to maximize outputs, including microbial metabolism and structure, function and interactions of proteins. New/engineered enzymes, microbial strains, novel catalytic entities and environmental conditions for efficient production/extraction of products from raw/ waste biomass; efficient, scaled-up production. Understanding catalytic mechanisms and pathways for secondary metabolite biosynthesis; improved whole-cell biocatalysis; metabolic engineering and system modelling to optimise performance. Microbial and gene screening, enzyme activity assays, cell-based bioassays. Improved processes to break down biomass for bioenergy and other uses. Improvements to key industrial processes including production/refining of biofuels; biomass gasifier technology; gas clean upgrade;

Fischer Tropsch catalysts and reactor design; upgrade of pyrolysis oil, bioethanol/butanol processing, bio-products for medicinal applications

- (4) **Biorefineries:** Design of new biorefineries, plant/microbial matter bioprocessing, extraction and separation techniques, fast-track molecular breeding of feedstock species for improved raw materials, consistency and yield. Bolt-ons to existing/first-generation biorefineries.
- (5) **Environmental biotechnology:** Bioremediation, using bio-resources including: plants and micro-organisms to treat organic/chlorinated solvents; remediation of mine waters and metal ion contamination; removal of N and P from agricultural waters and of selenium by microbial processes; bioprocesses for desalination, treatment, purification and recycling of water. Reducing environmental impact of products, e.g. biodegradable packaging.
- (6) **Safety and societal aspects of biotechnology:** understanding implications for environment and health, and of public attitudes/behaviours, with regard to new applications of biotechnology, to underpin proportionate risk-based controls and sustainable exploitation.

1.3. Secure, Clean and Efficient Energy

The Strategic Energy Technology (SET) Plan outlines the technology development priorities to achieve the EU's 2020 energy and emission targets and 2050 vision. The UK supports these objectives, which are set in the context of meeting consumers needs for affordable and secure energy in a way that retains EU competitiveness. The plan has the potential to act as the energy technology development pillar to deliver the objectives of the EU's Roadmap for moving to a competitive low carbon economy in 2050 and the EU's Energy Roadmap 2050 and will need to be accompanied by measures to encourage commercial exploitation. Priority should be given to:

1.3.1. Key technologies identified by the SET Plan as important for reaching 2020 objectives

These include: 2nd generation Bio-fuels (e.g. from crop residues), CO₂ Capture, Transport & Storage (CCS), Wind, particularly Offshore Wind, Photovoltaic (PV) & Concentrated Solar Power, Smart Grids, Energy efficiency in buildings, transport & industry, and Nuclear Fission (including waste management).

There is also the need to include marine / ocean energy technologies and energy storage, and for a further SET plan focus on the need to develop a coherent European approach for international Science and Technology cooperation, as well as supporting intra-EU collaboration activities.

The UK recognises that support for these technologies will need to continue beyond 2020 for further development as required.

1.3.2. Key technologies identified in the SET Plan which are expected to have an important role for the EU in 2050

These include: energy storage, hydrogen fuel cell vehicles, generation IV nuclear fission, nuclear fusion, trans-European energy networks, and new technologies for energy efficiency, notably in respect of the built environment and its integration with vehicles and transport systems.

1.3.3. Energy technology-related development in complementary research, development and demonstration areas

For example, new materials research and Information and communication technologies, and possibly collaboration with other complementary themes such as space research, where many of these areas of innovation are also being developed and applied. Also, indirect complimentary activity, for example: on barriers to deployment including consumer behaviour and acceptance, skills, and mobilising finance, such as the schemes currently included under Intelligent Energy Europe. There also needs to be continued investment in energy systems engineering tools, including techno-economics, in order to support effective and evidence-based decision making about priorities and targets and the development of physically, politically and economically robust systems that meet people's needs. These capabilities should be available to inform decision making at enterprise, national and EU levels and will be important to future quality of life and competitiveness.

1.3.4. New energy-related technology and innovation likely to be significant to 2020 and 2050 targets and vision

There should be an element of flexibility in the list of technologies that can be supported to allow for new ideas and developments, for example the concept of Virtual Power Plants.

1.4. Smart, Green and Integrated Transport

There is an increasing need for mobility both to transport goods and for people to travel for business or private, social reasons as detailed in the Commission's Transport White Paper. It is important to have an integrated seamless overall transport system. This requires activity both in overall transport inter-modality but also effort in the modes of surface and air transport.

Space technology is a key enabler here for smart integrated transport systems. Global Navigation Satellite Systems (GNSS) is currently used for a multitude of applications that is continually growing in complexity and integration including a range of consumer products. There is increasing interest in the further potential from areas such as, location based services, road pricing / road user charging, emergency services, regulatory enforcement, freight and logistics, rail, air traffic management, maritime, and advanced driver assistance Systems (ADAS). In addition applications could improve safety in the transport networks, e.g. collision avoidance, improving fuel efficiency, and reducing delays.

1.4.1. Transport Policy/Integration

European transport policy recognises this sector is an engine for economic growth but, also one that must be greener and safer so that it improves the quality of life across our communities. In recent years, mobility by road, water and air has become cleaner and more energy efficient, but increasing demand means transport remains a major source of noise and local air pollution. Greater integration between transport networks should result in improved systems for moving goods and people, better modal choices and targeting of investments so that we can build a balanced, dynamic and low-carbon economy.

1.4.2. Surface Transport

Economic growth and green technologies should be at the centre of future research and innovation priorities and involve a broad range of instruments from Level 0 to Level 2. Understanding and facilitating passenger travel choices is also important. Future activities must be underpinned by work to promote an increasingly safe and secure transport system. Future priorities include:

- (1) **Further development of Green Technologies:** Reducing transport related GHG emissions will remain a top priority and will focus on: Greener fuels for the internal

combustion engine; the advancement of battery technology in terms of costs and energy storage density; a step change in hydrogen fuel cell technology; and new sustainable fuel sources.

- (2) **Improving the quality of our Integrated Networks:** In order for the transport system to contribute to economic growth there is a growing need to improve the interchanges between modes of transport and the connectivity between and within our cities and international gateways. Planning for capacity limits being reached on strategic road and rail networks is also a priority.
- (3) **Understanding and facilitating passenger travel choices:** Identifying ways to manage demand for travel during the peak times without resorting to efficient but unpopular pricing measures or rationing through congestion (which is inefficient and unpopular). Equally important is an understanding of the factors that will influence future demand and passenger choice between home/remote working, videoconferencing etc. and making commuter / business trips. Developing a coherent picture enables the creation of effective and integrated schemes to free up capacity across the most constrained parts of our transport infrastructure networks.
- (4) **NO₂ Reduction:** EU air quality objectives on ambient concentrations of nitrogen dioxide remain challenging to achieve. An efficient means of removing NO₂ from the air would be of benefit to all EU Member States in achieving their air quality objectives.
- (5) **Health impacts of particle emissions:** Vehicle particle emissions are controlled by limits applying to new vehicles. Further research on the health impacts of nanoparticles may help confirm whether further action to control particle emissions is appropriate.
- (6) **Technology development to advance safety systems:** Research, testing and development of Advanced Driver Assistance Systems such as ESC (Electronic Stability Control), AEB (Advanced Emergency Braking Systems) and LDWS (Line Departure Warning Systems). Consideration must also be given to human factors relevant to these systems, such as operator behaviour, or to economic factors such as the balance between risk and cost.

1.4.3. Aviation

The UK fully supports the Flightpath 2050 report of the Aviation High Level Group on Aviation Research and its vision Maintaining Global Leadership and Serving Society's Needs. The UK, with the largest aerospace industry outside the USA, with world class prime companies operating in the UK and with a strong UK supply chain is fully engaged with the formation of the new Strategic Research and Innovation Agenda in Aviation carrying forward the vision in Flightpath 2050 with the elements below. The aviation industry works to long timescales because of the complexity of the integration of complex systems and because of the safety and regulatory processes involved in the introduction of new products. There is considerable future market potential worldwide with air travel predicted to more than double in the next 20 years. Aviation is a significant enabler for growth through enabling business travel and the transport of goods. To meet this demand competitively the sector as a whole needs to plan across the life of Horizon 2020 to give coherent research plan. Hence Aviation requires stability and certainty of a dedicated programme and budget over the life of the Framework involving the full spectrum of research and technology development from Level 0 to Level 2 projects through to a powerful Joint Undertaking (such as Clean Sky) for large scale demonstration.

- (1) **Meeting Societal and Market Needs:** For European citizens to make more informed mobility choices; flights arrive within 1 minute of the planned arrival time; air traffic management system capable of handling 25 million flights per year in Europe; a coherent ground infrastructure.

- (2) **Maintaining and Extending Industrial Leadership:** Aviation industry remains strongly globally competitive; Europe maintains leading edge manufacturing and system integration capabilities and jobs; streamlined systems engineering, design, manufacturing, certification and upgrade processes to address complexity and decreased development costs.
- (3) **Protecting the Environment and the Energy Supply:** 75% reduction in CO₂ emissions per passenger km, 90% reduction in NO_x emissions, 65% reduction in perceived noise; emission-free aircraft movements during taxiing; aircraft designed and manufactured to be recyclable; Europe established as centre of excellence on sustainable alternative fuels; Europe at the forefront of atmospheric research.
- (4) **Ensuring Safety and Security:** European air transport system has less than one accident per ten million commercial aircraft flights; weather and other hazards are properly mitigated; seamless operations through fully interoperable and networked systems; efficient boarding and security checks allow seamless security; air vehicles are resilient by design to security threats; the air transport system has a fully secured global high bandwidth data network.
- (5) **Prioritising Research, Testing Capabilities and Education:** European research and innovation strategies are jointly defined by all stakeholders; a network of multidisciplinary technology clusters exists; strategic European aerospace test, simulation and development facilities are identified, maintained and continuously developed; courses offered by European universities closely match the needs of the aviation industry.

1.5. Resource Efficiency and Climate Change

The economic and societal imperatives for European investment in environmental research are clear. The Stern report calculated the cost of inaction on climate change to be 5-20% of global GDP by 2050, with Europe potentially facing losses of up to €65 billion annually in the 2080s. Globalisation, climate change and the rapid growth of emerging countries are putting greater pressure on resources with 60% of the world's major ecosystems being degraded or used unsustainably and the impact of lost environmental services estimated at US\$2-5 trillion/year. European leadership in responding to these challenges, and our ability to move to a resource efficient, climate resilient, and low carbon economy, will depend on strategic investment in trans-disciplinary environmental research and innovation to provide a broader evidence platform on which to build policies to improve society's ability to use natural resources and ecosystem services optimally, and to increase societal and economic resilience to environmental change. Responding to environmental challenges offers major opportunities for green economic growth, not only by reducing costs and improving competitiveness and resilience, but also by creating and growing new markets in the race to the green economy - e.g. space derived data and services which provide us with a unique and comprehensive means to study changes to the Earth, its ecosystems and climate. Horizon 2020 must provide a framework that can interact effectively with policy processes, identifying and prioritising evidence needs, engaging end-users and other stakeholders, and responding to new and emerging challenges. We outline below specific areas that Europe should address in the framework period.

1.5.1. *Adaptation to and mitigation of climate change*

- (1) **Advances in fundamental climate science to improve predictions and reduce uncertainties:** Earth System Model development focussed on improving the fidelity of ESMs; process-based ESM evaluation drawing on a wide range of observational data and diversity of strategies; development of regional and decadal-to-seasonal scale models of climate and its impacts to provide detail and accuracy for decision-makers. Understanding, predicting and avoiding "tipping points" in the Earth System, for example, rapid change in the Arctic and potential impacts on European climate and economy; understanding accelerating ice sheet loss and predicting impacts for sea level rise and vulnerable coastal

societies; and understanding ocean acidification and the consequences for the carbon sink and marine bio-resources integration of investments in infrastructure (including world-leading High Performance Computing); and understanding the implications of international emissions agreements. Bridging the gap between new knowledge and user needs for climate and climate related risk assessments and other services, based on close collaboration between public and private sectors.

- (2) **Robust decision making through assessing risk:** EU commitments to reducing Greenhouse Gas (GHG) emissions mean that all sectors of the economy must achieve the necessary reductions, requiring a range of evidence to support new approaches and technologies for mitigation. Despite the best computer modelling and efforts to reduce uncertainties in climate predictions, some will remain, so it is essential for decision makers to be able to make robust assessment on climate risk with this uncertainty present. Research that looks at the effectiveness and successful uptake of different approaches to dealing with climate risk, in the face of uncertainty is, therefore, essential alongside improved modelling. Understanding and overcoming barriers to the successful uptake of climate information is a key part of this. It also covers research on the impacts of climate change on European countries for use in risk assessment including a focus on the vulnerability of different systems as well as potential future climate change impacts; an increased effort on the socio-economic and cultural dimensions of behaviours and adaptation; and understanding whole system impacts of new technologies, including renewable energy systems and geo-engineering, to optimise associated environmental benefits and avoid unintended negative consequences.

1.5.2. Protection and efficient use of natural resources

Research and innovation must support an ecosystems approach for the protection of all environmental assets and living resources such as biodiversity, soils, water supply, air quality, waste systems, the marine and coastal ecosystems, agriculture, forests and fisheries. It should address how ecosystems function, the way they deliver services and how they can be managed to increase resilience, provide an improved understanding of the economic and social value of such services, and how this can be fully reflected in decision making.

- (1) **“Natural value”:** understanding the economic and non-economic value of natural resources, ecosystems and the services they provide within urban and rural environments; embedding an ecosystems approach in policy and decision making; public engagement and behaviour change; developing novel, collaborative and sustainable land management systems; understanding impacts on ecosystems, their resilience and sensitivity; management of ecosystems and the services they provide; developing approaches to address cultural values and intergenerational equity; linkages/interactions between ecosystems and the services they provide. Research and innovation to reduce resource depletion (including minerals), sustainably extract previously difficult resource supplies, and understand and manage whole system environmental trade-offs of new resources and treatments.
- (2) **Biodiversity:** Critical gaps in monitoring of species and habitats; economic and social values of biodiversity and link with ecosystem services; impacts of climate change and ecosystem-based adaptation and mitigation; options for improving site and ecological connectivity; robust policy relevant biodiversity indicators; risk assessment and control measures for invasive non-native species; support for the IPBES.
- (3) **Marine:** Human pressures including fishing, hazardous substances, nutrient enrichment and climate change and the impact of new pressures such as offshore renewable and the impact of cumulative pressures; state of the marine environment including descriptors to help track progress towards Good Environmental Status; economic and social aspects, including valuing ecosystem goods and services, and identification of key socio-economic

drivers and incentives; and science for integrated management, including identifying measures to balance activities and deliver sustainable development.

- (4) **Air quality:** Improving projections; gaining a broader understanding of the health effects of air pollutants; gaining a greater understanding of public “valuation” and response to air quality impacts; and the monetary valuation of air pollution impacts on ecosystems and wider health effects.
- (5) **Soil protection:** addressing significant evidence gaps to inform policy development; better protection of agricultural soils; role of soils in mitigating and adapting to climate change; carbon in for example peatlands and forest soils; dealing with contaminated land; sustainable management of soils in the light of pressures such as climate and population change; in situ impacts of soil degradation.
- (6) **Forest ecosystems:** achieving improved forest protection, resilience and adaptation to climate change; and responding to pressures arising from intensifying global trade in timber, forest products and from practices that allow the spread of pests and pathogens.
- (7) **Water security:** influencing change towards more sustainable management and use of water; reducing the impacts of a range of pollutants on the aquatic environment; achieving the environmental objectives of the Water Framework Directive; developing holistic approaches to integrated catchment management (including urban water management); technology, innovation and behavioural changes in achieving more efficient use of water; optimising the level of protection for aquatic ecosystems from over-exploitation; fully incorporating ecosystem service evaluation, flood and drought management, climate change considerations, and behavioural change in water policy; ensuring a safe supply of drinking water.
- (8) **Sustainable consumption and production:** SCP measurement methods; sustainable products, services and materials; business, economy and the environment e.g. materials, energy and water use in construction processes in relation to energy efficiency and carbon performance and to extend asset life; understanding and influencing behaviour. The EU's reliance on, and the impacts of, critical raw materials, especially those essential to the transition to a green economy; increased understanding of consumer use of products and services to identify how to influence individuals and communities to adopt more sustainable behaviours; and increased understanding and effective interventions for changing business behaviour.
- (9) **Waste:** Evidence related to product policy, e.g. in establishing minimum standards for products such as energy efficiency or recycled content, end-of-waste criteria and interventions to improve the impacts of products, identifying and improving overall life-cycle impacts of products and packaging, and consumer and business behaviours in relation to products; supporting business in improving operations to conserve resources; evidence on the collection, sorting and preparation for reuse of packaging, products and materials (including food) once entering the waste stream; evidence on all methods of waste treatment (recovery and disposal) relating to design and choice of treatment.

1.5.3. Other research and innovation priorities

- (1) **Risks and emergencies related to environmental change and natural hazards:** Evidence for emergency preparedness and in relation to handling risk and uncertainty; ensuring ecosystems, human health, and the economy are protected from environmental risks and emergencies, including major animal, plant or public health crises; risks related to chemical, biological and other hazards; other major environmental incidents; and disruption to the food, water and waste supply chains; building community and environmental

resilience to natural hazards for example in earthquake-prone and volcanic regions, including improved forecasting of multiple natural hazards.

- (2) **GMES:** This cuts across the thematic and resource priorities. The GMES core services will support land, marine, atmospheric domains and, in the longer term, a climate service. The data and information from these will support research priorities but they should be also defined by the long term needs arising from research priorities. Where appropriate, priorities within technical research programmes, such as space, should be aligned with environmental research priorities and support the efforts of GEO to create a coordinated global observation system. Coordinated observing systems in the Polar Regions will be among the priorities.
- (3) The “Environment (including climate change)” theme of FP7 should be examined to ensure that other areas, such as the need for research to safeguard Europe’s cultural heritage a unique resource and an important component of individual and collective identity, do not fall between stools.

This challenge will underpin and cut across other challenges in Horizon 2020. For example, deriving **energy and natural resources from marine ecosystems** (e.g. wind and tidal energy, fisheries, bioenergy, minerals) will require research on wind and tidal systems to optimise generation capacity whilst addressing whole-system environmental impacts and benefits to avoid unintended negative consequence, and evidence to sustain marine ecosystem benefits in response to environmental change. **Environmental management related to food security** will require research to enable the sustainable use of wider ecosystem services.

1.6. Inclusive, Innovative and Secure Societies

The adoption of this challenge, and opening the other challenges to related contributions, will ensure that social science, and arts and humanities research contributes fully to the goals of Horizon 2020. This challenge will deliver greater understanding of the roles of individuals, communities, states and cross-national collaboration over time that is crucial for Europe’s future. In an increasingly globalised and interconnected world, the need for diverse cultures to understand and communicate with each other is stronger than ever.

Whilst interactions between the aims of inclusive, innovative and secure societies may be beneficial there is also the potential for tensions between them, which will require careful consideration of the practicalities. Social science, and arts and humanities can make an enormous contribution to security issues, but each will require specific support to deliver the aims of this challenge.

Given the importance of public engagement, developing an evidence base for best practice in research education, diversity, public engagement and other elements of responsible research and innovation remains important. As such there, is a case for this to be a research subject within the Inclusive, Innovative and Secure Societies challenge. However, as mentioned earlier, research into the social sciences, arts and humanities have a role in addressing issues relating to societal change and should be embedded in all aspects of future programmes. Equally, public engagement activities also need to be encouraged across all the challenges proposed for Horizon 2020 as they are not only relevant to inclusive, innovative and secure societies.

1.6.1. Inclusive societies

- (1) **Inclusion:** In an increasingly globalised and interconnected world, the need for diverse cultures to understand and communicate with each other is essential in enabling inclusive societies. Greater understanding is needed of how social trust, cohesion and solidarity can be achieved. Research is needed on how differences between citizens can lead to creativity and innovation, how differences and conflicts can be reconciled, how shared

senses of purpose may emerge, and the kinds of institution, policies and practices that are needed to enable this.

- (2) **Social and economic inequalities:** persist in European societies and have implications for social inclusion. These inequalities include income, wealth and opportunity, but also power, cultural and social capital, security and vulnerability, health and wellbeing. Further understanding is needed of the processes which create and sustain these types of differences, and how relative inequalities change over time.
- (3) **Employment types and patterns:** The range and balance of skills in demand, the training for this and the contractual arrangements of labour will continue to evolve. There are implications for inequality and inclusion that will require rigorous examination so that policy responses can be effective and evidence-based.
- (4) **Global poverty:** Europe has a direct interest in a better understanding of alleviating global poverty and raising living standards in low income countries. Helping sub-Saharan countries to raise their living standards would benefit Europe through new trade opportunities, and would help address the challenge of large-scale migration.
- (5) **Resilience:** Changing societies, environments, threats and hazards raise issues of how communities understand, respond to and recover from challenges, what are the factors guiding adaptation, variation and creativity in these scenarios, and how do you balance need for redress with need to re-build whilst allowing expression of thought, feeling and belief within and alongside practical reconstructions.

1.6.2. Innovative societies

As global economic activity develops new patterns and shifts eastwards the need for rigorous analysis and understanding of the social, economic and political systems of different regions of the world increases. Research will continue to be needed on how global economic systems, markets and movements operate, interact and evolve if Europe is to make the most of its future prospects. Research is also needed on understanding innovation, including development of new business models and harnessing the potential of digital innovation.

- (1) **Economic performance:** Uneven economic development is a feature of most societies. A better understanding is needed of the specific factors and underlying causes of uneven economic performance and innovation, both across Europe as a whole and sub-regionally, in order to provide evidence from which policies can be developed.
- (2) **Digital Innovation:** The digital revolution is transforming creativity economies globally and an opportunity exists for Europe's creative economy to maximize the move to the digital domain in ways that increase businesses efficiency - by creating new business models from an understanding of impact on the creative practitioner, consumer and society as a whole. Development of creative content and cultural activities are key drivers both in digital innovation and the take-up of new technologies. There is great potential to use technologies in new and innovative ways, for example to exploit Europe's uniquely rich and diverse historic and cultural heritage.
- (3) **Innovation Systems:** While research has shown that linear concepts of innovation are outdated, we are still developing our understanding of how the best innovation systems are inclusive, open, and interactive. We need to know more about the ecosystem that sustains research and innovation in contemporary Europe. Research is also needed on the assessment of the health of particular areas of the innovation ecosystem e.g. high growth SMEs and on their connectivity with other actors, e.g. financial institutions.

- (4) **New Technologies:** Their development raises important legal, regulatory, ethical, cultural, historical and public responsibility issues that need to be explored as well as questions for research about how risks are regulated and controlled and how wider stakeholders can influence decisions on these matters. Issues of ownership, copyright, intellectual property and public access to information, as well as technical, design and 'creative content' are also central.

1.6.3. *Secure societies*

Real and perceived security threats change over time. Greater understanding is needed as to how social trust, cohesion and solidarity can be achieved in the face of cultural, social, economic and political change. Research on the development of effective legal regimes at local, national and trans-national levels is critical as new threats to security emerge. Research is also needed on the inter-dependencies between risks to identify the circumstances in which the occurrence on one type of risk raises the probability of occurrence of other types of risk. Greater understanding is also needed concerning issues of human rights, ethics, justice and public acceptability which are often raised by security strategies and interventions.

- (1) **Cultural exchange and transmission functions:** To effectively deal with global security challenges we need to consider how cultural exchange and transmission functions in a variety of circumstances and periods, including issues around communication and miscommunication, trust, and tolerance and migration. These factors are essential in effectively managing and resolving conflict situations as well as enabling governments to have a greater understanding of the factors that cause security challenges to emerge.
- (2) **Technical responses to security threats:** need to be developed in ways that enjoy the trust and confidence of the general public. Hence, there is the need for research into the types of technology, agencies and individuals citizens trust on security matters, including differences between communities.
- (3) **Organised crime:** Rigorous research to understand the organisations concerned is needed to combat this phenomenon, calling on the social sciences in particular. Likewise technologies developed to combat this activity must take account of research on the human aspects, such as how criminals or terrorists might respond to disruption of their activities by the technology and how the operators of the technology can most effectively carry out their work.
- (4) **Digital technologies:** The use of digital technologies in everyday personal or business tools, or in citizen interaction with government, raises a number of important questions. Multi-disciplinary research, incorporating social, legal, economic and behavioural approaches amongst others, is needed into such issues as cyber security, privacy and public access to information, rights and freedom, ownership and copyright of creative content. Research on these issues needs to take place in parallel as digital technologies develop. Challenges to cyber security in the European Union may be global in origin - and could come from state or private agencies or individuals. There can never be a guarantee of absolutely security, but rigorous research into the behaviours of the producers and the users of IT applications will limit the risks. Similarly, all security technologies need to be considered in the context of the people who design, build, organise and use them. Hence, it is essential that there is research into incentives, motivations and behaviours of the producers and users of security technologies.
- (5) **Weapons:** The proliferation of chemical, biological, radiological and nuclear weapons and technologies is an important potential mid- to long- term threat to the security of Europe. There are important issues for interdisciplinary research including questions of international and regional governance, the rationale for the use of such technologies as weapons, as

well as the issues around the scope for developing completely unknown technologies which are potentially dangerous.

- (6) **Ideas and values:** Local and international conflicts are underpinned by ideas and values. Research on, for example, the drivers of these ideas including “radicalisation” and terrorism, and those behind foreign policies of world countries and international politics and governance regimes, is essential.
- (7) **Conflict management/prevention:** depends on more understanding of the natures and drivers of insecurity at the level of individuals, groups, communities, organisations as well as states, and how this might transform into conflict or a different security threat. Future conflicts are less likely to include the formal involvement of states, and so effective alternatives to systems of international governance need to be found.
- (8) **Security of environmental resources:** As the consequences of global environmental change become clearer, the potential security implications of the competition for environmental resources will have increasing salience. Research is needed into areas of potential conflict. Environmental justice is an issue that merits major research.

1.6.4. Counter-terrorism

The terrorist threat is not just from international groups but also home-based organisations and extremists acting alone. International collaboration has been a key element to achieving successes in countering terrorism, and will continue to be the case. While funded research that addresses the technical response to security and counter terrorism issues should include the following priorities, it needs to be supplemented by rigorous interdisciplinary research that addresses the essential human and social input necessary to make these technological initiatives effective:

- (1) **Aviation and border security:** inbound and outbound cargo and passenger security, not just enhanced screening technologies but also considering the end to end process as a system with a view to improving the ability to identify and counter threats.
- (2) **Interoperability:** improving communications and cooperation of all incident response organisations including an improved understanding of the whole-scene picture.
- (3) **Horizon scanning:** understanding the future scientific and technical threats and opportunities in security and counter-terrorism to inform decision making.
- (4) **Cyber security:** improve the ability to detect and defend against a cyber attack, including home users, businesses, economic and infrastructure networks, and government networks.
- (5) **Critical infrastructure protection:** protection of trans-national infrastructure including cargo routes, energy supplies and communications networks.
- (6) **Protective security for crowded places:** detection and deterring threats to crowded places with minimal impedance on the ability of the public to go about their normal day to day business.
- (7) **Explosives:** detect, identify and counter novel and improvised explosives and explosive devices, including person and vehicle borne devices.
- (8) **Chemical, Biological, Radiological and Nuclear weapons (CBRN):** develop capabilities that support prevention, detection, preparedness and response to CBRN threats and incidents, in line with the EU CBRN Action Plan.

2. Key Technologies

This part of the Competitiveness pillar will support business research and innovation to create industrial leadership and competitive frameworks. Actions will cover increasing investment in enabling and industrial technologies.

2.1. Advanced Materials

Advanced materials represent an underpinning multidisciplinary technology platform, with many crossovers into other technical areas and with the potential to address challenges across a broad landscape of applications. The following areas are priorities to realise this potential:

- (1) **Structural materials:** A highly diverse area, with links to many sector areas (including transportation, energy, construction, healthcare, leisure, and defence and security). The major classes of structural materials include metals, metallic alloys and metal matrix composites (MMC); polymers and polymer matrix composites (PMC); ceramics and ceramic matrix composites (CMC); together with concretes, glasses and natural materials. Common technical challenges are materials to withstand more aggressive environments (e.g. high temperature, corrosive, erosive); the requirement to reduce environmental impact through life; the need to understand complete materials systems (e.g. coated components, sandwich structures, composites, joints and hybrids); improved modelling through the full life cycle, including lifetime prediction.
- (2) **Functional materials:** Controlling designed properties to meet specified application needs. Materials which generally exhibit some specific non-structural properties; for example electronic, magnetic or optical, and are incorporated into associated functional devices and systems; eg microelectronics, photonics and electrical machines. Areas for high development potential include metal-organic frameworks (MOFs), metal ions linked by organic bridging ligands with potential application in energy storage, catalysts and sensors; nano and micro electromechanical systems; quantum dots, graphene devices for energy applications and molecular electronic, sensors, nano-devices and systems.
- (3) **Multi-functional and 'Smart' materials:** Multifunctional materials represent a highly diverse and strongly multidisciplinary area, with links to functional, structural and biomaterials. Examples include damage tolerant, self-diagnostic and self-healing materials; and fully-integrated structural/power generating materials. Materials including smart textiles that react to changing environments; adding functionality to lightweight materials, controlled thermal responses, auxetic materials.
- (4) **Metamaterials:** Artificial materials that provide the ability to engineer material properties beyond those achieved from conventional materials and composites
- (5) **Biomaterials:** Materials applied to a biological system and materials derived from a biological source. Biomaterials can also be considered as a subset of structural, functional or multifunctional materials, operating in a specific, biological, environment. Areas identified for future development include: bioresorbables and bioactive materials and surfaces, together with novel manufacturing routes to achieve new properties in existing materials; new interfacial structures for the control of biomaterial-tissue interactions; and the integration of sensing systems into biomaterials for in-situ implant monitoring. Biopolymers offer the prospect of a renewable source of new materials within a low carbon society.

2.2. Nanotechnology

Nanoscale technologies are enabling technologies and are beginning to be applied to almost all market sectors especially in areas where the societal benefits can be described and quantified, significant examples being in the healthcare (through novel diagnostics and targeted delivery systems) and energy areas (such as next generation photovoltaics, and energy storage). They

are typified not just by scale alone, but the added functionality realised at that scale. Nanoscale technologies have the potential to help solve (with other technologies) the many societal challenges described within this document. The value of these technologies can only be fully realised when integrated into a system for use in a particular application area. Research on these enabling technologies will need to be complemented by measures focusing on building supply chains and exploiting opportunities for commercialisation. The following areas are considered to be priority to realise the potential of nanoscale technologies, but they should not be considered as individual pillars as they represent pillars across supply chains for technology development and commercialisation:

- (1) **New materials:** exploiting the functionality/multifunctionality and novel effects that can be found at the nanoscale through new materials development.
- (2) **New manufacturing:** Exploiting new manufacturing technologies through new and converging top-down and bottom-up approaches, and tackling the associated challenges, e.g. scaling up to industrially relevant volumes, removing agglomeration through new formulation techniques.
- (3) **New metrology:** Enhanced measurement and characterisation methods for nanoscale materials e.g., new imaging or nanoscale spectroscopy instrumentation including for detection in air, soil, water or other media and novel approaches to measurement, monitoring and control of exposure to nanoscale materials in the workplace, or environment.
- (4) **Integration into systems and final product:** Integrating functionality at the nanoscale into new devices and structures to exploit the value from incorporating nanoscale materials and effects e.g. through new diagnostic equipment, sensor technologies, next generation solar energy structures and systems.
- (5) **Potential safety, environmental and societal aspects:** further developing and coordinating the evidence base in understanding implications for environment and health, and of public attitudes/behaviours, with regard to new applications of nanoscale technologies.

2.3. Production Technology

To ensure growth of its core wealth-generating productive sectors in the face of global competition Europe must continually bring forward advances in production technologies. Production technology encompasses the application of a wide range of technologies and processes, and the means of efficiently controlling and integrating them. This applies both in controlled and miniaturised manufacturing environments and where production occurs in less controlled and more variable environments, or a mix of both, such as experienced by construction, forestry and other sectors. The majority of research and development spending is committed by companies in the manufacturing sector and the presence of a robust local manufacturing capability is key to successfully delivering new innovations. In combination with innovative new business models, new production technologies for the delivery of products & services are critical in achieving the four key improvement priority areas of greater sustainability, enhanced performance, faster delivery and greater overall international competitiveness. The following areas are considered to be priorities:

- (1) **Design & manufacture for through life sustainability:** building in sustainability through the full life cycle of manufactured products & services is fundamental to maintaining competitiveness as production inputs increase in cost and decrease in availability and anything other than desired high value outputs (waste/low value co-products) increasingly adds cost but not value. Design and manufacture for light weighting is the most fundamental route to achieving this objective. Use of widely accepted life cycle tools is a

key enabler to achieving the objective. Production of novel energy storage devices, energy management security systems are key priorities.

- (2) **Biotechnology & biological processing:** new manufacturing processes are required to deliver the sustainable use of non-food bio-resources to replace current oil based feedstock. Implementation of industrial scale biotechnology utilizing variable feedstock by optimizing process conditions for microbial metabolism and enzymic catalysis, work up and product isolation. Optimization of whole cell fermentation and bio-catalytic processes. Development of integrated bio-refineries at world scale. Further development of fully commercially viable pharmaceutical production systems using all or mainly biological systems. Development of process engineering capability leveraged across the chemicals, food and pharmaceuticals sectors is an additional key priority. Localized / distributed manufacture of cells for regenerative medicine.
- (3) **Flexible adaptive manufacture:** flexibility of production & manufacture supporting customized and rapidly reconfigurable manufacture. Process technology that can adapt readily to feed-stocks of different type / composition. Tool-less and one-shot manufacture including high productivity additive layer manufacture and rapid prototyping. High integrity powder HIP. Hybrid additive manufacture / net shape processes. Large scale 'plug and play' production systems. Manufacture of niche products leading to personalized and 'batch of one' manufacture. Distributed manufacturing systems.
- (4) **Automation and human/machine interface:** low volume, high quality production systems through automation. Automated lay-down for composite manufacture. ICT enabled intelligent manufacture. Exploiting intelligent and autonomous systems in production. Development of skills to support high value manufacturing is another priority area.
- (5) **New production processes for scale & economy with low energy use:** process needing development include high tolerance forging, flow forming and low energy forming, microstructure control and rapid insertion of materials in sheet forming, net shape forming / forging and re-configurable tooling. Advanced rotary friction welding. Continuous flow process manufacturing, continuous crystallization and continuous anaerobic processes, intensified process plants and low temperature chemistry. Design and manufacture at small scale and miniaturization. New methods in safety engineering and risk management.
- (6) **Process efficiency:** lean manufacturing and construction (on and off-site) process efficiency, eliminating waste at source; integrated ICT-enabled (i.e. Building Information Modelling and Management) processes; design for disassembly, de-construction and re-use.
- (7) **Systems modelling and integrated design / simulation:** development of ICT to model and simulate products and services through life. Understanding design and manufacture of formulated products by systems modeling. Design and manufacture for high integrity, real time data capture / processing to enhance product performance and new non-destructive testing methods.
- (8) **Smart, hybrid and novel materials:** new materials for sophisticated products e.g. electronic precision engineering and instrumentation. Enhanced joining capability with a range of materials. Tailored material properties and location specific properties. New manufacturing methods and application methods of advanced coatings including nano-materials.

2.4. Photonics

Photonics is a wide-ranging topic area which covers in general terms the generation, manipulation, and detection of light. It provides a set of technologies that are employed across many applications of economic importance for Europe. Photonics is acknowledged by the

European Commission as one of the Key Enabling Technologies for Europe. The following areas are considered to be priorities:

- (1) **Organic Electronics:** organic light emitting sources, energy efficient production processes, higher performance photovoltaics and light sensors, employment of materials with lower environmental impact.
- (2) **BioPhotonics:** the employment of photonics for detection of conditions or biological agents, treatment, therapy, processing of food or other biological products.
- (3) **Solid State Lighting:** including the development of not only light emitting devices but also reducing the cost and increasing the reliability of drive electronics. Improving energy efficiency through more sophisticated sensor systems which control the light level depending on operating conditions.
- (4) **Sensors and Imaging:** high precision systems potentially employed in hostile and challenging environments.
- (5) **High Power Lasers:** for applications in Industrial (for example cutting and welding), defence and security, also used in conjunction with Sensors as light sources for spectroscopy. This should include control systems for generation of high power pulses and/or Continuous Wave (CW) sources.
- (6) **Photonic Components and Systems:** for higher performance and/or cost reduced communication systems, including functions such as amplification, switching, attenuation, modulation, and detection.

2.5. Micro and NanoElectronics

Micro and NanoElectronics is the technology area that provides the materials and devices for a multitude of applications at a higher level of system integration. It includes the science behind the materials which make up the devices, the development of processes to deposit and manipulate the materials, the fabrication which makes up the devices, and the instrumentation which controls the processes and the quality of the end products. The challenges in this area are to improve energy efficiency, increase density and reduce cost in a fiercely competitive international environment. The economic impact of these technologies is wide-ranging, and hence Micro and NanoElectronics is acknowledged by the European Commission as one of the Key Enabling Technologies for Europe. The following areas are considered to be priorities:

- (1) **Fabrication Tools:** including instrumentation, processing equipment, and simulation tools employed in the design and manufacturing of substrates and devices. These are employed to improve yield, increase reliability, increase density and reduce cost of devices.
- (2) **Compound Semiconductors:** new material compositions, new substrates, improved adhesion and robustness for various material layer combinations.
- (3) **Electronic Components and Sub-Systems:** including more efficient devices for power management, MicroElectronic Machines (MEMS), increased density with finer resolution processes (“more Moore”), multi-functional applications (“more than Moore”).
- (4) **Packaging:** including more robust and cost reduced packages for multi-functional and high power applications.

2.6. Microsystem Engineering

Microsystems engineering is key to the development of miniaturized devices that incorporate functions of sensing, actuation and control. Such a “smart system” is capable of describing and

analyzing a situation, and take decisions based on the available data in a predictive or adaptive manner, thereby performing smart actions. Key priorities include:

- (1) **Integration and miniaturisation:** including integration of nanostructures
- (2) MEMS technologies
- (3) **Microfluidics (lab on a chip):** incorporation of materials sensitive to specific chemical species for new fields of bio- and chemo-electronics, with outlets across healthcare and drug development, environmental monitoring and security equipment.
- (4) **Innovations in packaging:** such as three dimensional integrated circuit (3D-IC), system-on-chip and system-in-package where density is increased by combining functionalities onto each chip and by stacking and bonding them into a 3D array.
- (5) Device- and system-level design, manufacturing equipment and processes.
- (6) New design and verification tools, and manufacturing processes.

2.7. IT Systems

Information Technology systems are essential in the modern world and affect almost every activity that people undertake. It is thus imperative that looking forward such systems are conceived, engineered, tested, integrated, deployed and used in an optimal way. As computer software technology pervasiveness increases, it is important to consider it in all its forms, from embedded systems, through devices and appliances (fixed, carried and mobile) to large-scale high performance (super) computing facilities. It is also essential that IT systems are not treated as an island but that the full potential of their integration with other technologies is realised. The development of demonstrators/testbeds will assist this. In addition to improving the activities listed above, the following topic areas are priorities.

- (1) **Intelligent and highly complex systems:** including large scale (multi) processing of extensive and complicated data sets (e.g. computer vision, Internet of Things sensors etc.), systems where emergent behaviours are un-obvious from even good understanding of component sub-systems, systems where machines learn and operate with degrees of autonomous behaviour, systems which exhibit more natural behaviour when interacting with humans (e.g. emotionally aware robot control systems, explained decision-making by machines etc.) and systems which can context-shift to support users intelligently, automatically and seamlessly.
- (2) **Natural interface systems for human users:** such that the underlying computing system apparently disappears and users are able to interact directly with information, media and make decisions without being (so) aware of the traditional computing infrastructure which has gotten in the way for far too long as computer technology has developed from its infancy. This may include new user interaction techniques, wearable computing, highly inter-networked cooperating self-organising (possibly micro) systems, and those systems that put the user(s) centre stage and simplify what they have to do.
- (3) **Software systems engineering quality:** including techniques to improve and ensure reliability, dependability, resilience to attack and malfunction, safety and correctness, of all software systems, but especially for those which are underpinning the most important infrastructure in our societies. Newer innovative tools and techniques will be required for the more complex systems of the future. Also includes self-diagnosis, self-repair and automatic recovery of software systems, as well as improved ways of integrating hardware, systems software and applications resulting in higher quality products across partners and supply chains.

- (4) **The inter-networked world of computing systems and data:** including networked data (processing, security & trust, traceability etc.), wide-area distributed processing, data sharing, (mobile) application development and deployment/management, threats and risks from distributed attacks, web-based media content and interoperability (including meta-data), socially-driven mass-market and crowd-sourced data systems impact and opportunity, visualisation of connected IT systems and data, machine to machine (M2M) pervasive systems, cloud-driven culture of information management for IT systems. Also includes software based systems that help people manage the extra decisions that they need to make due to always being connected and to filter the extra (sometimes massive) amounts of information that they are presented with in this interconnected world.

2.8. Communication Systems

The communications area covers in general terms the technologies, techniques, devices and systems for the transmission of information. Communications is one of the biggest industries and amongst the highest R&D intensity on the planet. Communication now underpins much of the modern economy and rapid advances in communication technologies can unlock new opportunities in various industries. The emergence of bandwidth intensive and/or mobile and/or large scale paradigms such as wireless internet, media consumption via the Internet, cloud computing and machine to machine communications will be the key drivers for innovation and technology advances in communications technologies. The following research areas are to be considered a priority. Activities such as coordination actions, addressing regulatory barriers and industry-led standardizations should be also considered high priority in this area alongside R&D&I priorities and well as the extensive use of realistic demonstrators.

- (1) **Novel wireless technologies:** including those allowing increased use of spectrum, cognitive radio and dealing with interference, air interfaces, mixed analogue-digital, low and zero power technologies, high capacity systems and novel architectures, signal processing. To also cover new business models ie how spectrum-sharing will work across organisations.
- (2) **Future networks:** covering topics such as content awareness, clean-slate approaches, ultra-high capacity networks, multimodal interfaces, novel protocols, all-optical networks, reconfigurable and autonomic networks.
- (3) **Managing system complexity:** including network optimization, virtualization, load balancing and distribution, handling heterogeneous networks and traffic, demand prediction and adaption, integration between network functionalities and services.
- (4) **Resilient, trustworthy and secure networks:** including mission-critical networks, fault tolerance, resilience to malicious attacks, large scale simulation of potential vulnerabilities, integration with service-level identity and security.
- (5) **Energy efficiency:** including end-to-end system approaches, low power components for mobile devices and M2M applications, energy harvesting technologies, low power transmission, system-level optimization and very short-range wireless power networks for devices.
- (6) **Massive M2M networks:** including topics such as heterogeneous networks, autonomic and self-configuring networks, multi-hop and ad-hoc topologies and protocols, fault-tolerance, information provenance and security, low power transmission and processing, novel ad-hoc communications technologies, large scale simulation and real test beds.
- (7) **Satellite communications:** including technologies for dramatically increasing capacity, overcoming delays and latency, interface with downstream networks, novel applications such as M2M.

2.9. Biotechnology

Biotechnology has the potential to provide solutions for many of the health and resource-based challenges facing the world such as food security, clean water and energy, sustainability of the world's ecosystems and climate change. Alongside these social benefits are economic benefits: improving the understanding of biological processes can contribute to economic growth as biotechnology will become increasingly integrated into many traditional industrial sectors such as energy; agriculture; chemicals, waste and construction. It already plays an important role in the environmental; food and drink; healthcare and personal care sectors. The following areas have been identified as priorities to realise this potential:

- (1) **Industrial biotechnology and energy:** bio-processes and products that can contribute to the shift from petroleum-based systems and products to a greener industry based on renewable feedstocks. A key challenge is the development of biological tools to break down plant biomass to generate bioenergy and other products.
- (2) **Agricultural biotechnology:** genomic technologies to increase yields, to breed specific traits needed for industrial uses and to optimise cultivation of non-food crops and use of non-edible parts of food crops that are suitable for non-food applications. Research to explore how pathways are controlled to develop future opportunities for synthetic biology approaches.
- (3) **Environmental:** bioremediation to reduce or extract selected substances in the environment.
- (4) **Medical biotechnology:** biopharmaceuticals and bioprocessing where the two main themes are understanding of biosciences to underpin improvement of bioprocesses for biopharmaceuticals and new enabling tools for implementation of bioprocesses. Medicine Discovery Platform Technologies include the development of novel tools and techniques to better access, understand and enable the exploitation of genomic, transcriptomic, proteomic and metabolomic information.

2.10. Space Technology

Today, space technology plays a continually expanding and integral role in our everyday lives - it is intricately woven into our economies and societies in a way unimaginable at the dawn of the space age. Space-derived data and services, together with the infrastructure needed to deliver them, have revolutionised capabilities in areas as diverse as international communications, global navigation and worldwide radio and TV broadcasting. Furthermore, as global warming assumes ever greater importance, space provides us with a unique and comprehensive means to study changes to the Earth, its ecosystems and climate. The following areas are considered to be priorities:

- (1) **Earth observation EO:** Applications for understanding underlying physical biogeochemical processes and feedbacks, examining long term trends in the data recording. Re-analyses combining data and models to provide the best and most complete picture of recent weather/climate. Including monitoring of climate consequences i.e. sea levels, fluxes of key greenhouse gases, coast erosion, flooding, heat waves, drought etc.
- (2) **Precision farming and crop forecasting:** land cover/land use mapping using EO. Including: global mapping and monitoring of changes in distribution of cropland area and the associated cropping systems; effective early warning of famine, enabling the timely mobilization of an international response in food aid; monitoring key habitats, monitoring of the sea with protection of fishing areas, assessment of fish stocks and protection of fishing legislations - measurement of photosynthesis and bio mass.

- (3) **Global Navigation Satellite System:** applications: traffic management and monitoring applications to increase transport efficiency through integration across all forms of transport. Including: integrated EO and communications applications for increased safety at sea; traffic monitoring and prediction; aircraft routing based on wind predictions at cruising altitudes; and satellite communications to support the 'internet of everything', to provide information for transport passing through remote areas (ships, planes especially) and as an integral part of air traffic management.
- (4) **Accurate high resolution forecasting:** Applications in the management of renewable energy, including: space based solar power; site optimisation and management for renewable energy generation; wind and wave potential power quantification and optimal location of infrastructure; alerts for space weather impacts on power distribution systems; space based technologies for power generation, storage and conversion; solar powered broadcast and broadband services to the whole continent; and complete solutions for smart-metering.
- (5) **Tele and mobile medicine:** telecoms and GNSS for positioning of medical services in remote locations or within a domestic environment for monitoring vulnerable members of society, including: high precision air quality measurement; particularly in urban settings; vegetation mapping (relevance to perception of well being); robotics technology under development for space exploration to assist those with disabilities; monitoring and prediction of the spread of airborne disease and pestilence; and monitoring of demographic movement and effects.
- (6) **Civil security:** emergency management, border control, monitoring of key infrastructure, land and maritime security, and including: disaster management; EO data to support prediction, monitoring and alerting of natural hazards: tsunamis, earthquakes, landslides; applications that improve the role of insurance in society e.g. manage risk, reduce fraud and thereby reduce premiums; increased capacity of satellite communications to meet growing demand; inclusive: provision of broadband via satellite for remote areas; and satellite machine to machine (M2M) communications applications.
- (7) **Space exploration:** facilitates technological development in many of the key areas mentioned above, but not without challenge. Key areas for consideration here are space power generation with nuclear systems - in order to advance space nuclear power development in Europe a number of cross cutting technologies are required, which will have benefits for a multitude of terrestrial and other space applications. These include: High efficiency robust thermoelectric conversion systems that can operate over broad temperature ranges; novel thermal management methods materials and processes for space applications; and radioisotope propulsion systems for advanced mobility concepts in space and on planetary surfaces. Systems autonomy - especially those that require independent action in dynamic, unpredictable environments typically found in space exploration. Research topics would include: software; architectures; sensor exploitation; situational awareness; decision making and planning; information management; verification of autonomous systems; and model building and learning.

2.11. Aviation Technologies

Aviation is an industrial area where Europe leads the world. This leadership needs to be maintained through continued investment in the specific integration of complex systems technologies in aviation. Aviation is a driver of innovation in other areas and is a key technology for growth of the economy.

In particular in this pillar there could be the potential for a new JTI/PPP for aviation. The structure will emerge as the Strategic Research and Innovation Agenda is formed to follow up the recent publication of the Flightpath 2050 report of the High Level Group in Aviation Research set up by Vice President Siim Kallas. It will certainly need to cover the areas of

airframes, engines and equipment. It is most likely that it could maintain the momentum of the current Clean Sky JTI and cover the needs of green aircraft, engines (including open rotor engines), manufacture, maintenance repair & overhaul, safety security and comfort (including airports). To ensure industrial leadership this PPP/JTI would be an industrially-led programme with Commission support.

2.12. Surface Transport Technologies

Strengthening and maintaining the competitiveness of the Green Economy ensures the necessary infrastructures are in place to support the uptake of green technologies, creates new opportunities to reduce the carbon footprint across transport modes and encourages continued investment in cross-cutting transport research.

To encourage private investment and support business innovation, this pillar has the potential to establish novel competitive frameworks that provide leadership in the development and take-up:

- *of greener fuels;*
- *the advancement of battery technology in terms of costs and energy storage density;*
- *a step change in hydrogen fuel cell technology; and*
- *new sustainable fuel sources.*

As these green technologies are developed and deployed to create greener transport systems, the supporting infrastructure (for example, physical road and rail networks, airports and ports) must also adapt to accommodate (and encourage) the use of these technologies.

This pillar of Horizon 2020 is well placed to support the adaptation of transport infrastructure, by encouraging leadership from the industry sector, ensuring green technologies features prominently in a competitive transport economy and emphasising the use of large-scale green technology demonstration projects (Level 2).