# Recommendations on Future and Emerging Technologies

## Report of the ICT Advisory Group (ISTAG)

••• **October 2009**

# Foreword

The European Commission formed the ICT Advisory Group (ISTAG) to provide advice to the Commission services regarding the ICT Theme of the Cooperation Specific Programme, part of the 7th Framework Programme for Research and Technological Development. As part of the ISTAG, a working group on Future and Emerging Technologies (FET) has been established with a two year mandate (2008-2009) to provide strategic advice and orientations on long term foundational research, in order to strengthen and broaden the science and technology basis of future ICTs.

The ISTAG FET WG performed a very detailed and deep analysis of the Future and Emerging Technologies programme in a series of meetings over the course of two years. This has culminated in the present report, which provides strategic advice and orientations on the role and positioning of FET in order to strengthen the mechanisms that support it and increase its impact and attractiveness. It also includes views and recommendations regarding FET proactive initiatives for the ICT Workprogramme 2009-10, discusses the specificities of the FET Open scheme and makes recommendations on how to further develop it. In addition to these issues that are focused on the "internal" quality and efficiency of the FET programme, the report addresses transversal issues related to the reach, the impact and the effectiveness of FET.

Based on early results of this work, the ISTAG chairman asked the ISTAG FET WG to perform an analysis of the scientific and technological areas where European research is strong, to determine the main scientific and technological challenges for 2020 and to propose flagship initiatives. The results of this work have been reported in a separate document, called "Future and Emerging Technologies Flagships: Transforming ICT for 2020 and beyond".

The chairmen sincerely thank all the members of the working group for their efforts and individual contributions, which were performed with complete independence and total scientific freedom. Discussions and debates were open, vigorous and sometimes colourful, but they always succeeded in consensual advice and recommendations. In addition, we gratefully acknowledge the considerable support of the officers of the FET Units.

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# History of this document

Work on this report started early 2008 within the ISTAG working group on FET and with a focus on FET-proactive. In particular Annex I was delivered as input to the workprogramme preparations for 2009-2010 in November 2008. Sections 2 to 4 of the present report, including its 30 recommendations, were finalized in November 2008. Section 5, including an additional 10 recommendations resulted from work during 2009. Note that in 2009 the working group produced also a separate report on FET flagships.

# Executive summary

Research on future and emerging ICTs operates in the context of a complex and dynamic landscape of public and private, upstream and downstream research and involves innovation activities managed either at European, national, regional or local level. FET plays a unique and seminal role for ICT within the framework programme. FET is an incubator for new ideas, and it explores new research themes that promise to be foundational and of long-term relevance for a sustainable future of ICTs in Europe. FET promotes high risk multidisciplinary research, offset by the promise of breakthroughs with high scientific, technological or societal impact. The research promoted by FET has become a benchmark of excellence. Hence the ISTAG FET WG recommends that the **FET funding be increased to 10 - 15 % of the total ICT theme funding, and that FET plays a role of catalyst for federating initiatives, both within the Framework Programme and with other European or international funding agencies.**

New ideas are important, but FET should also be an authority on trends in research, including societal trends. Early detection of new trends is the top priority within the mission of FET. **FET is encouraged to set up an action and methodology that enables a continuous analysis (measurement, assessment, risk-analysis, critical mass, identification of necessary resources) of emerging trends, and to further strengthen its trend-setting mission.** FET has a limited budget and the spectrum of research areas to be covered is very large. Hence there should be some priorities, and choices are mandatory. **It should define mechanisms and criteria for continuity/discontinuity of a FET initiative and strengthen the process of transferring a theme to mainstream research through a combined push-pull approach**.

FET not only supports basic research for ICT, but also multidisciplinary foundational research. FET nurtures inspirations from other disciplines into future ICT's while ICT is equally important to other disciplines as an enabler and facilitator of multidisciplinary research. The ISTAG FET WG recommends **promoting the interdisciplinary nature of FET research by ensuring that ICT and the other disciplines involved have synergetic roles and that they can mutually benefit from the collaboration.**

The analysis and discussion of the role of the EC funding schemes goes far beyond the current objectives of this ISTAG working group. **Nevertheless, the WG recommends that FET should network with the ERC in order to maximise synergies for identifying new emerging transdisciplinary research topics and support for community building, analyse the various ways of motivating new curricula in promising new interdisciplinary fields of research, and strengthen links with education-oriented programmes, for example the EIT-KIC on ICT.**

Working with companies is not mandatory within FET, but is certainly a plus to test the interest of the research project and disseminate ideas. The ISTAG FET WG recommends that the FET Units **encourage high-tech SME's and industry to engage more in high-risk long-term research and communicate FET results to them in order to foster the early take-up of new insights and opportunities**.

In addition to strengthening the "internal" quality and efficiency of the FET programme, a range of transversal issues related to the reach, the impact and the effectiveness of FET should obtain specific attention. **Increasing participation of young researchers as well as High-Tech SMEs and start-ups in FET -** for example by a direct role in a project, by implementing an industrial advisory process, or through a CSA -**, strengthening the FET scientific community, enabling open access to research results, promoting exploitation of results by companies, and widening international cooperation are amongst the key action points that the working group recommends.**

## FET Proactive scheme

The ISTAG FET WG analyzed the proactive initiatives that should be continued, the ones that should be discontinued or refocused and selected new proactive initiatives that should be launched. A list of themes for the 2009-2011 calls is listed. Moreover the WG recommends that **proactive initiatives should support risky, highly promising and focused research domains and that resources should be concentrated on**

**few initiatives. It proposes a list of criteria for selecting a proactive initiative (Scientific excellence, Potential impact, Timeliness, Critical mass in Europe, Ethical concerns).**

**Concerning the implementation of FET Proactive, the WG recommends that the FET Unit ensures** better coherence and consistency of themes for the planning of initiatives and calls over longer periods, and makes sure that the expertise of the group of evaluators selected matches best with the research topics and multidisciplinary aspects of a proposal.

## FET-Open scheme

FET-Open plays a unique role within the framework programme for ICT and within the FET programme. FET-Open is an incubator for new ideas that have not been detected so far, and it explores new research themes with long-term relevance for a sustainable future of ICTs in Europe. The ISTAG FET WG recommends that **FET-Open should be kept as open as possible, applying a broad definition of "ICT relevance" and should endeavour to attract top-class, high risk ideas with high potential impact in terms of lasting effects on science, technology or communities ('transformative').**

The type of the project (size, duration, partnership profile) should be appropriate for the topic of the project. FET-Open should allow for diversity of project types, with sizes adapted to the needs. Hence **STREPs interpreted in a very flexible way (size, duration, partnership profile) are considered the most appropriate tool for projects in FET-Open and new types of Coordination and Support Actions should be encouraged in FET-Open (community building, dissemination, publication of results, creativity…).**

**Targeted awareness-raising activities should be put in place to clearly communicate FET-Open expectations and to attract the best ideas and teams from the broadest range of scientific communities.** But FET-Open is not to be a purely academic programme. **Exposing companies, especially SMEs, to FET-Open research (by direct participation or otherwise) should also be a priority.**

Links between FET-Open projects and proactive initiatives should be exploited. The ISTAG FET WG recommends that **FET-Open should develop an exploitation strategy to maximize the impact of its project portfolio in view of exploiting potential links and synergies with existing FET proactive initiatives and for identifying topics for new ones.**

FET-Open is already an efficient and effective programme and is considered successful in its current mode of operation. **FET-Open should continuously benchmark itself against similar schemes and experiment with new mechanisms so as to provide Europe with the most efficient and flexible funding scheme for excellence in pathfinding research. In addition to its two step submission scheme, FET-Open should explore a new light-weight approach for rapidly launching small projects aiming at initial assessment of an idea in a short time.**

The question of peer review is very delicate for FET-Open because of the unforeseeable nature of the proposals that will be selected. **FET may establish, with the help of relevant research communities, a "College" of permanent peer reviewers for short proposals. Proposers should be invited to provide a positive and/or negative list of reviewers, to be used at the discretion of project officers to provide first orientation on review panel, and expose conflicts of interest as seen by the proposers (this could also be relevant for the proactive scheme).**

The success and impact of the FET-Open scheme can obviously not be measured in the short term. It is important that the long-term impact of the projects is monitored closely, even long after the projects have finished. The ISTAG FET WG recommends setting up **an internal system of FET-Open specific indicators that allows evaluating the impact of FET-Open in 5 to 10 years time with respect to the specific mission of the FET-Open scheme.**

# 1. Introduction

Research on future and emerging ICTs operates in the context of a complex and dynamic landscape of public and private, upstream and downstream research and innovation activities managed either at European, national, regional or local level. At the same time, the reality of research is also changing. Research institutes and organisations are becoming open, multidisciplinary and networked with more diverse players, funding or business models. The increasing international dimension of research is also an important element in the context within which the Future and Emerging Technologies (FET) programme [or: activity] is operating.

Within this complex scene of the ICT programme, FET acts as the pathfinder for future ICTs. FET is an incubator for new ideas, and it explores new research themes that promise to be foundational and of long-term relevance for a sustainable future of ICTs in Europe. FET promotes high risk multidisciplinary research, offset by promising breakthrough with high scientific, technological or societal impact.

Since its beginnings within the Esprit Programme, the research promoted by FET has become a benchmark of excellence. FET initiatives, which attract and foster collaboration between top European researchers, have made substantial contributions in bringing European research to the forefront of the state-of-the-art, as shown by prizes won by participating researchers and public visibility gained by FET supported projects.

In this Report the ISTAG FET working group provides strategic advice and orientations on the role and positioning of FET in order to strengthen the mechanisms that support it and increase its impact and attractiveness (Section 2). Section 3 of the report provides views and recommendations regarding FET proactive initiatives for the ICT Workprogramme 2009-10. In Section 4 the report discusses the specificities of the FET Open scheme and makes recommendations to further develop it. Finally, Section 5 discusses views from the working group on specific issues like young researchers or SME involvement and others related to the reach, impact and effectiveness of FET. The Annex, which was already finalised in November 2008, was delivered as input to the workprogramme 2009-2010 preparations.

# 2.  Role of FET

*Based on the analysis of the past and present activities of FET, this chapter presents the group's opinion of the role of FET in the ICT Programme and in the broader landscape of R&D funding and management. Then the types and general characteristics of projects that FET should attract and fund are discussed. In order to increase FET impact in promoting new trends of research, to improve its positioning with respect to other European or national funding mechanisms or industry, and to increase its visibility outside the scientific community, several recommendations are listed.*

## 2.1  Analysis of the role of FET

FET plays within the framework programme for ICT a unique and seminal role. FET is an incubator for new ideas, and it explores new research themes that promise to be foundational and of long-term relevance for a sustainable future of ICTs in Europe. FET promotes high risk multidisciplinary research, offset by promising breakthrough with high scientific, technological or societal impact. The research promoted by FET has become a benchmark of excellence. FET initiatives, which attract and foster collaboration between top European researchers, have made substantial contributions in bringing the European research to the forefront of the state-of-the-art.

Current role of FET mainly emphasises:

- o  Pathfinder for and incubator of new ideas, research directions and communities
- o  The importance and specificity of multidisciplinary foundational research
- o  Integrity, agility and breadth, of FET (encompassing the entire spectrum of ICT-relevant areas and topics)

Other issues considered by the Working Group are:

- o  Positioning with respect to ERC, EIT and the mainstream programme.
- o  Forerunner of new emerging themes leveraging follow-up in MS (and other way around?)
- o  Attracting and benchmarking excellence in research and research practices
- o  Stimulating a dynamic and diverse research community and the right conditions and 'spirit' for FET-research to blossom
- o  Impact, including industrial dimension/exploitation
- o  Roles, specificities, complementarities and interaction between FET's Open and Proactive schemes

### 2.1.1  Defining trends in research

New ideas are important but FET should also be an authority on trends in research, including societal trends. Early detection of new trends is a first priority mission of FET. It would need its own actions to identify these trends in the broadest range of disciplines, which can be implemented as part of the FET Workprogramme using the CSA instrument. Such an analysis should also include an assessment of the degree of complexity from combination of disciplines, and the availability of talent in Europe.

The criteria for selecting FET initiatives should be the impact they could have on the overall performance of the EU scale research. In particular, there are topics mainly developed or started in EU on which we have (at this time) considerable competitive advantage on the other research systems. We should mainly push for these themes rather than distributing resources over a large group of initiatives.

Like NSF, FET could take up on a trend (for example Simulation based research) and then hire a professional organization to make a comprehensive overview of what is behind it: to understand where a trend is going, what it would take to do it, to capture how it could be linked with other activities, to see whether an initiative can make a difference.

Based on this comprehensive overview (based on a more quantitative and knowledge oriented approach), FET could organize workshops inviting many experts to follow up on qualitative statements.

> **Recommendation 1:**
> **FET is encouraged to set up an action and methodology that enables a continuous analysis (measurement, assessment, risk-analysis, critical mass, identification of necessary resources) of emerging trends, and further strengthening of its trend-setting mission.**

### 2.1.2  New trends versus continuation

FET has a limited budget and the spectrum of research areas to be covered is very large. Hence there should be some priorities and choices are mandatory. Just picking up trends tends to be a conservative approach. FET has been successful in creating trends, rather than just picking up on them (nanotechnologies is an example). This is valuable and should be preserved. However there should also be some continuation. Hence a good balance between the two approaches should be reached.

Once a research area has been defined and financed, there should be a professional follow-up of initiatives and projects. The success or growth of a research area funded by FET, for the evaluation of its possible continuation needs to be critically assessed. The assessment should be based on the measurement of well-defined indicators of scientific production (papers and patents, first of all) and of impact (research and political). The evaluation should also use criteria related to industrial relevance, maturity of the theme and coherence of the research community.

Transfer of FET topics to the mainstream ICT programme is not effective if there is no pull from the mainstream side. FET should continuously inform and inspire stakeholders of the mainstream ICT programme on the findings and maturity of the FET topics.

As an alternative transfer route a FET research topic can also be continued by leveraging funding from other programmes, e.g. in national programmes or through a cooperation of national programmes (ERANET, art. 169 of the Treaty).

Based on this severe evaluation, a decision should be taken among:

- o Continuation of the FET support to the area.
- o Stop FET support.
- o Transfer to mainstream workprogramme.
- o Continuation in cooperation with national programmes.

> **Recommendation 2:**
> **Define mechanisms and criteria for continuity/discontinuity of a FET initiative.**

> **Recommendation 3:**
> **Strengthen the process of transferring a theme to mainstream research through a combined push-pull approach and involve advice from ISTAG FET Working Group when appropriate.**

### 2.1.3   Size of the programmes

Currently, the amount of money for supporting a programme within FET is relatively small. For most programmes, this is a wise policy. However more complex programmes may need larger support. In that case, FET may launch prospective projects or team up with other Framework Programme themes or initiatives, or organizations to raise support. Currently there are many contacts with other funding agencies, but there is no clear process to ask for their involvement in any structured and consistent way. To analyse the level of support needed by a programme, FET should adopt criteria based on the critical mass of research needed by the programme, the equipment needed for the research, and the potential synergies with other programmes. Other criteria are the foreseen speed and impact of uptake by the industry and society.

The funding of FET has been of the order of 8 – 10 % of the IST/ICT Theme with a lowering tendency, in spite of the high-level high-impact research funded. This trend should be reversed, and FET funding should be raised gradually to the 10 – 15 % level.

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**Recommendation 4:**
**Analyse the necessary level of support when deciding to launch a programme. If the level of funding required for a given initiative exceeds FET capacity, FET could play a role of catalyst for federating initiatives, also with other European or international funding agencies.**

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**Recommendation 5:**
**Raise the FET funding to 10 - 15 % of the total ICT Theme funding**

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### 2.1.4   Positioning FET in ICT

FET is not only supporting basic research for ICT, but also multidisciplinary foundational research. This raises the question of the role of ICT in FET: how far beyond ICT can FET go if ICT is just a tool helping research in other domains?

The relation between ICT and FET is twofold: FET nurtures inspirations from other disciplines into future ICT's while ICT is equally important to other disciplines as an enabler and facilitator of multidisciplinary research. The synergetic multidisciplinary FET research provides new ways for ICT and other disciplines to progress.

For example, synthetic biology is not ICT, but only possible with ICT. The design of new theoretical and conceptual tools to address the complexity of biology is a preliminary step to increase the performance of ICT techniques and technologies. Successful approaches to tackle research challenges in biology may also provide new insights for ICT and advance its state-of-the-art.

Multidisciplinary research is a way to the future, and it needs to be handled properly especially in the evaluation phase. Multidisciplinary research works correctly only when all the disciplines participating to a proposal are considered equally important. Considering ICT as a service to other disciplines is counter-productive.

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**Recommendation 6:**
**Promote the interdisciplinary nature of FET research by ensuring that ICT and the other disciplines involved have synergetic roles and that they can mutually benefit from the collaboration.**

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## 2.2    Positioning FET with respect to other funding schemes

The analysis and discussion of the role of the EC funding schemes goes far behind the current objectives of this ISTAG working group. The experts do believe that such an analysis is a first priority task of the EC.

### 2.2.1    Positioning with ERC

European Research Council tools are basically pure science-oriented and support individual researchers whereas FET is science and technology-oriented and support consortia. Science may lead to technology but not necessarily. Hence FET-Open is complementary to ERC since it drags new ideas into the picture. This complementarity should be reinforced in both ways by increasing the common knowledge:

- o    FET can learn from successful ERC science-oriented projects opening new and promising trends of research,
- o    ERC can learn from FET on the current state of transdisciplinary foundational research themes.

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**Recommendation 7:**
**FET should network with ERC in order to maximise synergies for identifying new emerging transdisciplinary research topics and support for community building.**

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### 2.2.2    Positioning with the European Institute of Innovation and Technology (EIT)

There may be a big gap between a FET proactive and a Knowledge and Innovation Community (KIC). But FET could learn from the way EIT is linking to education and to innovation. For a scientific field to grow, then it needs to educate also students.

On the other hand, KICs are more designed to build permanent entities in charge or research and education and not really oriented to work at the forefront of science, which is the premier objective of FET. But a KIC could be a prominent partner to FET for jointly pursuing new trends in research and participate to workprogrammes.

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**Recommendation 8:**
**Establish links between FET and EIT-KIC on ICT, so that EIT-KIC can foster and strengthen FET trends in education.**

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### 2.2.3    Positioning with respect to education-oriented programmes

Increasing the number of scientists and educated professionals is a big concern in new fields, particularly for multidisciplinarity. FET could act as a catalyst for this objective in many ways. First, it may include education activities within a programme where it is needed. Second, it may link with education-oriented programmes, like Marie Curie. Third FET could put together the different pieces of virtual universities to build a technology for education, by using virtual communities.

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**Recommendation 9:**
**Analyse the various ways of motivating new curricula in promising new interdisciplinary fields of research and strengthen links with education-oriented programmes.**

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### 2.2.4    Positioning with industry

Working with companies is not mandatory within FET, but is certainly a plus to test the interest of the research project and broadcast ideas. The implication of the company has to be analysed carefully with respect to its involvement in the project at the scientific and technological levels and the amount of resources and efforts that it can devote to.

In many domains, high-tech SME are more innovative than large companies. However, their financial health is often very fragile. Hence, it is important that the amount of administrative burden be reduced. Moreover, recently created SME should be encouraged to develop their technologies since they are sometimes more a research entity than a market-oriented company. Increasing their support may be a good incentive to participate.

On the other hand, FET project objectives are often too far from product development to be attractive to engage SMEs. Instead, when FET projects achieve new technologies, further actions should be encouraged, like new projects, even outside FET, with the participation of industry.

> **Recommendation 10:**
> **Encourage high-tech SME's and industry to engage more in high-risk long-term research and expose FET results to them in order to foster early take-up of new insights and opportunities.**

## 2.3   FET visibility from outside the scientific community

Communicating on research goals and issues towards European citizens become of premier importance for acceptance and support in order to prevent resistance to acceptance of new technologies. Explaining the impact of new technologies for their life using various media may be a good way to reach this goal. Hence some investments in dissemination for non-expert should be done at the level of unit when preparing the calls, ask for such deliverables in all the funded projects and finally reporting in the same style the results obtained.

Special events may be organized to communicate towards European stakeholders and members of the European Parliament.

> **Recommendation 11:**
> **Increase the awareness of FET outside the scientific community by actively raising the visibility of successes and breakthroughs in FET funded research via media channels and to decision makers.**

# 3. FET Proactive

*This chapter presents the group's opinion of the topics for future proactive initiatives, the mechanisms to identify and select proactive programmes and the implementation and operations of programmes.*

## 3.1. Topics for future proactive initiatives

In this paragraph, we analyzed the proactive initiatives that should be continued, the ones that should be discontinued or refocused. Furthermore new proactive initiatives that should be launched are proposed coming from the consultation workshops or from the FET Open portfolio or from the working group members.

The 2008 FET proactive project calls are defined and the candidate initiatives for 2009 have been outlined. The working group does not see any evidence for changing them.

During the winter 2007-2008, the FET proactive unit has organized several concertation workshops in order to define new topics. The ones that came out of the consultation are:

1. Overlay computing and communication
2. Synthetic living ICT
3. Zero power ICT
4. Creativity

Other themes were mentioned by the group and added to this list. After applying a clustering method, the group converged on the following challenges (from consultations – **in bold** -and from group members).

1. *Challenge Bio-ICT (cell level)*
   a. **Synthetic living ICT**
   b. Evolutionary technologies
   c. **Synthetic biology**
   d. Bio-ICT

2. *Challenge Embodied ICT (system level)*
   a. Living robots
   b. Embodied
   c. Soft-bodied

3. *Challenge Neuro-ICT*
   a. **Neuroinfo**
   b. **Brain computer interfaces**
   c. Hybrid bionic systems
   d. Visual computing
   e. **Creativity**
   f. Micro-scale hybrids

4. *Challenge Future computing technologies*
   a. **QIPC** (Towards)
   b. 0-power
   c. Novel switching devices
   d. Sub 32nm CMOS
   e. **Molecular scale devices and ICT systems**
   f. Displays and interfaces
   g. Digital capture

5. *Challenge Modeling and Simulation for large scale systems*
   a. Hybrid Modelling
   b. Eco-system computation
   c. **Large-scale simulation for complex systems**
   d. **Overlay computing and communication**
   e. Wire to service
   f. Pervasive adaptation
   g. Simulation based research
   h. **Multiscale and multilevel simulation**

6. *Challenge Social ICT*
   a. **Social ICT**
   b. **Systems for collective and social intelligence**

7. *Challenge Future programming technologies*
   a. **Massive ICT**
   b. **Modelling and formal methods**

More details on the selected challenges can be found in Annex I.

## 3.2. Mechanisms to identify and select FET Proactive initiatives

In this paragraph we address the question of how the themes for proactive initiatives should be identified, e.g. organising workshops, consensus conferences, foresight exercises, linking with scientific associations, Gordon conferences, multi-agency brainstormings, etc. We also discuss what methodology and what criteria should be applied for the selection of proactive initiatives for the workprogramme.

There is a certain risk to formulate initiatives in such an open-ended way that they become unfocused and loose the opportunity to build synergy within a proactive initiative. Another risk is to allocate insufficient resources to a proactive initiative making it subcritical, which would diminish its impact. Hence the working group recommends to focus the proactive initiatives to risky and highly promising research domains and to concentrate resources on excellent consortiums that are in a position to address the challenges with high success probability and in a synergetic way especially for multidisciplinary topics.

The question of the correctness of some of these topics has been addressed. Some members consider that some topics are ethically questionable. The relation to ICT has also to be analyzed and the clarity of the communication on these topics is considered to be crucial. Some of these themes should be discussed with serious involvement from biologists. This position was not unanimously followed. It was emphasized that many of these topics are currently happening in the laboratory and are not science fiction.

Some members expressed concern about the status of the categorization in chapter 3.1. The group would need to identify the grand challenges for ICT (e.g., power consumption, security, interface,…) and identify the most urgent ones. It is not clear how the present categorization contributes to this.

An informal process lead to the suggested timing of calls for 2009, 2010 and 2011:

**Call in 2009**
- Bio-ICT (cell level)
- Neuro-ICT
- QIPC
- (Towards) 0-power
- Future programming technologies

**Call in 2010**
- Sub 32nm CMOS
- Molecular scale devices and ICT systems
- Challenge Modelling and Simulation for large scale systems

**Call in 2011**
- Embodied ICT (system level)
- Social ICT

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**Recommendation 12:**
**Proactive initiatives should support risky, highly promising and focused research domains and resources should be concentrated on few initiatives.**

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The working group also discussed the criteria for the selection of proactive initiatives to the workprogramme and recommended:

**Recommendation 13:**
**The criteria for selecting a proactive initiative should be:**
° **Scientific excellence**
° **Potential impact**
° **Timeliness**
° **Critical mass in Europe**
° **Ethical concerns**

## 3.3 Implementation and operations

This paragraph analyses the adjustments that should be done to the FET Proactive scheme: instruments, timing of calls, critical mass per Initiative …

In the current scheme, each initiative gives rise for a call on the whole research trend. No proposal can be accepted once the call is closed. This may lead to imperfect timing since some excellent teams may not be ready for the call. Why not consider relation between an initiative and a call: an initiative is called every year, with a very selective process. In this way people could be more 'ready' when they really are rather than have to be ready for the scheduled call.

A second very critical issue is the selection of the reviewers. In order to evaluate multidisciplinary research, reviewers that work exactly in the same area are needed. This may be a very hard task for ethical or quality reasons. An efficient way to solve the problem and to find the kind of scientists best suited to understand the content of the proposal, is to ask the proposers to suggest a group of reviewers. They may also be asked to provide a list of people to which they refuse the proposal to be sent either for conflict of interest, professional conflicts or other ethical reasons.

**Recommendation 14:**
**Ensure better coherence and consistency of themes for the planning of initiatives and calls over longer periods.**

**Recommendation 15:**
**Make sure that the expertise of the group of evaluators selected matches best with the research topics and multidisciplinary aspects of a proposal.**

# 4.  FET-Open

*This chapter presents the characteristics of FET-open projects, the ways to attract innovative and first class projects, the mechanisms to evaluate proposals and select projects, and the implementation and operations of the FET-Open programme.*

## 4.1  Characteristics of FET-Open projects

FET-Open plays within the framework programme for ICT and within the FET programme a unique role. FET-Open is an incubator for new ideas that have not been detected so far, and it explores new research themes with long-term relevance for a sustainable future of ICTs in Europe. FET-Open promotes high risk multidisciplinary research, offset by promising breakthrough with high scientific, technological or societal impact.

### 4.1.1  Openness

FET-Open is by definition open to any project relevant to ICT with a broad definition of this domain. There are recent examples (nano-ICT, bio-ICT, …) of proposals with a clear impact in both domains. However there are proposals involving great research in a strategic area (nanomaterials for example) but with no clear ICT relevance. FET-Open should only fund activities which have the potential to advance the state-of-the-art in ICT.  This would preclude straightforward applications of ICT where all of the research challenges are in the application domain. Moreover, FET-Open should avoid bias that comes from implicit or explicit preference for example from experts, circumstances or trends.

> **Recommendation 16:**
> **FET-Open should be kept as open as possible, applying a broad definition of "ICT relevance".**

### 4.1.2  Risk and Impact

The role of FET-Open is to attract and fund highly innovative projects in ICT sectors beyond current programmes. It provides support for emerging or rapidly evolving research domains. It can also revitalise areas that have disappeared from the agenda, for example, when they get cross-fertilized with other areas (ex. data mining, end user development, parallel computing …). Taking risk in selecting new and non standard ideas should be a priority. The risk stems from starting from a new and unproven idea that challenges established thinking and goes beyond prevailing ideas and opinions, and does so beyond the boundaries of established disciplines.

> **Recommendation 17:**
> **FET-Open should ensure attracting the top-class high risk ideas with high potential impact in terms of lasting effects on science, technology or communities ('transformative').**

A convincing analysis of the foreseen impact should be done by the proposers in order to balance this risk.

> **Recommendation 18:**
> **Proposals should clearly demonstrate the potential for transformative impact and how it outweighs the risks.**

### 4.1.3   Instruments

The type of the project (size, duration, partnership profile) should be appropriate for the topic of the project. FET-Open should allow for diversity of project types, with sizes adapted to the needs. A FET-Open project focuses on establishing the validity and potential for impact of the novel idea proposed, for instance in terms of a proof of concept. STREPs interpreted in a very flexible way are considered the most appropriate tool for project. The range and nature of activities in an Integrated Project are not suitable to the nature of embryonic research that FET-Open seeks to fund.

> **Recommendation 19:**
> **STREPs interpreted in a very flexible way (size, duration, partnership profile) are considered the most appropriate tool for projects in FET-Open.**

Since FET-Open aims at funding highly innovative, even disruptive projects in domains where there is no critical mass, it should usefully support community building meetings such as workshops and conferences, and feasibility studies.

STREPs are complemented with Coordination and Support Actions for adding value in a broad variety of ways. Such actions could, for example, experiment new ways of organizing research, of disseminating results, for stimulating the emergence of new ideas or synergies between seemingly unrelated groups of projects.

### 4.1.4   Catalytic role

Since FET-Open projects are by nature unrelated to each other, the value of establishing links at the level of individual researchers should be emphasized, e.g., between researchers interested in a similar 'type' of research rather than by shared interest in a specific topic. This can not be community driven, since there is no community strictly speaking, thus FET-Open needs to play an active role to create opportunities, also by going out to 'other' disciplines.

> **Recommendation 20:**
> **New types of Coordination and Support Actions should be encouraged in FET-Open (community building, dissemination, exposure of results, creativity…).**

### 4.1.5   Industrial and SME involvement

In FET FP6 projects 13% of all partners were from the industry, but the number of SMEs was much less (5 %   SMEs in FET-Open FP7 batches 1 and 2). Aiming at target percentages may not be appropriate: FET-Open needs to have the right companies participating. Since FET research timescale goes far beyond that of  SMEs, embarking on SMEs has to be carefully considered. A SME in a project should play a central role and not be an invited guest. Hence, only high technological companies that could provide innovative technology and benefit should be involved.

Moreover, involvement can take different forms which are not necessarily a funding issue – e.g. being involved in advisory boards etc. Exposing companies, especially SMEs to FET research is a priority.

> **Recommendation 21:**
> **FET-Open should not be a purely academic programme. Exposing companies, especially SMEs, to FET-Open research should also be a priority for FET-Open. This can be done using various tools, for example by a direct role in a project, by implementing an industrial advisory process, or through a CSA.**

### 4.1.6 Reach and synergies

As already noticed, attracting high quality proposals is a priority for FET-Open. Hence it is necessary to promote FET deeply towards new teams in particular those who are not working in "classical ICT". Showing results obtained in previous FET projects is a good vehicle, but innovative communication media could also be used. The FET Conference should devote special sessions for this.

> **Recommendation 22:**
> **Targeted awareness-raising activities should be put in place to clearly communicate FET-Open expectations and to attract the best ideas and teams from the broadest range of scientific communities.**

Links between FET-Open projects and proactive initiatives should be exploited. The FET-Open portfolio illustrates the potential. A mapping with proactive initiates should be made more explicit to see where synergies are possible.

> **Recommendation 23:**
> **FET-Open should develop an exploitation strategy to maximize the impact of its project portfolio in view of exploiting potential links and synergies with existing FET proactive initiatives and for identifying topics for new ones.**

## 4.2 Implementation and operations

FET-Open is already an efficient and effective programme and is considered successful in its current mode of operation. However some weaknesses have been listed in terms of selecting the best proposals, minimizing the time to answer without reducing the quality of the evaluation and thus optimising the workload generated by an increasing number of submissions.

### 4.2.1 Setting a global standard

Looking for best practices and benchmarking with similar scheme within Europe and outside Europe, may lead to substantial improvements.

> **Recommendation 24:**
> **FET-Open should continuously benchmark with similar scheme and experiment with new mechanisms so as to provide Europe with the most efficient and flexible funding scheme for excellence in pathfinding research.**

## 4.2.2   Flexibility and efficiency

A more flexible process can be put in place for example to fund short (6-12 months) assessment projects with limited funding as an alternative path to a full-blown research proposal/project.

> **Recommendation 25:**
> **In addition to its two step submission scheme, FET-Open should explore a new light-weight approach for rapidly launching small projects aiming at initial assessment of an idea in a short time.**

Project officers could be given the discretion to quickly reject proposals that do not fit the criteria, in particular those that are not in scope or of insufficient quality. Desk rejection should be used, possibly in case of any doubt based on advice from one expert or a small expert panel. Mechanisms should be put in place to clearly discourage submission of proposals that address the 'wrong call'.

> **Recommendation 26:**
> **The FET-Open office should be allowed, upon its own discretion, to rapidly reject short proposals that are clearly not in the scope of FET-Open or that are of poor quality.**

Incremental improvements of the proposal should be discouraged for example by clearer guidelines on scope (high-risk / high-impact), on evaluation criteria and by setting limits to resubmissions (e.g., explicit advice on submitting to other calls, embargo with respect to other call windows, no resubmission in subsequent batches, by clearly asking proposers to state if the proposal has already been submitted, and if so what are the improvements,…).

> **Recommendation 27:**
> **FET-Open should develop procedures and guidelines for discouraging iterative improvements and resubmission of short proposals, as well as for submission that could clearly target other calls.**

Symmetrically, project officers could be given the discretion to fund up to a certain level based on positive peer-review without the need for the full assessment process. This would be useful in giving a quick turn round of decisions on small-budget proposals.

> **Recommendation 28:**
> **The FET-Open office should be allowed, based on rapid and positive review, to decide on funding of projects, up to a certain level and in particular for assessment projects.**

## 4.2.3   Peer review

The question of peer review is very delicate for FET-Open because of the unforeseeable nature of the proposals that will be selected. Applicants could be invited to suggest evaluators for inclusion or exclusion of the evaluation process. FET may establish, with the help of relevant research communities, a "College" of permanent peer reviewers.

> **Recommendation 29:**
> **Proposers should be invited to provide a positive and/or negative list of reviewers, to be used at the discretion of project officers to provide first orientation on review panel, and expose conflicts of interest as seen by the proposers.**

## 4.2.4   Programme success criteria

The success and impact of the FET-Open scheme can obviously not be measured in short term. It is important that the long-term impact of the projects is monitored closely, even long after the projects have finished. FET-Open should be in particular on the look out for ideas that started within FET-Open and that developed over time into major areas of research. In addition it is important to track the career development of researchers involved in FET-Open projects.

> **Recommendation 30:**
> **Set up an internal system of FET-Open specific indicators that allows evaluating the impact of FET-Open in 5 to 10 years time with respect to the specific mission of the FET-Open scheme.**

# 5.  Improving the reach, effectiveness and impact of FET

*In this section the issue of promoting good practice in FET towards the achievement of high impact within the scientific community, the society and the industry is addressed. FET already demonstrated in a number of ways how strategic and effective its path-finding mission is, and there is now need to systematically exploit the strong points that characterised the pioneering, launch phase of FET and its initial development. The ISTAG working group on FET identified a set of specific issues – no doubt not exhaustive - to stress for fostering the reach, impact and effectiveness of FET. The working group believes that the foundational, transformative, high-risk, purpose-driven, multidisciplinary and collaborative research characterising the FET programme can become a true advantage in global competition especially if supported by specific actions.*

## 5.1  Promoting young researchers participation in FET research

Supporting and exploiting talent is of strategic value for FET, since exploitation of new knowledge and cutting-edge technologies can best be done through people. Young talents are, in particular, the elective ingredient for fuelling this process, because of their natural attitude to think out of the box, to target frontier challenges, to invest energy in high-risk research, to understand and embrace new trends. To this aim, promotion of young researchers as principal investigators in small STREPs should be pursued, and at the same time statistics on career and success/failure stories of young investigators participating in FET projects should be performed in a professional way (e.g.: by specialized companies), and in a few years (e.g. five) time framework after the completion of projects.

Although classifications always involve arbitrary choices, it is useful to define the concept of "young researcher" (YR) in science and engineering in order to promote YR contribution to research by setting up clear mechanisms that foster this active participation. The proposal here is to define a YR as an active researcher within 10 years after getting her/his highest academic degree.

A better usage of existing instruments can be done as well as the introduction of new features. A proposal submitted after a call for projects could include a section entitled 'Integration of young researchers' (1 page). Consequently, one of the evaluation criteria under implementation should include 'the degree and quality of involvement of YR'. For larger integrated projects the involvement of YR should be strengthened via YR training modules, curriculum co-operation with universities and innovative courses or study programmes. Coordination and support actions could include slots for training conferences, maybe with Marie Curie label or conference modules with training aspects.

The participation of YR in Research and Technological Development is already supported and funded by an extensive funding landscape on national and international level, and the proposed initiatives are focused on what is still missing.

### 5.1.1  Twinning FET and Marie Curie programme

This proposal for the promotion of YR in FET tries to avoid a duplication of instruments with already existing programmes. It aims at instruments where both the quality of the research project and the training features go hand in hand. It is also taken into account that the tight limitations of programme budgets imply that the suggestions made would result in a simple budget reallocation with the People Programme (Marie Curie) and the ICT area in the Cooperation Programme. A good example could be to promote joint and co-funded Marie Curie – FET actions ("twinned programmes"), by using People funding for specific (i.e. top-down, rather than the currently adopted bottom-up approach) education and training actions.

> **Recommendation 31:**
> **Investigate how to twin Marie Curie actions such as Initial Training Networks with FET research in order to promote young researchers training and research careers.**

The following set of suggestions applies to different levels of YR involvement and builds on different cost/budget intensities. While number 5.1.3 is long term oriented (FP8), 5.1.2 and 5.1.4 may be implemented quickly.

## 5.1.2   FET Young Researcher grants

This instrument offers the opportunity for a small number of partners (including industry) to carry out a small budgeted Collaborative Project (CP). Experienced researchers may also be involved in the CP. The topic-driven (top down) calls should be manageable with low administrative efforts to allow for highly innovative YR to combine efforts on a European level. Applications should be single-stage and should not exceed 15 pages.

Via combining dynamic research and training, this instrument offers YR the opportunity to get involved in FET on their own responsibility. This makes the instrument an explicit 'window of opportunity' for YR. The grants would support the visibility of YR and foster networking with other laboratories and industry.

> **Recommendation 32:**
> **Launch calls for proposals explicitly aimed at raising the role of young researchers in FET, e.g. exploratory actions implemented via "small" collaborative projects with a minimal consortium.**

## 5.1.3    FET- Networking of Young Investigators

Within a Coordination or Support Action (CSA), FET could offer a 5 years' fixed amount contribution for international networking activities (e.g. 15,000 € p.a.) to junior independent group leaders within FET relevant projects.

This dynamic instrument would cross-link the best YR that work in various FET relevant fields. This topic driven and interdisciplinary instrument will support the formation of the vibrant ICT research community of the future. Overlaps with already existing funding programmes have to be avoided.

> **Recommendation 33:**
> **Implement networking actions for young researchers as part of the existing FET projects (in particular  within CSA's).**

## 5.1.4   "Young Researcher of the year" award

The aim of this action is to promote and stimulate research activities of YR on FET topics (top-down) by giving awards to YRs who will achieve the best results during each year. The amount of each award should be 10-20 K€ and the winner should spend this extra money to co-fund his/her research activities.

The award would stimulate excellent YRs to achieve excellent results in their research projects and be acknowledged for them. Furthermore, the winners of this competition will have some extra budget for their research.

## 5.2 Start-ups, spin-offs and high-tech SMEs

The FET program has probably the highest potential among all IST programs to generate novel business ideas that will drive the economy of the future. ISTAG feels that this potential is not yet fully exploited within the current program infrastructure. This is especially pertinent now when, due to the difficult economic scenario, European industries are focusing their efforts on short-term, market-driven research rather than high-risk ICT pathfinding work. FET represents a unique opportunity for companies and industries to exploit high-potential ICT research results, and it is important to show, through real data, how vital and beneficial this exploitation can be. Hence statistics about industrial collaborations and start-ups originated from FET projects should be regularly collected and published.

### 5.2.1 Large, small and medium companies

The inclusion of an existing company in a consortium is welcome, but is not necessarily a positive aspect because it may inhibit the disruptive and embryonic spirit that characterizes FET projects. Therefore, it is necessary to pay great attention that the participation of large companies provides the necessary support and is in line with the futuristic goals of the project. On the other hand, SMEs may be too small to afford participation in research projects that could lead to products not earlier than 5-10 years. More creative ways of including SMEs should therefore be devised.

Better mechanisms for engagement of research-oriented start-ups should be found. To a large extent, unless competition laws prevent it, companies should not be asked to co-share costs, at least for some programs. Schemes like the SBIR (Small Business Innovation Research, http://www.sbir.gov/) in US offer full funding to the companies, and models like STTR (Small Business Technology Transfer, information also available at http://www.sbir.gov/) are also a valid reference. Indeed the VSEs (Very Small Enterprises – i.e., at the very bottom of the SME pile) need to be embraced and, of course, this is also linked to joint research activities with immature spin-out companies too. These companies often 'slip under the radar' and are not able to make financial contributions to projects and yet they may be vital to incubating and creating products which exploit new technologies.

Some immediate steps could be taken for making the programme more visible and attractive to existing companies, for example through the following measures:

1. Industry is invited to participate actively in conferences or events organised by FET or FET projects (papers, address, etc.)
2. FET maintains an SME list for email broadcasting
3. FET establishes links with "chamber of commerce" (or technology transfer agencies in universities, districts, clusters, etc) bodies in member states
4. FET exhibition booths in major industrial exhibitions.
5. FET conference to include demos/press/media day specifically targeted at SMEs
6. FET Coordination Actions organising events for industries.

### 5.2.2 Start-ups and spin-offs

The creation of spin-off companies could be better encouraged in a number of ways.

1. The annual review form should include an item where reviewers assess the potentials of the project in terms of spinning off a new business. This is currently done only at the end of the project when it is too late for possible action and where new ideas may have already been published or disclosed (therefore limiting the possibility of applying for a patent).

2. Individuals of projects whose potentials for spin-off is high, should have access to special coaching for transforming ideas into ventures. This coaching can be done through the Venture program of participating universities (for example, EPFL has such a program where selected students can have 8 to 32 hours of free coaching and even paid leave to develop and test a prototype in case the project is considered promising). In case where no participating university has such a program, the FET program should sponsor training at selected centres.

3. We also suggest that the Venture Capital/Angels (linked with Chamber of Commerce and the equivalent of Regional Development Agencies) would be targeted -- either by direct contact and / or perhaps invited to an extra FET conference day. In the first instance, ideas can be explored how to maximise synergy from these agencies which currently usually work in isolation.

4. There should be more concrete support for a FET derived start-ups and spin-offs - perhaps even a small financial kick from for example the EU investment bank could be negotiated by FET for such start-ups.

5. It may also help if FET can provide some official statement or certificate of the most interesting start-up ideas that emerged - like an award - to help them in road shows with angels and VCs later on.

6. A mechanism could be introduced for fostering research exploitation, through extra-funding of business ideas, right after the end of selected projects. A portion of the total budget allocated to each call could be given to a small number of projects (e.g. two or three) after their final review, in combination with a few months extension of the projects and based on a careful analysis of exploitation plans. The extra funding and extension period should be focused on the editing of a high quality business plan and on the implementation of its first steps.

7. Possible idea: promoting a dedicated FET project (like a coordination and support action) whose aim is to connect individual research projects with external actors: existing SMEs, coachers, incubators, business angels, venture capitals, etc.)

8. Dedicated funding for FET innovators could be set up.

The ICT Advisory Group takes note of the fact that an independent study on High-Tech SMEs within FET is being launched by FET.

## 5.3 ERA - Joint programming initiatives and ERA-NET actions

The ERA-NET and ERA NET+ schemes aim at developing and strengthening the coordination of national and regional research programmes. It is a framework to improve the coordination among member state programmes and to provide additional EU financial support to participants who create a common fund for the purpose of joint calls for proposals among national and regional programmes. Joint ERA NET – FET initiatives could be organised to support the coordination of European, national

and regional research programmes to achieve the implementation of the FET flagships in Research and Innovation.

FET flagships are defined around scientific and technological areas where foundational research is strong in Europe, in the sense that essential competences and a range of dispersed initiatives exist that are mature to be brought together in order to achieve the next level of ambition. This will have a strong societal impact and evolve future markets in which Europe should play a prominent role, and we believe that joint ERA NET – FET initiatives will stimulate such process. For further discussion on flagships we refer to the recent ISTAG report, called "Future and Emerging Technologies Flagships: Transforming ICT for 2020 and beyond". The ICT Advisory Group also takes note of the fact that an independent study on the options for implementation of FET flagships is being launched by FET.

Synergies could be also sought with existing organisms already aimed at networking European research, such as ERCIM - the European Research Consortium for Informatics and Mathematics. This institution aims at fostering collaborative work within the European research community and at increasing co-operation with European industry, having leading research institutes from twenty European countries amongst its members. FET could discuss with ERCIM what actions to be jointly promoted and what could be the organisational framework for collaborating.

## 5.4 Skills, education and curricula including issues related to European Institute of Innovation and Technology (EIT)

Also in fostering education impact, as mentioned for research in section 2, it is important to avoid a duplication of instruments with already existing programmes, and synergies with the People Programme (Marie Curie) and the ICT area in the Cooperation Programme have to be found.

Within FET clusters, coordination actions should include a strong element of education and training, for example:

- o Summer schools, workshops, other seminar activities, complementary skills (e.g., business planning) etc.
- o Course modules or courses or even study programs (e.g. Master's program, PhD program) related to the cluster's main research areas
- o Internships in high-tech companies, including start-ups and spin-offs, where young professionals could acquire novel skills and competences, improving their academic preparation and their competitiveness. Internships could be co-funded by the EC and by involved companies

These education and training activities should be focused on young researchers and should try to link recent research developments, results, discussions of open problems and methodologies for possibly addressing them. These researchers should not only include graduate students or other researchers linked to the projects in the cluster, they should also include graduate students and young professionals from all EU countries. This can be done by appropriate education opportunities dissemination and open calls for participation. The coordination actions should have enough budget reserved, so that they can fund travel and living expenses of selected young researchers and professionals.

> **Recommendation 36:**
> **Education and training of young researchers and also possibly young professionals should move more to the centre of clusters of research projects funded by FET. Synergies should also be exploited with national research programs, with research projects, graduate courses and programmes of EIT/KIC, of other EU programmes such as the other ICT parts of the program, Marie Curie, ERASMUS and ERASMUS MUNDUS.**

## 5.5  International cooperation

International cooperation in FET should be based on:

- o  Recognition of each other priorities for basic and applied research
- o  Participation on FET projects of expert partners from non-EU countries should be encouraged based on specific competencies and added value
- o  Exploratory joint workshops and possibly coordination actions on research areas where priorities coincide in order to identify a list of topics where the two sides are willing to cooperate
- o  Coordinated calls for joint project proposals on the areas where an overlap of priorities and research areas has been identified
- o  Funding exchange of senior and young researchers based on joint experimental activities

**Recommendation 37:**
**FET should establish closer cooperation on basic and foundational research with, for example, USA, Russia, India, China, Brazil, Japan and Australia. Unique competencies may be identified in these and other countries in order to augment EU research capabilities in selected areas, also considering complementarity and synergy sought on specific priority fields of strategic value for both EU and the partner country. Beyond this, FET should be a forerunner towards a truly global scheme for funding multi-disciplinary transformative research.**

## 5.6.  Open access to scientific knowledge

Open access is critical to ensure fast and reliable access to EU-funded research results, in order to drive innovation, advance scientific discovery and support the development of a strong knowledge-based economy.

However, open access may question the copyright policy of scientific journal publishers. It should be noted that the European economic activity in scientific publishing involves about 780 publishers, and represents a market share of 49% of worldwide scientific journals.

In August 2008, the European Commission launched an open access pilot in FP7. Under this pilot, grant recipients in seven areas: energy, environment, health, information and communication technologies (Cognitive Systems, Interaction, Robotics), research infrastructures, science in society, and social sciences and humanities) will be required to:

- o  deposit peer reviewed research articles or final manuscripts resulting from their FP7 projects into an online repository;
- o  make their best efforts to ensure open access to these articles within either six (health, energy, environment, parts of information and communication technologies, research infrastructures) or twelve months (social sciences and humanities, science in society) after publication.

The pilot covers approximately 20% of the Commission's FP7 research programme budget, and will run until the end of FP7. Under FP7 grantees may take advantage of reimbursement for the full cost of open access publishing.

The collaborative PEER project (Pilot Programme Investigating the Effect of the Deposit of Author) between researchers and scientific publishers focuses on the impact depositing peer-reviewed manuscripts in repositories can have on policy-making.

Open access to journal articles should not interfere with patenting or other potential forms of commercial exploitation of research results, since it comes into play only when a decision to publish

has been taken. Decisions regarding whether to patent and commercially exploit research results are typically taken before publication.

It should be noted that in several scientific communities such as physicists, open access for preprints has been pioneered 17 years ago by American high energy physicists (arXiv.org website), and that a number of scientific publishers, including a major one, the American Physical Society, do not oppose to the authors submitting their preprint to this website. The papers may stay in the site after they have been peer-reviewed and published, without any cost for the authors.

It is clear that the FET programme should be involved in the open access action. It deals with upstream research, for which conflicts with patenting is lower than for other programmes. It involves participants belonging to scientific communities in which free open access is of common use. Open access to peer-reviewed results of FET funded projects should be strongly encouraged, either on the basis of free deposit on an archive system or using some type of agreement with scientific publishers.

The ICT Advisory Group welcomes the fact that FET is in the process of becoming part of this pilot initiative. There are, however, concerns on the limited time window for the open access state: 6-12 months after publication could only serve for publishers that end up owning the results and, at the same time, 6-12 months behind the curve does not really help in the race for innovation. While there are complex political and economic considerations, FET in particular should only stand for the ideal state where all possible innovators have all possible access as fast as possible. Based on these considerations, the setting-up of a FET archive, well structured and with effective search tools, where public project reports and documents are uploaded, could also have a major impact. In that case, the lack of peer-review could be counterbalanced by a specific label assigned to each document stating whether shown results have also been peer-reviewed on journals or not.

> **Recommendation 38:**
> **FET should develop a policy for making the results of its funded research available to everybody for free and as quickly as possible. Open access to peer-reviewed results of FET funded projects should be strongly encouraged, either on the basis of free deposit on an archive system – possibly a FET-branded dedicated archive - or using some type of agreement with scientific publishers**

## 5.7   Other initiatives

Beyond FET Open it would be useful to have a FET Competition (in the spirit of, for example, the DARPA Grand Challenge), with no money provided upfront. The winner's, lab, institute would get a prize. This has already been experimented in the US and it resulted that institutes invested much of their spare resources to compete - for pride, glory and the money. An open competition is vital to driving innovation and FET also needs a similar initiative, in addition to risky proposals. It is noteworthy that such competitions are not expensive and generate relevant activities with respect to the allocated money, and can be experimented at small, pilot stage. They would be even more interesting if FET makes them world-wide eligible to give FET international visibility as the ICT scout of the 21st century.

As for "Grand Challenges", dedicated Calls for ideas could be launched and the winning team could implement the programmatic aspects.

> **Recommendation 39:**
> **The FET-Open and Proactive schemes should be complemented with ambitious but concrete and measurable challenges that call for competing groups to mobilise resources on a voluntary basis.**

Another important initiative is the FET Conference. The European Future Technologies Conference and Exhibition 2009 (FET09) was a huge success: more than 750 participants, a swirling mix of 6 keynotes, 29 scientific sessions, 29 exhibits, 22 on-the-fly sessions, 64 posters, 1 science cafe, and a sparkling multidisciplinary atmosphere among the participants. Conferences and exhibition are important instruments to disseminate frontier research results and ideas in FET among scientists, policy-makers, industry representatives and science journalists. A systematic dissemination approach is necessary to effectively exploit the FET strategies and results and to increase public understanding of science. The organization and funding of big events such as FET09 constitute important actions on which is worth to invest for presenting and discussing today's frontier science, tomorrow's technologies and the impact of both on tomorrow's society. Last but not least, the FET Conference represents a true "FET Community building event", able to strengthen relationships between current players in FET and to extend FET impact beyond the existing community, promoting the new view on science and engineering that FET represents.

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**Recommendation 40:**
**Engage in the organisation of community building activities that cut across topics and disciplines, like the FET09 conference which could be repeated every 2 or 3 years. These events should be designed to stimulate exchange between a broad diversity of stakeholders that FET aims to attract.**

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A last recommendation concerns the birth of new ideas. **FET should maintain a 'Think Tank'** as a forum where 'futurist', over-the-horizon ideas could be discussed with the benefit of setting out contexts and possible future FET agendas.

# 6. Conclusions

Research on future and emerging ICTs takes place in the context of a complex and dynamic landscape of public and private, upstream and downstream research and innovation activities, managed either at European, national, regional or local level. Within this complex scene of the ICT programme, FET acts as the pathfinder for future ICTs. FET is an incubator for new ideas, and it explores new research themes that promise to be foundational and of long-term relevance for a sustainable future for ICTs in Europe. FET promotes high risk multidisciplinary research, offset by the promise of breakthroughs with high scientific, technological or societal impact. Since its beginnings as part of the Esprit Programme, the research promoted by FET has become a benchmark of excellence. FET initiatives, which attract and foster collaboration between top European researchers, have made substantial contributions in bringing European research to the forefront of the state-of-the-art, as shown by the prizes won by participating researchers and the public visibility gained by FET supported projects.

In this Report, the ISTAG FET working group has provided strategic advice and orientations on the role and positioning of FET in order to strengthen the mechanisms that support it and increase its impact and attractiveness. This report includes views and recommendations regarding FET proactive initiatives for the ICT Workprogramme 2009-10, and discusses the specificities of the FET Open scheme, and makes recommendations to further develop it. A set of 40 recommendations have been established that all tend to a unique goal: improving further the quality, efficiency, reach, impact and effectiveness of the FET programme so that it can establish itself firmly as a reference for high-risk transformative research funding within the EU and worldwide.

# ANNEX I : Details on proposed future FET proactive initiatives

*Note that this Annex was finalised in November 2008. It served as input from the ISTAG Working Group on FET to the workprogramme 2009-2010 preparations.*

The Working Group analyzed the proactive initiatives that should be continued, the ones that should be discontinued or refocused. Furthermore new proactive initiatives that should be launched were proposed coming from the consultation workshops or from the FET Open portfolio or from the working group members.

The 2008 FET proactive project calls are defined and the candidate initiatives for 2009 have been outlined. The working group does not see any evidence for changing them.

During the last months, the FET proactive unit has organized several concertation workshops in order to define new topics. The ones that came out of the consultation are:

1. Overlay computing and communication
2. Synthetic living ICT
3. Zero power ICT
4. Creativity

Other themes were mentioned by the group and added to this list. After applying a clustering method, the group converged on the following challenges (from consultations – **in bold** -and from group members).

1. *Challenge Bio-ICT (cell level)*
   (a) **Synthetic living ICT**
   (b) Evolutionary technologies
   (c) **Synthetic biology**
   (d) Bio-ICT

2. *Challenge Embodied ICT (system level)*
   (a) Living robots
   (b) Embodied
   (c) Soft-bodied

3. *Challenge Neuro-ICT*
   (a) **Neuroinfo**
   (b) **Brain computer interfaces**
   (c) Hybrid bionic systems
   (d) Visual computing
   (e) **Creativity**
   (f) Micro-scale hybrids

4. *Challenge Future computing technologies*
   (a) **QIPC** (Towards)
   (b) 0-power
   (c) Novel switching devices
   (d) Sub 32nm CMOS
   (e) **Molecular scale devices and ICT systems**

   (f) Displays and interfaces
   (g) Digital capture

5. *Challenge Modelling and Simulation for large scale systems*
   (a) Hybrid Modelling
   (b) Eco-system computation
   (c) **Large-scale simulation for complex systems**
   (d) **Overlay computing and communication**
   (e) Wire to service
   (f) Pervasive adaptation
   (g) Simulation based research
   (h) **Multiscale and multilevel simulation**

6. *Challenge Social ICT*
   (a) **Social ICT**
   (b) **Systems for collective and social intelligence**

7. *Challenge Future programming technologies*
   (a) **Massive ICT**
   (b) **Modelling and formal methods**

## 1.1   Bio-ICT (cell level)

Key topics:
Synthetic living ICT, Evolutionary technologies, Synthetic biology and Bio-ICT.

Developments in ICT and biology are approaching a stage where the relationship between the two disciplines faces a paradigm shift: from ICT that mimics biology, to ICT that uses biology for information processing. This implies closing the feedback loop, so that biology does not just 'inspire' or inform ICT development, it becomes the basis for the information and communication processing platform itself. The result would be a radically new kind of coupled information, computation and production technology, with a complete integration of information processing and production. Such integration is only seen in living systems today.

In synthetic biology further progress depends on more systematic design methodologies and manufacturing processes. Research should aim to develop a more systemic approach to the design and manufacture of bio-based systems through the application of design automation. This would lead to a deeper understanding of fundamental issues in biological complexity, and the ability to harness these systems for a wide range of application domains.

In addition, major advances are needed at the 'hardware' level – in interfacing ICT with biological systems at the micro-/nano-scale. Research should aim to interface bioware, software and hardware within a programmable substrate which allows the customised design of bio-artificial devices. Specific attention should be given to how to adapt communication language and protocols so as to communicate with biological systems.

## 1.2   Embodied ICT (system level) (Call in 2011)

Key topics:
Living robots, Embodied systems and Soft-bodied systems.

The concept of embodiment is going beyond the original statement that "intelligence requires a body" and look more closely to the relation between the shape of the body (the morphology) and the behaviour and intelligence that it determines. Intelligence is somehow 'distributed' in the system, not only between a central and a peripheral level, but also at the level of the mechanical structure. This is inspired by Nature and by the study of (even simple) animals. Biology also offers suggestions for a hierarchical organization of an embodied artefact. Biological tissues and systems are organized hierarchically, starting from simpler structures that build more complex ones. Examples are amino-acids constituting proteins, myofibrils composing muscle fibres, tropocollagen building tendons, etc. This approach can be helpful in building soft-bodied systems that exploit the basic working principles of living organisms.

To experience virtual/augmented reality it is necessary for participants to suit up in various ways (at a minimum it is necessary to put on a pair of special glasses). Obtrusiveness comes also from the lack of realism of the virtual elements. The challenge is to invent displays and interactive systems that are entirely unobtrusive, so that the transition from physical to virtual/mixed reality is essentially unnoticeable.

Sensory perception is the awareness of phenomena through physical senses. It may be possible to enable new forms of sensory perception for both natural phenomena and information using smart clothing, ubiquitous displays, brain computer interfaces or other technologies.

## 1.3 Neuro-ICT (Call in 2009/10)

Key topics:
Neuroinfo, Brain computer interfaces, Hybrid bionic systems, Physiological Cybernetics, Visual computing, Creativity and Micro-scale hybrids.

Recent advances in the domains of ICT and neuroscience enabling the activity of a large number of neurons to be observed and modelled open up the possibility that the detailed functioning of substantial parts of the brain may now be studied for animals. The projects funded under the FP6 FET proactive initiative Bio-I$^3$ have made progress in this area and identified further bottlenecks, but are expected to exhaust their funding in 2009. However, the underlying long term challenges remain and the recent workshop held to discuss this domain identified the following key areas.

A first research objective is brain-inspired hardware. Very large scale (eg wafer-scale) synthetic implementations of reverse engineered neural circuits, exploiting the fault-tolerant properties of such approaches.

A second research objective is multi-scale and multilevel modelling of the brain, theory building and applying the lessons learnt.

- o Recording and imaging the brain simultaneously at different levels. In order to understand how the brain works, it is necessary to link dynamic variables at various levels of integration e.g. single unit recordings should be combined with LFPs, EEG etc to observe the behaviour of synaptic conductances, spiking neurons and neural assemblies simultaneously.
- o Data management, data sharing, visualisation. Visualise, Interpret and model the massive amounts of data that will be forthcoming as a consequence of research in the neurosciences. Extract general principles of biological information processing from these models.
- o Use of these models as an inspiration for IT applications. Use models of the brain to create systems that mimic human creativity in finding new solutions and are capable of the directed fusion of sensory information for greater autonomy.

A third research objective is the human/machine interfacing and prosthetics: develop implants using long-life electrodes combined with real-time analysis of neuronal signals using insights into learning mechanisms and plasticity in general.

Several hybrid bionic systems (HBSs) will be implanted in the next years in humans affected by different types of disabilities. The following main questions have to be addressed:

- o analysis of the performance of the HBS and of its ability to learn and evolve. In particular, it is important to understand whether the performance of these systems are good enough to address real-life situations and whether it is possible to control/use the HBS while carrying out other activities
- o analysis of the modifications in the nervous system of the subject related to the control/use of the HBS. Invasive and non-invasive imaging techniques and dedicated modelling algorithms could be used to address this issue;
- o analysis of the efficacy of the delivery of sensory feedback.

A fourth research objective is the use of cultured neurons in bio-hybrid systems: grow neuronal tissue from stem cells as part of a hybrid carbon/silicon structure enabling better instrumentation of brain activity than is possible in in-vivo studies.

An understanding of how information is processed in the central and peripheral nervous systems of animals would have a huge impact on ICT, opening the way for new computer architectures and advanced human aids such as neuroprosthetics. The processing done in the brain, using massively parallel techniques but consuming only ~20W of power, is substantially different from conventional Turing-type machines. Harnessing this massively parallel approach may lead to more capable

computers, able to perform tasks that current machines find difficult eg handling unfamiliar situations. Knowledge of how the information is represented, communicated and processed would also enable better cochlear implants, retinal neuroprostheses and artificial limbs etc, as well as potentially reducing the learning required to use new devices. The challenge for confluence is to go beyond Computer-Supported Co-operative Work, to create new forms of collaborative sensing and distributed intelligence.

## 1.4 Future computing technologies

Modern technology is racing forward with techniques for building systems on atomic and molecular scales, and for exploiting novel quantum degrees of freedom. We can expect a vast new range of powerful ICT technologies, but we still lack practical and efficient means for fabricating and controlling such devices. We face an urgent challenge to develop techniques for assembling devices on an atom-by-atom basis, and for controlling their interactions.

Experts also projected that the impact of the entire field of quantum and nano-technologies will be greatly amplified when we acquire the ability to integrate many atomic and bio-molecular nanostructures into complex networks and systems. This achievement would bridge today's gap between individual nanodevice research and large scale integration by IC manufacturers, and support a new generation of integrated circuits using nanoelectronic devices.

### 1.4.1 Quantum technologies

QIPC has the potential to remove the current bottleneck associated with extrapolation of present-day technologies, which will not be sufficient to secure steady progress in information processing. It offers a "Beyond Moore" route to continuing Moore's Law, introducing modes of computing and communicating which are not mere down scalings of CMOS based architectures. The initiative focus on integration of components and their reliability as QIPC moves from research oriented problems to applied and even commercial quantum technologies.

The first objective is the scalability of quantum processing systems, including fault tolerance and error correction. The challenge is to tame and overcome the broad variety of sources of errors leading to decoherence and thus limiting the performance of quantum information systems.

The second objective is the long distance quantum communication and reversible interconversion of qubits. The aim is to overcome the current distance limitation for quantum key distribution through the development of quantum repeaters.

The third objective is the quantum information theory, algorithms and paradigms. In order to achieve complete realistic schemes for coherent manipulation and high-precision performance, and fully exploit the opportunities offered by QIPC, a close interplay between theory and experiment will be needed.

The fourth objective is the entanglement-enabling control and entanglement-enabled quantum technologies. The aim is to overcome the lack of full coherent control, thus allowing the exploitation of a few qubits in a variety of real-world entanglement-enhanced technologies.

The challenges listed above will eventually lead to a pool of reliable technologies for the different components of quantum architectures. Breakthroughs in this area will make possible scalability of quantum information technologies in the presence of environmental noise, thus enabling their real-world deployment. Finally, reinforcement of Europe's leading role in this promising technology domain is to be expected, as well as the identification of new opportunities fostered through the technology transfer from labs to industries.

## 1.4.2  Nanotechnologies

According to the ITRS roadmap, macromolecular scale devices are now on the horizon. The current roadmap predicts that the minimum feature size of silicon CMOS technology will approach 20 nm as early as 2010. As silicon CMOS technology scales beyond these dimensions, new device structures and computational paradigms will be required to replace and augment standard CMOS devices for ULSI circuits. These possible emerging technologies span the realm from transistors made from silicon nanowires to devices made from nanoscale molecules. Most of those devices will require significant breakthroughs in the development of new nanomaterials and associated fabrication processes. Some of the main areas of research are:

- o *Low dimensional devices:* Theoretical models have predicted that graphene, a form of carbon consisting of layers one atom thick, could be made into transistors more than a hundred times as fast as today's silicon transistors. Recently, first steps towards experimental verification of these properties have been reached in the US. This has triggered a worldwide race for a new, potentially very powerful switching technology.

- o *Macromolecular devices:* There is a strong need for both fundamental and applied research in devising and implementing novel high-performance, enhanced-functionality atomic or molecular devices, modules and platforms, and high-yield bottom-up fabrication technologies.  There is also a need to adapt current logic architectures to the specificities of molecular switching and the requirements of terascale integration based on these devices.

- o *Spin state devices:* Instead of controlling the flow of charge, spintronic devices operate by manipulating the direction of the spin and the coupling between spins. The goal of this applied spintronics is to find effective ways of controlling electronic properties, such as the current or accumulated charge, by spin or magnetic field, as well as of controlling spin or magnetic properties by electric currents or gate voltages. The case at hand is metal spintronics, which has already revolutionized computer industry with a device based on giant magnetoresistance (see e.g. high capacity magnetic storage disks). The ultimate goal is to make practical device schemes that would enhance functionalities of the current charge-based electronics.

- o *Investigation of system-ability*:  From an applications perspective, the combination of new switching technologies with existing nano-CMOS is a very important consideration. This raises the issue of system-ability of future devices.

Within 15 years we will reach the ultimate scaling of CMOS. This will enable the billion transistor chips needed for ever more complex ambient intelligent systems. However, it is not at all clear that nanoarchitectures will necessarily be used in the same way as in current computer architectures, since nanoelectronics does not necessarily provide superior computing ability for many traditional applications / algorithms. Rather, the unique characteristics of nanoelectronics may enable radically different computational models, but these models must ultimately be incorporated into mainstream computing.  Realizing these systems requires coping with the accumulation of nanoscale physical phenomena disturbing the digital abstraction needed for complexity management.

With semiconductor technology reaching the nanometer scale, concerns such as complexity, power, variability and reliability are forcing major shifts in design paradigms. There is no question that fault tolerance, device variability, and defect generation are going to be serious problems, and probably at a level not seen since the earliest days of computing. Important research topics include such ideas as multiple level, hierarchical tolerance, possibly even reaching up into software itself. Incorporating such complex fault tolerance into the entire design flow and the design tools is another very important challenge. And all this needs to be done in a cost-effective manner, so that the density advantages of nanoscale circuitry are not compromised.

The fact that electronics parts are no longer identical due to material and process variation increases with every new step on the miniaturization roadmap. This is considered as the main bottleneck in Silicon/CMOS scaling.  In face of these nanoscale challenges, the entire design flow should be reconsidered to build energy-efficient systems with performance/throughput guarantees at the system

level. Rather than taking conservative margins (by worst-case or statistical design techniques), a better approach is to go for design techniques that allow systems to safely operate under uncertainties, while being as energy-delay optimal as possible. In this respect, electronics device variability is becoming a subchallenge of the user's standpoint "energy per operation" challenge, with other related subchallenges being better software, better architectures, and better interconnects.

### 1.4.3   Zero-power ICT

Zero-power ICT has the potential to stand as a novel approach, more than a novel technology, which can bring ICT to be truly integrated with the environment and with applications, from the energetic point of view. The achievements from this approach can be truly wireless and autonomous devices, ambient intelligence, pervasive computing, etc. In other words, it is a fundamental for many applications. Among the objectives along this line are new technologies for energy scavenging, new very-low-power actuators, sensors and communication devices, and wireless powering.

### 1.4.4   Massively parallel systems

By 2020, the semiconductor industry is likely to be able to manufacture integrated circuits with close to 1000 billion devices. It will not be possible to design such chips, to program processors with this many devices or to manage likely faults in these chips with evolutionary improvements of the tools available today. In parallel, progress in communication and integration technologies is enabling the development of systems also comprising such large number of components. The initiative looks at scalable methods for the architecture design and programming of chips and systems.

The first research objective is the design of dependable systems composed from unreliable components. The challenge is to develop methodologies and approaches to the design and construction of dependable systems in the face of unreliable components arising from hardware or software faults.

The second research objective is the complexity of design and run-time of heterogeneous HW/SW systems. The aim is to devise concepts, propose design paradigms and methods, and develop proof-of-concept for multi-engine heterogeneous systems addressing both the complexity of the design and the run-time complexity. Hardware, software and possibly "configware" (reconfigurable hardware) solutions should be found, so that the systems are usable and effectively support chosen applications.

### 1.4.5   Displays and interfaces

Novel display and interfaces, such as miniaturized portable projectors, high dynamic range and high resolution imagery, user tracking devices, and haptic interfaces are poised to make dramatic changes to the computer usage and interactivity. These technologies enhance realism, usability, interactivity and ubiquity of digital imagery, and have potential to enable widespread deployment of virtual and augmented reality. Various technical challenges need to be overcome to make them practicable. Additionally, of particular importance is research into human factors (sensory, perceptual and cognitive issues) that determine the usability of the technologies.

### 1.4.6   "Digital capture" of our world

Methods exist for capturing 3D virtual archives of physical things, places, and events. However, the technologies are costly and specialized and the data produced by these systems is typically noisy, incomplete and non-intuitive. A key emerging challenge is to provide technologies for capturing meaningful, interactive digital representations of our world with standard equipment such as digital cameras and mobile phones. This would allow individuals to cooperate to create a semantically rich virtual representation of (potentially all) things and places in our world, which could be navigated, queried and accessed according to arbitrary physical or functional criteria. In order to achieve this, the properties of the world to be represented also need to be understood both physically and cognitively. Key research issues include: (1) technical challenges in the acquisition of 3D data using consumer devices; (2) the statistical structure of the world to be captured (3D shape, surface properties,

illumination, motion, image statistics, etc.); (3) perceptual and cognitive parsing of the data, to enable the transition from raw data to meaningful units; (4) novel uses of enormous collective image ensembles (e.g. internet image archives).

## 1.5 Modeling and Simulation for large scale systems (Call in 2010)

Key topics:
Hybrid Modelling, Eco-system computation, Large-scale simulation for complex systems, Overlay computing and communication, Wire to service, Pervasive adaptation, Simulation based research and Multiscale and multilevel simulation.

High-throughput production of data in all disciplines makes it difficult to manage them properly at systemic level. Models of reality are more and more urgent to use them as surrogates of the phenomena we are interested in. Once the model is validated against the real data produced by experiments can be used as synthetic data producer and to carry out experiments. Simulation then will play the role of observation and should lead to the generation of new hypothesis for real experiments. All the disciplines (biology, physics, ecology, astronomy, social disciplines) can benefit from this approach, reducing time and costs. To handle real-size problems we need to address multi-level and multi-scale modelling to cover all the different aspects that can occur in studying a given phenomenon. Model composition is another urgent issue if we want to create an incremental knowledge builder. Notions of abstraction and refinement are needed to 'observe' the in-silico models at the right level for the properties of the phenomenon under investigation. Quantitative modelling is also absolutely needed to drive simulations and hence new modelling executable languages should be designed.

## 1.6 Social ICT (call in 2011)

Key topics:
Social ICT and Systems for collective and social intelligence.

Large scale ICT systems increasingly involve many people who make their own independent decisions, and react in unpredictable ways. These "socio-technological" systems cannot be understood, engineered or managed using traditional techniques for distributed computing and communications networks. A key challenge is to develop some analytical understanding which would allow limited predictions of system behaviour and relative certainty regarding properties such as stability and security.

An important challenge is to learn how to prevent or discourage unwanted, malicious behaviour in such systems, while at the same time encouraging and rewarding good behaviour. A promising solution is to learn principles, inspired in part by social phenomena, for doing so in a natural way that preserves individual autonomy, as well as how to design more adaptive ICT systems that co-evolve with the social structures in which they are embedded.

ICT is becoming embedded in every area of the life, reshaping how people work, play and interact. In these pervasive environments, the communicating entities are not just humans but also a whole variety of agents, sensors and devices. The growth of pervasive computing and communication environments creates new challenges in terms of how value is shared and extracted from knowledge and information. New approaches are needed to understand and manage this pervasive computing landscape, which take into account collective and distributed forms of intelligence.

Another challenge is to develop a new semantics of information to harness collective intelligence and facilitate collaboration across dynamic groups and communities. In addition to conventional semantics, research should focus on *pragmatics* - the practical interpretation and use of signs by agents or communities within particular circumstances and contexts.

A last aspect is using ICT as a key tool for stimulating creativity and innovation in the knowledge-based economy. Research is needed to further understanding of how creative processes can be enhanced by supporting the interaction of culture and ICT, and capturing and understanding ICT as a social and creative tool. In addition, there will be a need to enable the development of high-quality information that is created from diverse entities and sources in self-organising ways.

## 1.7  Future programming technologies (Call in 2009)

Key topics:
Massive ICT and formal methods.

The dramatic miniaturization of computer hardware is now making it possible to not only increase the "functionality per chip", but to integrate an increasing number of full "processor cores" on a single chip. In the not-too-distant-future we will see hundreds of cores on a single chip, which will make it possible to design laptop computers whose hardware performance easily exceeds today's supercomputers. While this seems to be a natural evolution due to the shrinkage of silicon structures, it is, in fact, a revolution that has gone widely unnoticed, and one that will radically change the face of the computer industry.

The reason is that up to now, very little has been known about how these new system architectures can be effectively and efficiently put to work. Totally new programming paradigms will have to be developed in order to achieve an adequate performance level – these architectures cannot be exploited simply by adapting the classical object-oriented imperative or functional programming paradigms. In order to make the benefits of multi-core processing based on hundreds of cores available to mainstream developers and, ultimately, to consumers, completely new conceptual and computational solutions will be needed. The same applies to the programming of parallel Systems-on-Chip (SoC) and – to an even greater extent – to mastering the programming of Field Programmable Gate Arrays (FPGA).

There is a wealth of possibilities for generations of programming "languages" and operating systems. One could take inspiration from the way in which biology or nature in general handles parallelism in an efficient way, or, for example, from the way that colonies of animals handle the problem of load balancing. This would, however, need to be translated into similar mechanisms at the computational level, in order to be transparent to both the programmer and user. Such an effort would of course attack also the complexity of the design of novel application and infrastructures by devising new programming methodologies and environments that address both speed and efficiency of code development and acquisition of data and resources through heterogeneous, widely distributed architectures.

The EU has been the leader in the programming language field for many years and can now exploit the results obtained at the theoretical level by actually transferring them to the huge market of new programming environments. If this is done correctly, in theory, the leadership position that the EU enjoys could actually pay off now – by becoming the leader in a new key technology in software.

Formal methods for software development are becoming essential in order to achieve reliability and automatic derivation of code in these massive ICT systems. Modelling and formal methods are successful approaches and we would like to see them further stressed.  The outcome could surely help developing new devices by providing engineered principles that at the moment are missing.  The recent experience from embedded systems, soft real-time systems and resource-limited systems such as smart cards suggests that these methods should include quantitative and probabilistic techniques as well as the more traditional approaches based on discrete mathematics.

# ANNEX II: Members of the ISTAG Working Group on FET

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# Recommendations on Future and Emerging Technologies

## Report of the ICT Advisory Group (ISTAG)

••• **October 2009**

**European Commission**
Information Society and Media