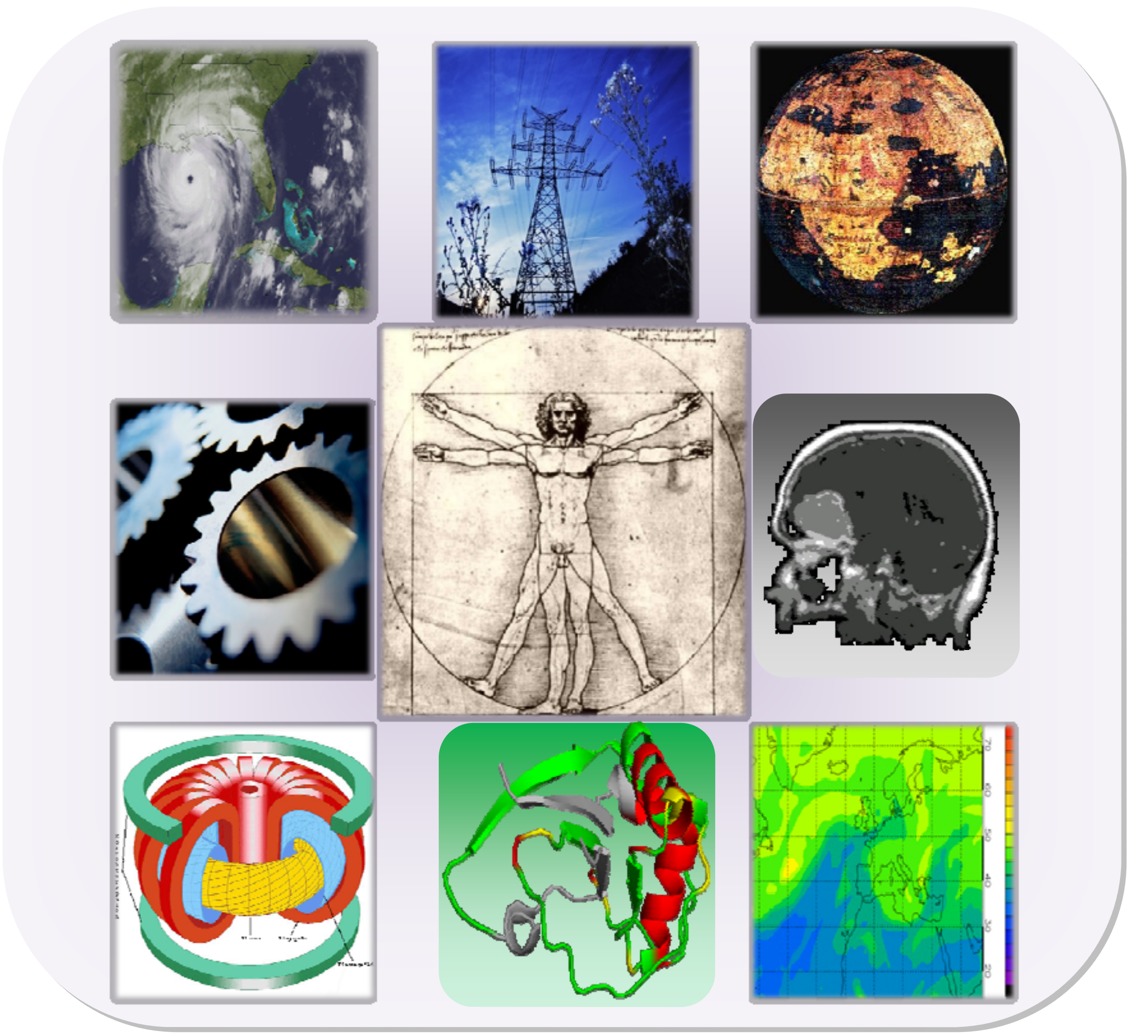
High Performance Computing in Europe: a vision for 2020

the enabling technology for Innovation in Europe



This document defines the vision for High Performance Computing in Europe in 2020 and is edited by the members of the PROSPECT Association in view of inducing future collaborations with any organisation that shares partially or fully this vision.

Author's preamble

Knowledge creation brings prosperity to society. By 2020, the use of supercomputers and computer clusters to solve advanced computation problems (referred as high performance computing in this document) is awarded the enabling technology to drive innovation and to sustain European global competitiveness and prosperity.

We strongly believe that High Performance Computing designed in Europe will be a worldwide leader by 2020. By then, we must implement solutions for the following:

- *scientific and business applications requiring advanced skills in computational science,*
- *prediction of and reaction to sporadic and long-term phenomena with impact on European society,*
- *efficient use of energetic resources and novel materials,*
- *mastering the design and, if need be, the development of hard- and soft-ware technology for HPC*

Key domains in which new knowledge will be essential and required will only be accessible through High Performance Computing and data processing, while computational tools will become mainstream. Furthermore, we strongly believe that challenges with a high degree of complexity cannot be tackled without sophisticated high performance computing resources.

as Martin Behaim said: 'Only when we have completed the circle can we start drawing the lines'.

High Performance Computing in Europe: a vision for 2020

In 2020, High-Performance Computing (HPC) technology will be critical for European industrial competitiveness and to stimulate innovation, productivity and growth in leading industrial sectors in Europe.
It will play a key role in:

- ✓ Exploiting the intellectual potential of Europeans and guarantee leadership of our world-class industry,
- ✓ Ensuring Europe´s independence in mastering key computing resources and technologies,
- ✓ Maintaining growth in Europe´s software industry and other ICT industries,
- ✓ Fostering cooperation between science and industry
- ✓ Attracting a growing number of students to engineering and science jobs.

Due to its unique ability to recreate sophisticated environments and process large amounts of data simultaneously, HPC will provide advanced solutions for tackling the following challenges:

- Shortening innovation cycles in new product development,
- Complex problem solving in scientific realms,
- Complex operational tasks involving high volumes of data,
- Sporadic and long-term phenomena with impact on European society,
- Efficient use of energy resources and novel materials,
- Developing advanced skills in computational science for scientific, engineering and business applications.

Our objective is to facilitate the achievement of global leadership in the following areas:

- The number of inventions in Europe due to HPC,
- The accuracy of complex predictions of phenomena with impact on European citizens and on life on the planet,
- Skills and business ventures in the area of HPC technology and applications,
- HPC system performance per unit of energy,
- Energy efficiency in supply chain operations (e.g. energy providers' networks, water networks, transportation networks, food supply chains, manufacturing, etc.)

Foreword

Signatories of the Group of Personalities attesting for the ETP Vision

Representatives of public entities

- **EU Commissioner**
- **EU MS National Ministries**
- **HPC service providers (public/private)**
- **Universities**
- **Public Mission-critical HPC centres (weather forecast, etc)**

Representatives of private entities

- **Industrial HPC users**
- **HPC vendors (HW/SW)**
- **Vendors of HW Components' for HPC (electric/power supply; cooling, etc.)**

High Performance Computing in Europe: a vision for 2020

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High Performance Computing: key asset for the future of Europe

This chapter argues that High Performance Computing (HPC) skills are essential to achieve competitive advantage for European industry in today's global economy. It introduces the specificities of HPC technology in the European context and the reason why such a technology is important for Europe, the supply and demand markets for HPC, the competitiveness advantage of HPC technology and, in the guise of a conclusion, the need for private-public partnerships in HPC in Europe.

What is High Performance Computing?

High Performance Computing (also referred to as parallel pervasive computing or as supercomputing) is the focal point of all research and development efforts to provide ICT at the 'extreme' of what can be provided by:

- Micro- and nano-electronics (miniaturisation of microprocessors),
- Computer systems (architectural design, inter-process communication, exchanges of data with memory and input/output systems),
- Photonics (interconnects, fast communication with storage devices),
- Software (compilers, tools, middleware and applications).

HPC brings innovations to computing systems architecture, component design and software tools that become the basis for a wide spectrum of future commercial applications. High Performance Computing (HPC) is about how to harness a huge computation power and optimise the work of hundreds of thousands, and in the future millions, of processors (through e.g. specific operating systems, middleware, libraries, and applications). Sophisticated visualisation techniques are also important technologies in HPC, since the complex results obtained by computations must be made accessible to human perception.

HPC is a tool to open new horizons by exploiting computing performance at extremely fast scales: currently reaching peta-flops[1], expected to reach exa-flops[2] in 2019-20. This craving for high processing speeds is not a futile quest in HPC, it is a must! The higher the computational power of a system, the higher is the accuracy of the calculated results to the reality of the problem under study.

[1] A *peta* floating point operations per second (*peta-flops* in short) is the equivalent to a one thousand trillion (10^{15}) arithmetic operations per second. To put the performance of such a computer in perspective, we can imagine a scenario in which all six billion people on earth used hand-held calculators and performed calculations 24 hours a day and seven days a week: it would take those 46 years to do what a *peta-flop* machine can do in one day!

[2] An *exa-flops* is the equivalent to a thousand times *peta-flops* computing speed (10^{18}).

HPC is a strategic tool for: *excellence* in know-how, market *innovations*, *precision* of results, 'world-class' *quality* in services and *leadership* amongst peers.

HPC is about a vision of ´moving beyond frontiers` of what is known, of what is possible, of what can be reached. This applies equally to the very nature of this technology: every 5 to 10 years, a thousand-fold increase in computing performance occurs and users are attracted to exploit it in the most efficient way!

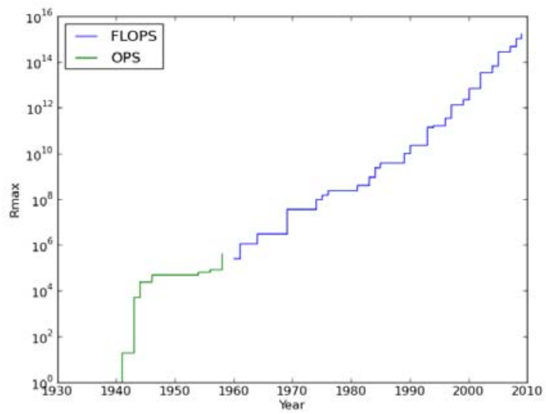

Figure 1: Fastest supercomputers worldwide: log speed (Rmax) versus time (Year). Legend: OPS stands for operations per second, FLOP stands for floating point operations per second. [Source: Wikipedia]

HPC has an impact on many industrial and engineering sectors and on research in natural and human sciences. HPC is applied to solve complex problems, run large-scale simulations or volume-based operations.

HPC enables to explore the unknown as if playing with a tool box: in a safe and controlled environment!

Manufacturers increasing rely on sophisticated models to design prototypes for new products in order to shorten time-to-market and reduce costs, risks and time on physical prototyping and testing. HPC is a key tool for breakthrough solutions that use energy efficiently and, thus, reduce carbon emissions.

Computer based simulations are used where "real life" experiments are not feasible. HPC enables to simulate phenomena that would not be easily or ever explored in the micro- or macro-world due to time, physical, ethical or computational constraints. HPC enables to explore the unknown as if playing with a tool box: in a safe and controlled setting!

Figure 2: High Performance Computing (HPC) attributes.

Why do we need High Performance Computing?

Strategic importance: Europe needs a consolidated effort!

- For Europe's industrial leadership
- For addressing societal challenges
- For branding the European Research Area

One of the most remarkable recent examples of giant leaps forward in science and technology was the advent of the *Information Society* that resulted from the widespread use of Information and Communication Technologies (ICT). ICT profoundly changed human experiences and societal endeavours. Nothing was left untouched: the interface with public administration and health services, new forms of employment and education, the access to up-to-date

HPC is of vital importance to European citizens: predictions can shed a light on the solution of today's societal challenges!

HPC is for the ICT industry what Formula 1 is for the automotive industry: a catalyser for novel technologies and innovation!

HPC is a key resource for leadership of the European industry: in advanced economies, to Out-Compete is to Out-Compute!

information sources, facilitation of communication links with implications on the globalisation and the transnational circulation of ideas, languages, or cultures.

Numerous examples exist of innovation in ICT due to advances in HPC; it is only fair to say that today's desktop computers exhibit similar techniques to those of the supercomputers of a decade ago. Currently, innovations in multi-core and many-core processor technology as well as in homogeneous and heterogeneous architectures are, to a large extent, driven by HPC.

Conversely, the trend in today's supercomputers is to use large numbers of commodity processors coupled with high-performance interconnections.The concentration of efforts on teh design of scalable system architectures and system software is a pre-condition for efficient exploitation of ICT's commodity components for HPC. Thus, High Performance Computing (HPC) is for the ICT industry what Formula1 is for the automotive industry: an inspiration and test bench for novel ICT and, years later, innovative commodity products.

HPC is a key resource for *innovation* and *leadership* of the industry in Europe. Research and development of new drugs and research on medical sciences uses HPC. The location and extraction of fuel that powers our vehicles and heats our homes and the research on new forms of energetic fuel resources (e.g. hydrogen and fuel cells, nuclear fusion, etc.) depends critically on the availability of HPC resources. HPC plays also an integral part in the design of the vehicles we drive and the airplanes we fly in. The research on novel vehicles that efficiently use energetic resources with high safety to passengers actively exploits HPC.

HPC is of *vital* importance to European citizens: civil protection needs accurate predictions of the spread of a natural catastrophe ('urgent computing`), enabling to make adequate decisions on how to reduce human casualties and property damages. On a daily basis, the production of weather forecasts that we use to plan our activities uses HPC; so does research that studies the causes and effects of climatic perturbations.

HPC facilities are a key resource (i) for *branding* the European research Area (ERA) with excellent infrastructure and services and (ii) for attracting and securing the best researchers. For scientists and engineers alike, HPC is a necessary tool for *advances* in their own domain. Nobel Prize winners use HPC facilities; international 'best-in-class' companies agree that HPC is a key factor in their ability to innovate. The motto for using HPC is, thus, 'Simulate first, Prototype later' in order to express the need for a fast scan of the universe of possibilities prior to identifying a reduced set of plausible solutions and, only then, perform physical validation tests.

According to a recent study on HPC in Europe [IDC2010], to Out-Compete is to Out-Compute. In other words, HPC becomes a necessity for higher added-value economies to compete with economies having lower labour costs. This is because virtual experiments help to reduce both labour and equipment costs incurred in physical experimentation. In addition to this, digital prototyping and large-scale data modelling enables for much faster time-to-market, less expensive products and is

The traditional HPC industry will be worth $21.8 billion (109) by the year 2014, predicts Intersect360 Research in its newly released Traditional HPC Total Market Forecast: 2010 to 2014. The market research and consulting firm anticipates the HPC market growing at a compound annual growth rate of 7.8% for the next five years.

Other examples:

Aircraft design - Dassault Aviation (France) developed the Falcon 7X combat aircraft entirely in a virtual environment using HPC product life cycle management software.

Car crash simulations - Mercedes Benz and Volkswagen (Germany) build safer cars based on HPC simulation results.

Search for gas and oil - Repsol (Spain), an oil and gas company, uses supercomputers for processing large amounts of seismic data in a timely manner.

Development of new chemicals - Bayer or BASF (Germany) exploit HPC in research on digitally designed chemicals.

more conducive to innovation than the traditional way of design and testing a series of physical prototypes (see examples of innovative products that were conceived in Europe thanks to the use of HPC in Appendix 1).

An outstanding competence

Europe's national research centres and universities, corporate industry (e.g. automotive, aeronautics, oil&gas, chemistry, pharmaceuticals, finance) do deploy HPC facilities of their own and their research simulation laboratories continuously keep up-to-date with world developments and trends in HPC technology. Their staff has renowned 'world-class' competence in HPC.

HPC centres are the meeting point of prominent scientists, computational experts and mathematicians. As such, they constitute the cradle for the outbreak of novel ideas in Science and innovative Technology-based solutions (see examples of research breakthroughs with the help of HPC in the Appendix 2).

A study[USCompet2008] of U.S. firms conducted by IDC indicates that the majority of the firms that used HPC considered it essential to compete and survive.

This explains why the United States, China, Japan and Russia will invest billions of Euros in Research and Development on HPC.

Up to now, Europe has not viewed HPC as a strategic key enabling technology. However, the worldwide competitiveness of science and industry in Europe will depend, to a large extent, on Europe's own competence to, not just exploit, but also to design HPC technology. It is, thus, of utmost importance that Europe joins forces with a worldwide network of open innovation. By doing so, Europe will be able to maintain and refresh the outstanding competence in HPC demonstrated up to now.

Furthermore, leadership-class HPC is reaching the level that no country in Europe, acting alone, can afford to:

i. Finance its periodic renewal[3], energy supply and cooling costs;
ii. Supply a critical mass of professionals with the adequate competence to cater for scaling user codes to massively parallel computing architectures.

It is precisely the second issue that is dearest to the HPC professionals in Europe: there will be soon a scarcity of careers in the HPC sector since the current generation of professionals is reaching retirement age and fewer and fewer graduates are available to take up their roles. Therefore, there is a pertinent need for a renewed effort to recruit young professionals that can still be trained by the previous generation of professionals. For this, a reform of educational curricula and attractive job offers is one of the issues that must be taken into account to bring this vision into a reality.

The value of High Performance Computing for Europe

[3] A periodic renewal of 3 to 5 years occurs in leadership HPC centres to obtain a system with a better computing performance per unit of energy consumption (megawatt).

HPC is successfully employed at Airbus in designing new airplanes. According to Nigel Barry of Airbus - "HPC is now pervasive in Airbus. It is a core technology for all design. The HPC systems must work correctly and provide timely results. Airbus requirements on HPC are 100% availability, guaranteed performance, support a long application lifetime ("101 years"), lower system power consumption and a smaller system footprint". [Source: Hoise.com].

According to the recent study (see footnote 3) to define a strategic agenda for European leadership in HPC in 2020, Europe has substantial strengths today in many areas in which HPC can contribute to gaining competitive advantage. These include, but are not limited to: weather and climate research, clean and sustainable energy, automotive and aerospace design, engineering, bio-life sciences, particle physics, cloud computing, molecular dynamics, modelling the properties of materials, and exa-scale applications across a wide spectrum of disciplines. These are all scientifically and economically important areas and can provide the basis for innovation and for pursuing worldwide leadership in certain economic fields.

According to the same study, the economic returns of HPC in Europe can be viewed as coming from two major areas:

- The HPC supply chain (*potential to add 0.5% to 1% to Europe's GDP* in 2020);
- Industries that leverage HPC to improve their products and services (*potential to add 2% to Europe's GDP* in 2020).

According to the market consultant IDC, the value of the worldwide HPC market[4] is of €*12.9* billion in 2009, and is forecast to be of €*17.3* billion in 2013. The same values within the EU amounted to €*3.3* billion in 2009 and IDC forecasts that total HPC spending within the EU will surpass €*4.6* billion by 2013. As with the worldwide forecast, the systems category is expected to experience the lowest growth rate among the other revenue categories. Storage, in particular, has been growing at a pace of several percentage points higher than HPC systems, owing to the "data explosion" associated with running increasingly large, complex simulations.

The value of the European HPC systems sales shows that the EU spending was greatest for the University/Academic category (€278 million), followed by Bio-sciences (€266 million), Computer Aided Engineering (CAE), Government departments and finally Defence. The predictions of IDC up to 2013 are shown in Figure 3 [IDC2010]; the same five categories will feature the greatest revenue with Computer-Aided Engineering exhibiting the highest growth rate amongst the first five.

The leveraging of of the above industrial categories by using HPC is, however, not available; such figures constitute the internal business plan of a company and are to remain confidential. However, if we look at the figures for the share of the total value-added in European industrial strengths of ICT technology in automobile (25%), consumer appliances (41%) or health and medical (33%), it is fair to say that the lack of investment in mastering HPC technology is a threat to the entire European manufacturing and service sectors.

It must be clearly stated that it is precisely the catalysing effect of HPC modelling and simulation on European

[4] The HPC market value includes not only the revenues from sales of HPC systems but also of other categories such as storage, service, application software and middleware. In the IDC forecasts, an HPC system includes both the systems priced above €375.000 each but also the systems priced less than €375.000 each.

industry in terms of: (i) innovative products and services, (ii) employment, productivity and growth that constitute the value added of HPC for Europe! It is not the increase in the amount of revenues from sales of HPC equipment manufactured in Europe!

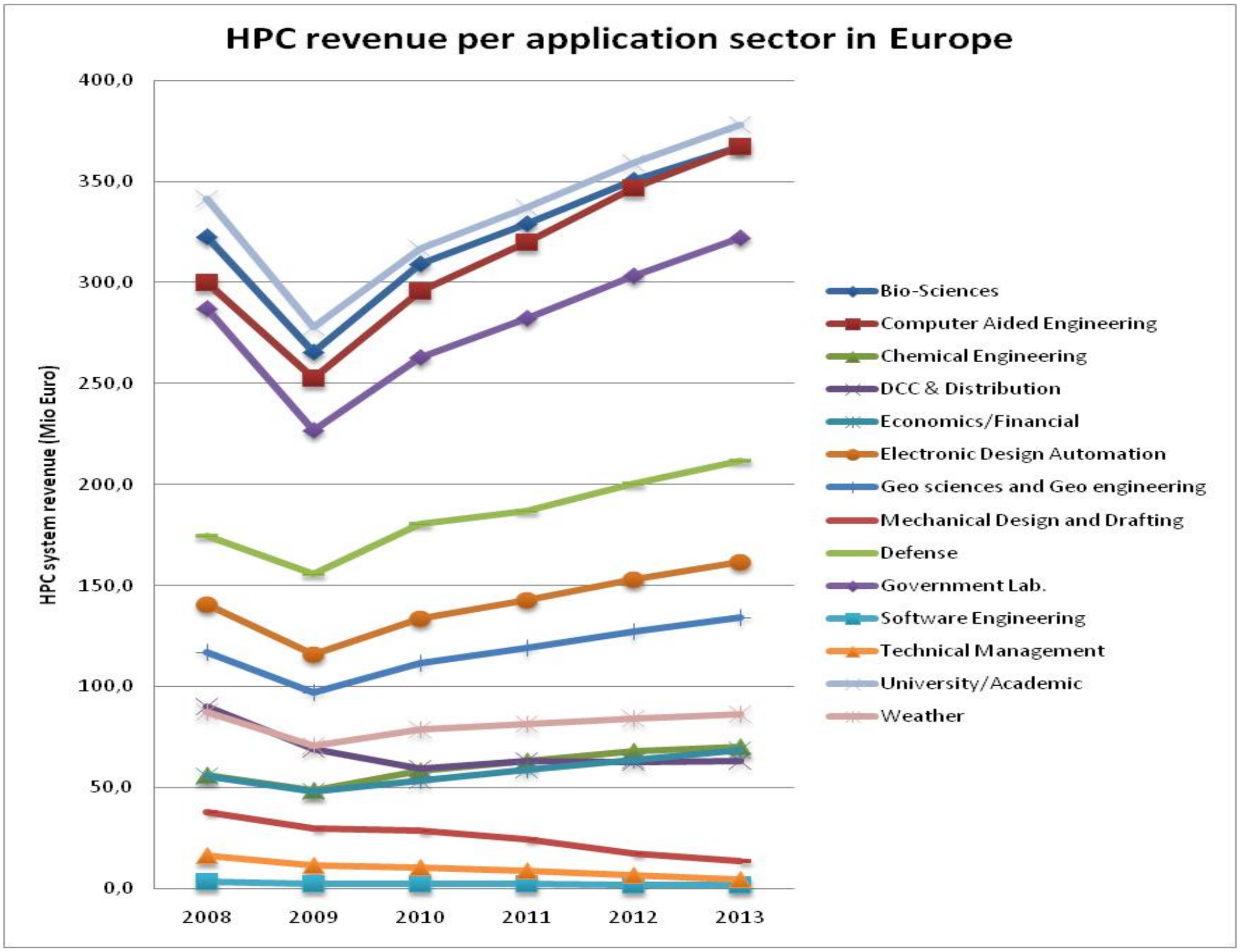

Figure 3: European Union - HPC Revenue (€000) Forecast by Application, 2008-2013 (Source: IDC, 2010)

Competitive advantage of HPC technology for Europe

Strengths:
Leadership in innovative industrial and research areas
Weakness:
Underinvestment in HPC
Threat:
Strong position of foreign vendors
Opportunity:
Software applications can be rewritten to meet new HPC standards.

Tackling Europe´s unemployment problem
Innovation is the best cure for unemployment. As many European states are suffering from excessive unemployment levels, those with the most innovative economies are more immune to the changing conditions in the world economy. As HPC is key to successful prototyping, more and more companies rely on HPC models in their innovation processes. A strong HPC sector means more jobs created in the most robust parts of our economy.

HPC´s impact on competitive advantage

HPC has become essential to sustainable economic growth by facilitating:

- *innovation* in European leadership economic sectors with solutions for fast and cost efficient prototyping (e.g. simulating new aircraft models);
- *solutions* to areas of distinctive expertise (e.g. Europe´s green technologies, bio-economy);
- increase in *speed* and improvement of the *quality* in business operations (e.g. design engineering);
- *innovation* in the Information and Communication Technology (ICT) industry (e.g. new programming paradigms for multi-core computing systems);
- access to new energetic *resources* (e.g. solar and ocean wave energy)
- natural environment management (e.g. climate change, natural disasters);
- solutions for *complex* societal challenges (e.g. ageing population, spread of epidemic diseases).

Competitive Strategy for Europe´s HPC

HPC technology can boost the competitive advantage of many of Europe´s industries provided that the following market and operations strategies are applied.

- Market strategy
  - Target industrial sectors with distinct advantage in order to achieve global leadership using HPC
  - Maintain European leadership in strategic scientific and industrial areas during the shift to exa-scale architectures by setting application and system software standards
  - Increase the share of European vendors in the global HPC supply chain.
- Operations strategy
  - Direct public funds into areas with the highest impact on Europe´s competitiveness, that is:
    - ✓ Use pre-commercial procurement in order to promote pre-competitive research
    - ✓ Allow industrials to advice on new investment solutions
  - Eliminate any red-tape in the process of absorbing research funds (e.g. delays in assigning funds, duplication of project areas)
  - Increase the effectiveness of investment in research and development
  - Improve the quality of training, education and academic curricula
  - Prepare the value chain for technological challenges
  - Involve European small and medium enterprises (SMEs) in the

supply chain and research programmes

What happens if we do not act now?

- We will lose job expertise in HPC to other economic regions.
- We will lose our most talented computer scientists to other economic regions in order to work on more attractive research programmes.
- Our industry will solely depend on the provision of HPC services and technology by companies subject to other economic regions trade policies.
- Our most competitive industries will lose their market share due to lack of innovation.
- Our ICT industry will produce fewer innovative solutions.
- The potential of academic and entrepreneurial talent in our region will not be fully realised.
- Our businesses will find it hard to compete in terms of speed and quality in the global market.
- Many of our environmental challenges will remain unresolved.
- The cost of energy and resources will hinder our competitive advantage.
- Stagnation of the European market offer on HPC technology.
- Effects on European best-in-class companies.
- Effects in European ICT in general and, in particular, in the micro-processor, components and software industry.

Why do we need in Europe a concerted public and private effort on HPC?

The United States continue to dominate the top500 list of the most powerful computing systems worldwide (274 systems and 56% of the worldwide computing performance. Europe comes next (125 systems and 25,2% of the computing performance) followed by Asia (84 systems and 16,6% of the computing performance. The progression of China has been impressive: it more than doubled the number of installed systems (now 41, before 24), two of which are in the top10. (source: top500 Nov. 2010)

The need for coordination

In Europe, the HPC sector has been suffering from a fragmentation of efforts for the last decade in terms of:

- fragmentation of European investments amongst different ICT areas related to HPC (funding scattered among too many and too academic projects with insufficient long term market vision).
- insufficient coordination of European Union's investments with Member States's own investments in HPC.
- lack of cohesion at international level among country-led HPC initiatives as well as lack of cohesion among the involved parties — science community, industrial end users, hardware and software providers, infrastructure service providers and government bodies.
- fragmentation of know-how and low level of involvement of SMEs.

This vision paper acknowledges the need to overcome the current fragmentation of efforts. Moreover, it re-affirms the need to:

- coordinate efforts from private and public sectors at EU and national level;
- create a roadmap to tackle important strategic research goals;
- the development of interoperable components in HPC and the promotion of standards to that effect;
- foster a diversity of HPC systems' architecture;
- ensure that smaller and new Member states can be involved
- avoid control of the market by monopolistic vendors
- ensure a fair-play in partnerships in order to allow SMEs to co-exist with large corporations in the market (shared ownership of foreground, protection of background, etc).

To compete in the HPC race

Europe is a recognised world-player in embedded systems and communications technology. However, Europe has now been absent from the compute race for more than a decade (see also side note). This is demonstrated by the lack in Europe, at present, of manufacturers of microprocessors for HPC

However, Europe still has leading roles in various fields of HPC applications (examples ??). In addition to this, Europe joined recently the race to turn the Internet into one vast distributed computing and data management resource. This is now an initiative recognised worldwide and has been recently institutionalised via the creation of an organisation, the European Grid

Initiative (EGI), with its seat in Amsterdam.

Likewise, Europe has successfully combined leading national and regional HPC systems in a distributed HPC environment, which led to the creation of an organisation, the Partnership for Advanced Computing in Europe (PRACE). PRACE provides high-end HPC services to European researchers from private and public sectors. Furthermore, PRACE was established to offer a variety of HPC services for world-class researchers by operating several supercomputing systems of highest performance level.

Both of these initiatives[5] contribute now with adequate HPC infrastructure and services to international research centres (e.g. CERN[6], ECMWF[7]) and collaborate with private sector firms that supply HPC technology and services.

What will be, thus, the window of opportunity for a return to the HPC market in Europe?

Today, the general trend in HPC hardware development is to use commodity components to build massively parallel systems in order to achieve maximum computing performance at minimum costs. Since energy is a major constraint for future multi-peta to exa-scale systems there is a big opportunity for Europe to come up with a novel, highly energy efficient, HPC system architecture leveraging its outstanding expertise in embedded systems design.

Another key area is software developments at system, middleware and application level. It is high time to start to (i) promote good practices in programming for HPC and (ii) to promote standards that enable applications to be developed with as much independence of hardware as possible[8]. To meet the diversity of parallel structures of different codes, it is necessary and unavoidable that a variety of HPC architectures be developed and provided.

In software terms, a new programming paradigm is required to exploit parallelism approaching millions of processors. This will start a new episode in the history of HPC because, in order to obtain faster and faster computing speeds by increasing the density of the number of cores per computing unit (processor), a balance needs to be achieved in terms of the density of the cores and the sustained performance that can be reached by applications. Europe can definitely play a major role here and, to prove this, a collection of success stories in hardware and software developments on HPC in Europe can be found in Appendix 3 .

To leverage from current public investments

The establishment of the partnership PRACE means that European member states are pulling together financial resources to provide the most advanced

[5] The projects EGEE (predecessor of EGI) and DEISA (predecessor of PRACE) are important examples of successful ventures in advanced computing in Europe.

[6] CERN is the European Organization for Nuclear Research.

[7] ECMWF is the European Centre for Medium Weather Forecasts.

[8] Compiler, optimisation tools and adapted parallel libraries would then be used to exploit the characteristics of specific hardware architectures.

systems and technology to European researchers. A concerted public and private effort is there to create the means for:

- Vendors of HPC systems, technology and software to match the needs of demanding customers.
- Customers from science and industry to be able to acquire the HPC solutions that suit them the most and have a means to influence the HPC solutions made available in the market.
- Companies focussed on HPC systems and technologies in Europe to increase their own stake in the market.

Currently, the situation in Europe is such that, with some exceptions, customers hardly influence the solutions that are on offer in the high-end HPC market. This would be particularly pertinent for publicly supported research centres some of which collaborate with international firms on the design and testing of HPC technology.
In this respect, the use of pre-commercial procurement[9] opens new options. Pre-commercial procurement is defined as the European public procurement for research and development *services*. The pre-commercial procurement phase opens the possibility for European actors to come forward (e.g. in partnerships) and be able to compete on an equal basis with their international peers in a subsequent public procurement phase.

This is the moment for consolidating efforts

The Exa-scale challenge has been recognised to require efforts that no country, acting alone, can face: an international engagement is required to join efforts in a worldwide collaboration and reach Exaflops computing speeds by 2018-20!

This is an opportunity for HPC companies in Europe, which are or were associated to HPC, to network and create the most suitable partnerships to solve common objectives and goals. Such private-public partnerships, being composed of a mix of academic, research centres, HPC suppliers and industrial users constitute the basis through which sucessfull partnerships can start to take shape.

Private-public partnerships are being formed already right now. However, they do not have a focussed and concerted target and are driven mostly by the agenda of corporate suppliers of computing systems and its components. There is limited space for SMEs to participate in this state of affairs.

The situation is to be reversed if both public and private funding is invested in a strategic research agenda that is open to the participation of all players with a stake in the HPC domain on a large scale, that is, not just in the domain of HPC systems but also of all related technologies and products, such as energy supply, cooling and packaging,

[9] The European Commission adopted at the end of 2007, a communication on pre-commercial procurement [COM(2007)799 and accompanying staff working document SEC(2007) 1668] which is defined therein as a procurement of research and development services which is exempted from the provisions of the public procurement directives and does not constitute State Aid (see more on this at cordis.europa.eu/fp7/ict/pcp).

visualisation, data management, just to mention a few.

The HPC market, being a specialised market, does not thrive without strong collaborations between risk-taking vendors and potential customers (public and private) that are competent in the use of the technology.

Due to the recent increase in the number and variety of processors and system architectures available on the market, the challenge of programming applications that efficiently exploit the available computing performance has become a daunting task.

At the moment, it is clear that a drastic reduction in energy consumption per processor must be achieved. These developments can only become a reality if a healthy collaboration exists amongst the suppliers of hardware, software and services and potential users (universities, dedicated HPC research centres and industry's research laboratories).

The European HPC vision for 2020 presented next chapter is broad and comprehensive. It seeks to bind and coordinate the efforts of key HPC actors in Europe towards a strategy for innovation and excellence that can effectively address present and future computational challenges. It can only be achieved if the vision is shared and put to action by all. The rewards are for the next generation: a strategic tool for innovation in Science and Engineering and a key resource for informed decision making on societal challenges.

Our vision for High Performance Computing in Europe in 2020

This chapter will present the vision for HPC technologies in Europe for 2020 and beyond. It is based on the need for mastering computational technology of world-class standard in a period of dramatic transformations both in computing hardware and software (exhausted CMOS performances, new computing paradigms for transparent and reliable use of underlying technology, etc). It should, thus, be understood neither as a promise nor as a science fiction story. We cannot simply visualise today what will be the technologies available in such a fast developing area but we know that we might lose our competitive position if we remain as mere spectators and consumers of key technology that we do not master ourselves.

The vision for High Performance Computing (HPC) in Europe in 2020 can be summarised as follows:

- *Europe will be a global leader in inventions that successfully exploit HPC resources.*
- *HPC will provide increasingly accurate and responsive predictions on both short and long-term phenomena that impact European citizens, such as weather, climate change, and epidemics.*
- *The use of HPC will enable Europe to achieve world-leading levels of energy-efficiency in areas such as electricity generation and transmission, transport, food supply chain, water supply, product design etc.*
- *HPC technologies designed in Europe will lead in energy-efficiency.*
- *Europe will have the know-how and skills to master the development of HPC technology components in the areas where it excels, and to master the exploitation of HPC across a wide range of industries and disciplines.*

A tool for Innovation in Science and Engineering

- *Europe will be a global leader in inventions that successfully exploit HPC resources.*

The EU's new strategy for sustainable growth and jobs, called *'Europe 2020'*[10], urges the different Member States and the European Commission to re-focus Research and Development (RTD) on the challenges facing our society, such as climate change, energy and resource provision, health and demographic change, ageing population and economic and civilised development.

Moreover, Europe 2020 aims to achieve the target of investing 3% of GDP in RTD (already stated in the Lisbon agenda), in particular, by improving the conditions for RTD investment by the private sector, and by developing a new indicator to track innovation.

HPC technology is a tool that has been proven to facilitate the progress of scientific research and to enable industry to produce innovative products. All of this thanks to the use of simulation and virtual models to mirror realities that are difficult to experiment physically or to reduce production costs due to extensive prototyping in the design phase of a new product.

Historically, it has been observed that top-level HPC solutions have become an integral part of novel commodity PC products roughly five years after its appearance in the HPC market. Research and development on HPC constitutes, thus, an incubator of novel ideas for computing technology and associated applications that can be at the origin of a patent, an innovative product or an increase in the efficiency of an industrial process.

We will endeavour to make the following goals become a reality:

In 2020, it can be demonstrated that HPC has been an active catalyser of innovation in the European Union via the establishment of suitable partnerships between Industry and Academy and a focussed staff training programme. The set of metrics proposed in Table 2 enables to assess the impact of HPC on European competitiveness. Amongst these metrics, the number of filled patents and acknowledged inventions resulting from partnerships in Europe around the HPC theme and using HPC technology shows a visible increase.

In 2020, it can be demonstrated that European researchers represent 50% of the worldwide publications ranked according to the h-index for scientific publications. Europe has also been able to attract and maintain the best

[10] See for more details http://ec.europa.eu/europe2020/index_en.htm

scientists worldwide as attested by the percentage of European research cited in the global top 10 h-index country ranking.

A resource for informed decision making on societal challenges

- *HPC will provide increasingly accurate and responsive predictions on both short and long-term phenomena that impact European citizens, such as weather, climate change, and epidemics.*

Natural catastrophes have human and economic impacts as attested by the effects of earthquakes (and associated tsunamis) on critical infrastructure. In particular, nuclear disasters (radioactive pollution or failures in nuclear power plants) are disastrous episodes with huge human and environmental damages. Other important sources of dramatic disasters are, for instance, man-caused catastrophes like mass panic in stadiums .

In the presence of such scenarios, civil protection acts based on carefully planned rescue procedures. The rescue takes into account the predictions of the evolution in time of a specific disaster. Such predictions are often based on sophisticated models of the possible evolution of the disaster translated to computer simulations. The accuracy of the calculated results increases with the available computing performance, assuming the simulation is based on a well calibrated and validated model.

HPC tools, because of the powerful computing power on offer, can make a crucial difference on the *quality* of the predictions obtained and on the *speed* at which the calculations are made. The speed factor is a particularly important factor if human lives are at stake.

In the future, HPC-based planning, decision-making and rescue systems will become the standard tool in managing the dynamics of large crowds. This is already the case with the extensive use of HPC simulation as an essential tool in nuclear waste management. Because the safe disposal of nuclear waste needs to cover thousands of years, physical tests are as effective as digital models simulating the physical experiment. Moreover, physical tests are associated to a certain percentage of risk for life in the planet whereas simulations done in HPC systems are innocuous.

HPC can also become an essential tool in the medical field as a means to analyse the effects of a drug in a patient with specific clinical data or to choose the adequate plan of action before engaging in a chirurgical intervention (personalised medicine).

For all the above user scenarios, HPC is both the powerful and handy tool to be mastered and applied. This vision paper will foresee the following:

In the near future, the simulation codes that are essential to make informed decisions on societal challenges will be identified and partnerships will be established to further enhance and maintain the performance of such codes with a special care on the validity of the results.

In the near future, carefully parameterised and validated simulation models will exist for civil protection actions or for managing critical infrastructure with an impact on human society or on the vitality of the planet as a whole.

In 2020, if not before, the access to high-end public HPC infrastructure is granted at a government's request for using HPC resources at full capability. Simulations will be performed to obtain results that will help governments to make informed decisions in domains such as health, water and food supply, biodiversity and energy provisioning, transport, demographic and climatic challenges.

In 2020, HPC will be considered as a strategic resource and, therefore, Europe will deploy the necessary investments to ensure that it has set in place suitable competence and resources to provide independent access to this technology if need be.

In 2020, HPC systems and technologies designed in Europe are amongst the awarded bidders in the open phase of public procurement processes and are dominating a large spectrum of the HPC systems acquired by the public and private sectors. Protectionist market attitudes will be deferred in favour of (i) competence and know-how to master the use of the technology and (ii) competitive HPC systems and products.

A tool for competitive advantage of European economic sectors

- *The use of HPC will enable Europe to achieve world-leading levels of energy-efficiency in areas such as electricity generation and transmission, transport, food supply chain, water supply, product design etc.*

In Europe, best-in-class companies in the aeronautics, automotive, maritime, oil and gas, pharmaceutical, bio-technology, finance, amongst others, are competent users of HPC. However, for many other European companies, obstacles in the structure of the application codes prevent them from exploiting effectively the benefits of simulation in HPC computing platforms.

For companies that are still in the process of exploiting HPC technologies, a 'passerelle' to proficient use needs to be established; it encompasses the access to resources and expertise in the required application field. A starting point could be to stimulate the creation of successful partnerships between PRACE members and the first 10 European companies in the ranking of socially responsible companies[11]. Such partnerships aim to improve the performance of their favourite simulation code by a factor of 1000 to make it suitable to exploit currently available peta-flopic HPC computing architectures. Next to this, a training plan must be devised that enables SMEs and companies to use HPC technology in the best way to improve their business.

With this experience in mind, a suitable programme providing grants for access to HPC resources and programming support to society-minded, innovative projects coming from SMEs and other private sector firms would be put in place. The programme fosters, in particular, to support companies that put the highest priority on efficient use of energy resources in their product portfolio and on minimising their footprint in terms of environmental pollution.

In 2020, a suitable and well-tested legal framework exists and enables companies that are HPC users to engage in short-, medium- or long-term collaboration with research centres and academia on HPC R&D projects. The legal framework promotes robustness, flexibility and protection of the owner's Intellectual

Goals
for companies that are HPC users

To establish a focussed training plan on the real needs of companies that would like to use HPC technology but lack the expertise to do so.

To create in Europe an INCITE-like Programme. Such Programme grants companies located in the European Union access to computer time and code support services in HPC platforms (e.g. PRACE Tier-0 and Tier-1 systems).

Create the most suitable legal framework for EU firms to engage in short-, medium- or long-term collaborations with Research Centres and Academia for research and development purposes.

[11] For more on this consult the Ethibel Sustainability Index at www.ethibel.org

Property Rights.

In 2020, world-class EU firms and emergent SMEs have access to HPC infrastructure and support for the improvement of simulation codes' performance thanks to a European INCITE-like program. This enabled companies that did not invest in internal HPC resources or that did not see the need for doing so to have a 'taste' of the possibilities of HPC tools and services and to consider using it in a production environment.

In 2020, a 10% increase of the total market share in European key sectors such as software applications, biotechnology, automotive and aeronautics will be observed.

In 2020, an average of 5 new products or new tuned services will be on offer for each 10 private-public partnerships set off to exploit HPC in a specific market sector.

Branding HPC technology designed in Europe

- *HPC technologies designed in Europe will lead in energy efficiency.*

To date, HPC centres from the private and public sectors procured and financed their own HPC solutions with higher or lower insights on the potential of the acquired HPC solution. The need for combining efforts in terms of sharing expertise, promoting a particular product line development, seek out to establish standards for tools and services specific to HPC, etc, where given lower priority compared to other priorities.

However, with the cost of powering HPC systems increasing over time and the common practice to build systems based on commodity components, which might not be the most energy efficient solutions for HPC, the optimisation of energy consumption became a priority for both manufacturers and end users (see as a proof of this the launch of the Green500[12] ranking).

Europeans value energy cost-efficiency as one of the major requirements in their procurement for new HPC systems and are already forming private-public partnerships with vendors to obtain the most suitable systems that fulfil their requirements. The support given by public and private funds to suitably focussed research and development activities enables Europe to feature, **in 2020**, the highest delivered computing performance per unit of energy amongst peers according to the top500.

In addition to this, **in 2020**, a suitable ranking based on metrics to evaluate the real performance of a system as opposed to the Linpack performance, will be in place. It enables to rank HPC technology designed in Europe amongst the 10 best performing HPC systems.

Other suitable initiatives that will be key to achieve this are the following:

1. To make European consumer's aware of 'Who is Who' in Europe in the HPC market.
2. To inform European consumers on 'What' is HPC and the difference between capacity and capability computing modes.
3. To collect European consumer's feedback on HPC use in order to assess user requirements for HPC.

All the above stated initiatives seek to influence the HPC solutions put on the market and to give European HPC consumers the power they need in order to get the best out of the HPC solutions that they are interested to exploit. This would, in turn, give higher trust on HPC capabilities to users

Goals

For HPC systems & technology providers

To edit a compendium of 'Who is Who' in Europe in HPC that lists the firms that provide HPC technology, systems or services both from a consumer and a provider's point of view. The compendium should classify the companies according to economic parameters and be updated every 2-5 years for a proper analysis of the market evolution.

To create a virtual Centre of Competence on HPC systems, tools or services whose role is to:

- Orientate procurers of HPC systems to best-practice solutions to specific problems;
- Put consumers in contact with expertise;
- To provide recipes for use cases of HPC technology.

[12] See at www.green500.org the ranking of the world's most energy-efficient supercomputers.

which still hesitate in the adoption of HPC for their specific business practices and would start to create the specificities of the European HPC market.

Thanks to all this, and **from 2020**, we can see a steady increase of the number of jobs offers in Europe related to computational science expertise. With the expansion of the job market for HPC professionals, tuned education and training offers become available to train the next generation of HPC professionals.

Furthermore, **from 2020 if not before**, the percentage of the European Union's GDP contributed by the HPC and associated industries will be accounted for and a smooth but steady increase starts to be demonstrated.

Identifying the key HPC technology components where Europe excels

- *Europe will have the know-how and skills to master the development of HPC technology components in the areas where it excels, and to master the exploitation of HPC across a wide range of industries and disciplines.*

In 2020, Europe understood that innovation needs to go hand-in-hand with a commitment to quality; the consumer's culture in Europe changed to become a more environmental friendly consumer society and it is now commonplace to accept that it is not because a product is innovative that the consumer needs to buy it! There needs to be the assurance that it offers a better quality expressed by its price/performance ratio where price includes also the associated energetic and environmental impact costs.

In 2020, there is a focussed public policy in Europe and the Member States to promote HPC use in Science and Engineering to guarantee innovation in markets, excellence of European ICT professionals and quality of European branded products.

In 2020, the key technology components of HPC systems (software and hardware) where Europe excels have been identified and the supply and demand chain for these components will be carefully analysed in view of a clear competitive role in the worldwide HPC market.

Table 2: Success metrics on targets set for 2020

Objective	Indicator	Today	2020
Industrial competitive advantage due to HPC	% of the total market share in key sectors (e.g. software applications, biotechnology, automotive and aeronautics)	Substantial	10% increase per market sector
Job creation	Number of jobs created in Europe due to HPC	Small	Significative increase
Innovation via HPC	1/ Number of EU inventions and patents 2/ Number of breakthrough innovations	1/ To be asserted 2/ To be asserted	1/ Average of 1 in 200 patents per year 2/ Average of 2 every 5 years
Cooperation between academia and industry on HPC	Number of market products/solutions from projects involving industry and academia (due to HPC)	Small	Average of 1 products/solutions per 5 partnerships
The quality and results of research	Combined European h-index[13] among top 100 publications ranked according to h-index	33%[14]	Significative increase
Attracting best scientists	% of European research in global top 10 h-index country ranking	50%	Increase or, at least, keep same percentage
Independence in the provision of a strategic resource (HPC)	Increase the share of worldwide economic value of HPC systems located in and outside the EU with participation from EU both in hardware and in software (R&D, IPR, Partnerships)	Small in hardware; medium in software	Significative increase both in hardware and in software
The contribution of HPC industry towards GDP	% of EU's GDP contributed by HPC industry	Unknown	0,5-1%
Energy efficiency of HPC technology designed in Europe	Delivered computing performance per unit of energy	To be asserted	Amongst top 5 of the worldwide ranking
Codes suitable for risk management	Number of codes certified (per year)	To be asserted	Significative increase

[13] The *h*-index or *Hirsch* index attempts to measure both the productivity and impact of the published work of a scientist or scholar (see more at en.wikipedia.org/wiki/H-index.

[14] See also www.scimagojr.com

Identifying a strategic research agenda

The research agenda must have in mind the vision for 2020 and the goals identified. It is not the purpose of this document to define a detailed research agenda since the agenda will evolve with the time and the priorities to concentrate on either large or small programmes in a few key areas capable of maintaining the interest of all actors and access for small companies.

Table 3 groups some of the main themes under 7 main categories. This is not an exhaustive list of the issues but intends to provide a first impression of the research challenges ahead. The HPC market is itself a demanding market for specific technologies and services and, those that are deemed essential must be included also in the HPC strategic agenda. We are thinking here about issues such as custom-tailored middleware for visualisation and storage, power supply, on-site assembly and cabling, service scheduling, just to mention a few.

Table 3: Research Challenges (examples)

Power and cooling	Memory and Storage	Concurrency and Locality	Resiliency and Fault Tolerance	Programmability and Application scaling	Parallel File Systems	Silicon optics
Low-energy consumption HPC architectures using indigenous European components	Low-power memory technologies, such as non-volatile storage (Flash, PCM)	Programming languages and tools for concurrent programming mode		Development of *latency* tolerant programming models to cope with the latency of non-volatile memories	File access with end-to-end data security	Optical interconnects for extreme fast transmission of data
Performance analysis tools to improve the efficiency on the use of resources	Novel memory and storage solutions	New algorithms for upscaling applications to peta-scale performance	Adapting applications and algorithms for dynamic load balancing in case of failures	Parallel programming models for code portability across multiple heterogeneous architectures (e.g. GPU, FPGA)	Highly scalable parallel file systems	
		Highly scalable numerical algorithms and libraries	Architectures and runtime systems for detection of failures and automatic re-execution of code in case of failure	Novel algorithms for execution on architectures featuring accelerators, (task decoupling, etc.)		

The way forward: Creating Partnerships for Research and Innovation

The vision paper calls for a coordination of private and public efforts towards common aims and goals. The current fragmentation of competences across Europe constitutes an asset to embrace the challenge of promoting HPC technology as the enabling technology for innovation in Europe. However, a coordinating initiative is required to make sure that the HPC demand requirements are met by the offers available in the market. First and foremost, a detailed roadmap for research and technological development (RTD) is required to make this vision a reality. The spontaneous creation of private-public partnerships in the context of the RTD programmes constitutes the building blocks for the emergence of a truly European landscape in the HPC domain.

The role of private-public partnerships

Global trends show that progress in HPC requires concentration of efforts since a critical mass of resources is required in order to ascertain progress. National support programmes play a major role in other regions' success in the HPC area. Europe will not be an exception to this rule. This is because pure market forces will not enable the market for this technology to strive in Europe since, at present, a well established number of global players exist already in the US and other countries.

Europe has the competence and expertise to be amongst the best players in the HPC market and the absence of monopolies amongst vendors enables the current players to engage in collaborations that are purpose driven and enable each to maintain its independent role in the market with strong trust from their own customer base. In addition to this, private-public partnerships will enable the development of local HPC competencies in the areas in which Europe lacks leading expertise and in which Europe can achieve a leading position.

Europe requires investment in research and development to achieve a leading position in the mastering of HPC technology itself. Private-public partnerships will facilitate the creation of successful initiatives in this area by:

- Allowing industry to directly influence research priorities in the market areas with the most competitive relevance,
- Addressing the issue of the fragmentation of the European HPC industry and research base by providing a forum for collaborative research projects,
- Stimulating the growth of the European HPC value chain,

- Defining the technological barriers to the exploitation of the technology for innovation purposes.

Essentials to succeed

The creation of successful private-public partnerships in HPC will be both an interesting and challenging undertaking. In order to secure a maximum of chances to succeed in triggering successful partnerships, the unique features of HPC technology and its market need to be highlighted. These are:

Its International dimension: potential collaboration partners might be at the same time market competitors. We believe that a positive, collaborative approach that allows companies to choose with whom to partner with is a key to the success of this vision rather than the approach of framing collaborations to within European Union borders. However, fairness is a must and collaboration agreements need to contemplate the European added-value and the interest of public entities in engaging in collaborations with private ones whether they are established in Europe or abroad.

Scientists meet Technologists: in order to have the expertise to use simulation, the user needs to have a precise, accurate and well calibrated model of the problem at stake. A multi-disciplinary team of technologists, scientists and mathematicians is required to build such models. Each of these disciplines tend to work separately and only a few teams in the world are able to transpose the know-how of different domains into the task of creating applications for simulating the complexity of the challenge at stake. In Europe, we can be proud of our proficiency in this field and this is important in order to be able to exchange know-how between academia and industry.

Transfer to mass market: the technologies that are searched for in HPC are such that a fast transfer to the ICT mass market cannot be expected to occur immediately – but is definitely not to be excluded – given the technological advances in HPC compared with those available in today's ICT products. However, the transfer of HPC know-how to the mass market is, in one way or another, a must for all the HPC manufacturers. Most of the high-end HPC systems available in the market today would not have been produced if their components or the know-how obtained in assembling them would not be transferrable to other business strategies within the same company.

Essentials for successful partnerships

In order to establish strong and active collaborations between consumers and vendors both sides need to be able to account for the benefits obtained in the collaboration compared with pure market surveillance exercises.

If we look at the collaborations focussed on the high-end HPC systems, supercomputing centres from both private (usually large corporate industry) and public entities have an interest in collaborating with vendors because it gives them the insight on the potentialities of the system on offer and, therefore, enables them to have the know-how on how to bring the applications to the best level to exploit the computing performance soon to be available. Moreover, the computational sciences expertise found in research alliances between HPC centres and nearby universities helps both parties to surmount any lack of expertise when engaging in collaboration with HPC vendors.

Vendors of high-end HPC systems have an interest in engaging in collaborations with potential users since the know-how acquired can be exploited both in the supercomputing market and in the commodity mass market with innovative technologies tuned to the requirements of demanding users. Such users tend to be the most competent technology experts available in the market and human resources are a scarce resource in the HPC domain.

A significant part of the HPC systems available on the market is composed of systems owned by companies that use applications licensed by Independent Software Vendors (ISV). Such codes have a higher or lower scalability level to highly parallelised computers and are often licensed from third parties. It is an important market sector and private-public partnerships would help with improving the scalability of codes to exploit the computing performance available. Issues such as visualisation and pre-processing of data are also important services to promote the attractiveness of HPC to such users. However, prior to promoting partnerships involving ISVs, a focussed training programme is required to bring ISVs to the level required to exploit parallel computing architectures with a higher or lower degree of homogeneity.

Bearing the risk of failures

The risk of a product failure inherent in building computing architectures at the boundaries of what is technologically possible has been up to now supported by public funds (civil and defence) for research and technological development. Some European Member States have been more committed than others to support research associated to HPC. It is, therefore, very important that the funding organisations (national research councils, private foundations, the European Framework Programme for Research and Technological Development) take part in the initiative to define the strategic definition of priorities for the research agenda on HPC in Europe. Without this support, the commitment of private companies to long term goals cannot be sustained.

The pathways to design focussed strategic research agendas requires a regular dialogue between HPC actors from public and private sectors at the highest political levels both in Member States and the European Union. The research agendas are to be adopted every two years and are composed of a work programme and a coherent and coordinated approach to optimising research efforts.

To this effect, the Advisory Council for HPC technologies in Europe (EAC-HPC) will be the body that will approve the Strategic Research Agenda and endeavour to make it a reality. The Council is made up of representatives from the following types of actors:

- HPC hardware and software vendors
- HPC centres (private and public)
- Academia
- Member States (observer role)
- European Commission (observer role).

There is a high expectation that the participation to the Advisory Council is a commitment of all stakeholders to plan for the participation in the research programmes in alignment with the strategies fixed in the research agenda. The participation to the Advisory Council enables funding authorities to better articulate support to research in HPC at the national and European levels.

The Advisory Council is to become the body that promotes educational policies and the creation of standards and protocols needed to ensure that talent and competence in HPC are available to the industry and research community. In particular, the dialogue ought to cover the relations between civil and defence funds for research in the field and the protocols and framework required to orchestrate in the most harmonious way these two types of funding.

Recommendations

Maintain consensus amongst stakeholders based on the goals identified in this vision document and an assessment of the financial and in-kind commitment to implement strategic priorities.

Optimise access to existing computing and research facilities for prototyping and testing.

Ensure both excellence in RTD and a broad base of applications of HPC worldwide.

Foster synergies between civil and defence sectors. Both sectors share many of the technology needs and the gains obtained by bringing the two together can be of competitive advantage for Europe.

Create new synergies between EU, national and regional research programmes. The duplication of research efforts needs to be minimised whilst fostering a healthy degree of competition between funding agencies.

Give education a high priority to ensure long-term supply of first-class, well-trained staff in HPC technologies and simulation code development.

Financing the vision

The gradual realisation of our ambitious vision must be facilitated by an increase in both public and private investments. The current European and national public investments in HPC research infrastructure are to be complemented by a significant participation to the costs to support RTD on HPC technology in Europe in order to achieve the objective of this vision: HPC technology is to be seen as the enabling technology for innovation in Europe by 2020!

Although it is a preliminary estimate, total funding required from public (European Union, Member States and Associated States to the Framework Programme) and private investors (foundations, HPC vendors, HPC corporate users) over the next 20 years could go beyond 12 billion Euros. This financial envelope is based on the estimation that, in addition to the current investments, 600 million Euros are gradually made available per year in the first 5 years with a moderated increase of 10% per year after this initial 5-year period.

Defining initial milestones

> *Europe needs to think strategically on HPC* systems and technologies; the Advisory Council for HPC technologies in Europe (EAC-HPC) is to start working in the fall of 2011 and to deliver a Strategic Roadmap by early 2012.

> *The European Union, private companies and Member States are the main sponsors of the strategy.* Financial engineering and securing resources should be concluded by 2013 (end of the current Framework Programme 7).

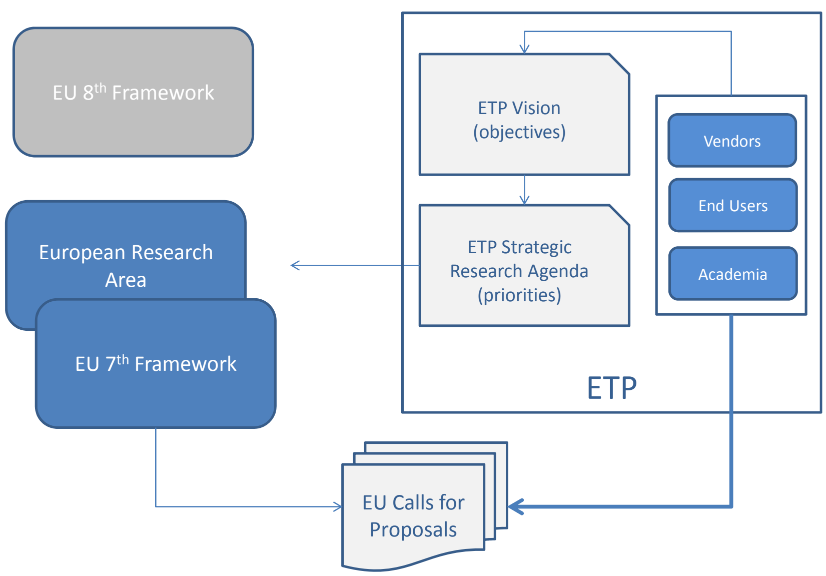

Figure 4: Modus-operandis of the European Technology Platform on HPC.

Summary

In Europe, HPC vendors, research organisations and end-users are based in various countries with different levels of coordination. Similarly, research funding sources are distributed at regional, national and European levels. Therefore, the need for a co-ordination effort at the European level to define which are the research priorities in the HPC field and align them with industrial business strategies.

The research infrastructure on supercomputing, PRACE, integrates Europe´s tier-0 HPC centres. However, this is not complemented by a similar concept optimising the use of research funds. According to IDC, Europe is the world´s most open competitive market with a high level of regional independence [IDC2010]. In contrast, its competitors (US, Japan, China, Russia) are singular political and economic entities in which research priorities are dealt with at pan-state level.

We propose to establish a coordinating initiative on investments on research and technological development in HPC in Europe, implemented as a European Technology Platform (ETP), in which research priorities clearly reflect the priorities of market vendors and end users. An ETP would form a collaboration framework led by the industry and including infrastructure providers, end-users, research and development organisations as well as research funding entities. The ETP will coordinate efforts to attain the objectives stated in this vision document.

The Platform’s strategic objectives are as follows:

Research

- Let the industry lead the process of defining research priorities in order to maximise competitive gain for Europe.
- Propose work programmes that enable to direct funding into the areas with the highest market relevance.

Technology

- Focus on technological barriers that might hinder industry progress in the most competitive areas.
- Perform a gap analysis of market objectives, industry capacities and technological challenges.

The above should be achieved through a Strategic Research Document (SRA) with the aim of influencing the allocation of HPC research funds in Europe. The SRA will define research priorities for Europe´s HPC industry and it will facilitate the coordination of European, national and regional research programmes in order to increase the Return on Investment of the funds available.

Glossary

CMOS – Complementary Semi-Oxide Semiconductor

EAC-HPC – The Advisory Council for HPC technologies in Europe

EGI – European Grid Initiative

ERA – European Research Area

EU – The European Union

FPGA – Field Programmable Gate Array

GDP – Gross Domestic Product

GPU – Graphics Processing Unit

HPC – High Performance Computing

ICT – Information and Communication Technology

ISV – Independent Software Vendor

PCM – Phase Change Memory

PRACE – Partnership for Advanced Computing in Europe

RTD – Research and Technological Development

SME – Small and Medium Enterprise

US – The United States of America

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Appendix 1: HPC success stories in engineering

In Europe, the following are examples of innovative products that were conceived thanks to the use of HPC:

- Dassault Aviation (FR), specialised in the design of combat aircrafts and business jets, has developed the Falcon 7X entirely in a virtual environment. Dassault used product life cycle management software from Dassault Systèmes, a virtual product development software suite to develop the aircraft in terms of design, development, construction, assembly, system integration, test and maintenance. The design of Dassault Aviation products is nowadays fully done using HPC calculus.

- Automotive companies, such as Mercedes Benz and Volkswagen (DE) are increasingly turning to crash simulation software and HPC to figure out how to build safer cars.

- HPC and numerical simulation is recognised at Electricité de France (FR) as an indispensable tool. They are used in such important daily operational matters as such as optimising production schedules, choosing the safest and most effective configurations for nuclear refuelling. At EDF, HPC helps explain complex physical phenomena behind maintenance issues, assess the impact of potential modifications or new vendor technology and anticipate changes in operating or regulatory conditions.

- Repsol (ES), an oil&gas prospection company, uses HPC primarily for the processing of seismic data. Repsol uses a range of algorithms some of which are proprietary, for example Reverse Time Migration (RTM). Repsol chooses to use HPC and simulation because it estimates to be the only tool that enables large amounts of seismic data to be processed quickly. When prospecting for oil and gas, there is significant commercial advantage in knowing where the most promising fields are, given the highly competitive nature of the sector.

- ENI (IT), another oil&gas prospection company introduced HPC technologies for the processing of seismic data in its exploration activities in the late '90s. Currently, ENI runs in production mode a range of proprietary and third-party algorithms for seismic data analysis and the overall capacity of ENI HPC systems is of the order of tens of thousands of cores. HPC and simulation gives to ENI a competitive advantage in filed exploration combining fast processing of large amounts of seismic data with a high accuracy of the results obtained.

- In the chemistry sector, companies like Bayer or BASF (DE) exploit HPC capability on its research towards digitally designed chemicals.

Appendix 2: HPC success stories in research

The following are just some examples of advances in Research that were possible thanks to the use of simulations and access to European and nationally provided HPC infrastructure:

- the AQUILA project led by scientists from Durham University (UK), which brought together over 30 researchers from all over the world under the auspices of the Virgo Consortium for cosmological Simulations, has used HPC resources in Europe to simulate the formation of a realistic galaxy. The results of this project will represent the most complete and largest set of galaxy formation simulations ever performed.
- Researchers from the German Aerospace Centre (DLR) have done remarkable progress in the use of Computational Fluid Dynamics (CFD) for the design of new aircrafts by the European airframe industry, significantly reducing the reliance on wind-tunnel and flight tests. This trend has resulted in a progressive shift of CFD priorities from numeric to flow physics and, ultimately, to turbulence modelling. The current goal is to simulate full aircraft configurations with deployed flaps and landing gear.
- Bad cholesterol is a condition mainly affecting those in modern industrial countries. Using the HPC resources in Europe, the LIPOS research project explored the structure and functions of low density lipoproteins, whose excessive accumulation in coronary arteries can lead to the formation of cholesterol plaques. The LIPOS project has broken new ground in its field of science because the research method was unique and made possible thanks to the use of large computing resources.
- The SOLEX project carried out, on the DEISA infrastructure, investigations of the flows near the solar surface. The project began in September 2008, and was conducted by researchers from the Faculty of Mathematics at the University of Vienna (AT) and the Max Planck Institute for Astrophysics (DE). The significance of the SOLEX project lies in its uniqueness. The research group has inserted two features into the ANTARES code in order to maximize informational output for a given computational effort: high resolution numerical schemes and the option for grid refinement.
- The correct description of key biological processes such as protein folding is indispensible for the understanding of diseases like Alzheimer and Parkinson. Recent experimental results show unambiguously a new effect: at room conditions, excess protons are located close to hydrophobic surfaces in liquid mixtures, in contrast to intuitive considerations. Previous approaches to explain this behaviour seem to be inefficient. A group of researchers from the German Research School of Simulation Sciences (GRS) uses the Juelich supercomputing centre capabilities to perform ab initio molecular dynamics of an excess proton in the presence of a water/decane mixture as used experimentally. They want to calculate the free energy of the process using thermodynamic integration and determine at which distance from the surface it is most probable that the proton localizes. This will be a significant contribution on the path to fully understand protein folding.

- Biological enzymes are large molecules within cells that function as catalysts, speeding up the chemical reactions that make life itself possible. Understanding these, then, is crucial to a better comprehension of the bio-molecular world; however, until recently, the vast computational resources required to accurately simulate enzymes at a molecular level simply didn't exist. Seeking to exploit supercomputing resources, a team of researchers from the University of Bristol (UK) and the Wroclaw University of Technology (PL) set out to simulate the catalytic functions of one such enzyme in unprecedented detail.
- Investigating High Energy Physics with computational methods is very often the only possibility to guide complex experiments at large-scale accelerator facilities (like CERN's LHC) and to analyse their results. With rather time-consuming and sophisticated simulations it becomes possible to tackle the underlying theory of strong interactions, called quantum chromo dynamics (QCD). The simulations allow "to go back in time" to analyze the properties of strongly interacting matter under "extreme conditions". A collaboration of three renown European research groups (Bergische University of Wuppertal, Eötvös University Budapest and CNRS Marseille) published one of the ten 2008 SCIENCE journal breakthroughs and is leading in this domain. Their goal is to determine the equation of state of the QCD matter providing a self-consistent description of the "charmed particles" on sufficiently fine lattices.

Appendix 3: HPC success stories in Hardware and Software for HPC

Hardware	*Software*
The *QPACE* supercomputer, developed by a European consortium of universities and research centres led by the University of Regensburg together with the German IBM R&D Centre in Böblingen, is among the first 10 in the world's list of the most energy-efficient supercomputers. The technology concepts developed for the QPACE project are setting the trend for future high-performance computers. One example of this is the new cooling concept developed in the IBM R&D centre in Böblingen, which can contribute significantly to the energy efficiency of future HPC installations.	*StarSs* developed by the Barcelona Supercomputing Centre is a programming model with important characteristics such as the support of incremental parallelization, automatic overlap between computation and communication and load balancing.
The *Loewe-CSC Cluster* recently installed at the Goethe University of Frankfurt also ranking ranks amongst the world´s first ten energy efficient supercomputers). It is the first supercomputer architecture targeting a performance ratio of less than 500 kW for 285 teraflops (including cooling) due to a reduction of cooling requirements down to 10% of the computer´s power.	*Scalasca* developed by the Juelich Supercomputing Centre and *Vampir* developed by University of Dresden are performance analysis tools that became worldwide leaders in terms of their scalability to hundreds of thousands of processors.
	Paraver/Dimemas developed by the Barcelona Supercomputing Centre is another performance analysis tool highly regarded by the HPC programming community. The tool provides extremely detailed metrics and predictions of the evolution of the computing performance of application codes; this helps the programmer to identify which code optimization efforts will be the most productive.

Appendix 4: Analysis of the competitiveness of Europe's HPC market

	Positive Impact	Negative Impact
	Strengths	**Weaknesses**
Internal	• Leadership in industrial and research areas such as weather and climate research, clean and sustainable energy, automotive and aerospace design engineering, bio-life sciences, particle physics, cloud computing, molecular dynamics/modelling the properties of materials, exa-scale applications across a wide spectrum of disciplines. • A world-class scientific and engineering community • Established processes of knowledge transfer to industry • Experienced and diverse ICT supplier base • HPC software expertise • Expertise in certain advanced technology areas (e.g. embedded systems, communication technology) • Strong Small and Medium Business (SMB) sector • Success of a number of cross-regional industrial programmes (e.g. Airbus) • Strong semi-conductor industry (e.g. STMicroelectronics (Holland), Philips Semiconductors (Holland), Infineon (Germany)	• Under-investment in HPC (while other regions are ramping up) • European scientists consider European research programmes uncompetitive in comparison with those of other regions • Limited internal market size might hinder HPC growth unless the industry is competitive globally • Shortage of qualified HPC job candidates • Financial crisis in some of Europe´s economies might affect the availability of research and development funds • Lack of European companies among world-wide HPC manufactures • Lack of next generation HPC scientists
	Opportunities	**Threats**
External	• HPC solutions have the potential to strengthen Europe´s most competitive industries (example above) • The shift to exa-scale HPC computing will require new technologies • Software applications will need to be rewritten in order to meet HPC requirements • Deployment of significant funds within the EU aimed at facilitating HPC infrastructure (circa Euro 400 million between 2010 and 2014) • Revenue growth rate for the non-computer categories has been, and is projected to remain, higher than for the HPC systems. Storage in particular has been growing at a pace several percentage points higher than HPC systems, owing to the "data explosion" associated with running increasingly large, complex HPC problems and workloads [source: IDC].	• Players from other economic regions such as America and Asia are quite advanced in developing HPC technology. • Lack of strong local HPC know how and skills creates a dependence on HPC technology providers from other economic regions. • Technological barriers (Highly parallel programming and the need to rewrite applications, HPC system imbalance and the "memory wall", energy efficiency and availability, fault tolerance and resilience, storage and data)