SPECIAL STUDY

A Strategic Agenda for European Leadership in Supercomputing: HPC 2020 — IDC Final Report of the HPC Study for the DG Information Society of the European Commission

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IDC OPINION

This is the Strategic Agenda Report (Deliverable D3) of the study "Development of a Supercomputing Strategy in Europe" by IDC EMEA, the multinational market research and consulting company specialized in ICT markets, on behalf of DG Information Society and Media of the European Commission.

This report presents the results of WP3 — Strategic Agenda. The recommendations in this report are by IDC. We thank the Technical Strategic Committee contributors for their ideas, insights, and suggestions that helped crystallize the findings in the report. External members included Hervé Mouren and Christian Saguez, Ter@tec; Richard Blake, STFC Daresbury Laboratory; Arndt Bode and Herbert Huber, Leibniz-Rechenzentrum/LRZ Munich; and Friedel Hossfeld, Forschungszentrum Jülich.

This plan suggests that the EU needs to create and implement a far-reaching vision for high-performance computing (HPC) leadership, and suggests that it be based on this vision: *Providing world-class HPC resources to make EU scientists, engineers, and analysts the most productive and innovative in the world in applying HPC to advance their research in the pursuit of scientific advancement and economic growth.*

The results of this plan could provide immense improvements to the EU by 2020:

- Europe would be recognized as the hotbed for new science and engineering research and innovation
- The plan would preserve existing jobs and create many new jobs in both science and industry, and cause national economies to grow faster

To succeed, it will require many investments, actions, and strong leadership, including implementation of these high-level actions:

- Expand the number, size, and access to HPC resources across the EU
- Create a set of HPC exascale development lab/testbed centers
- Attract more students into scientific, engineering, and HPC fields, and to attract more experts from around the world to join EU scientific collaborations
- Invest in developing next-generation exascale software
- Target a few strategic application areas for global leadership

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TABLE OF CONTENTS

P

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TABLE OF CONTENTS — Continued

P

TABLE OF CONTENTS — Continued

P

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LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

EU Challenges and the Need for a European HPC Strategy

The primary driving need for an enhanced high-performance computing (HPC) strategy is the immense returns possible to the EU, its researchers, and the population.

How many people know, for example, that HPC plays an integral part in designing the vehicles they drive and the airplanes they fly in, locating and extracting the fuel that powers these vehicles and heats their homes, developing life-saving new drugs and medical treatments, and producing the weather forecasts they rely on to plan for daily activities and severe weather that can devastate lives and property?

Recent worldwide studies by IDC have consistently shown that HPC has become indispensable for both scientific advancement and economic competiveness. It has proved to be a substantial multiplier of scientific and economic investments, a major productivity tool for researchers, and a critical asset for global competitiveness as it can often produce scientific and industrial solutions faster, less expensively, and with higher quality than traditional theory and experimentation alone. HPC is also valuable because it can help address "grand challenge" societal problems that are impractical or simply impossible to test (e.g., future climate changes, star formation) to evaluate with "live" physical experimentation.

HPC-based modeling and simulation in particular is becoming a necessity for competing with other advanced economies and is a powerful tool for competing with nations having lower labor costs, especially as labor and equipment costs for physical experimentation have skyrocketed in the past decade. That is why today major nations and global regions are vying for HPC leadership as a prerequisite for scientific and economic leadership.

High-performance computing is integrally linked to government policy in the U.S., Japan, Russia, and China, to name a few. Some EU Member States have clearly delineated national HPC policies. In all of these cases, policy action was needed to legitimize, prioritize, and drive HPC initiatives.

Europe has played an important role since HPC's beginnings and possesses a wealth of HPC-related experience and talent, but in recent years Europe has under-invested in HPC and is falling behind other regions of the world (see Table 1). The table shows that from 2007 to 2006, Europe has lost 10% market share in the worldwide HPC supercomputer market space, a very significant decline. In order to catch up and keep pace with competing nations and regions, Europe needs to both increase its HPC investments and find ways to apply HPC in a more productive and innovative manner.

TABLE 1

Worldwide HPC Supercomputer System Revenue (€000) by Region, 2005–2009

Data	2007	2008	2009
Total WW revenue	2,011,793	2,014,596	2,527,058
North America revenue	932,183	1,031,201	1,291,493
Europe revenue	692,038	592,535	627,732
European percentage of WW	34.4%	29.4%	24.8%
Asia/Pacific revenue	228,972	219,970	226,608
Japan revenue	122,733	137,872	348,448
Rest of world revenue	14,464	14,692	13,362

Source: IDC, 2010

The scale of these challenges requires HPC infrastructures which are beyond the resources available at the national or regional levels in Europe. They require collaboration which involves the very best scientific and technical expertise. The PRACE initiative (Partnership for Advanced Computing in Europe), which was launched in 2008, laid a sound foundation for the establishment and future development of world-class HPC infrastructures for European researchers in computational science and engineering.

By investing more heavily and in a smart way, the EU can use HPC as a primary tool for advancing science and getting EU economies back into a healthy growth mode.

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The Consequences of Not Taking Action at the EU Level in HPC

- Europe will lose ground as a scientific and research power house.
  - Europe could become inferior to the U.S. and Asia in science and become increasingly reliant on the U.S. and Asia for scientific, industrial, and technological advances. Table 1 shows that Europe has already fallen behind by 10 share points over the past two years.
  - Europe and the EU Member States could experience an escalating brain drain to the U.S. and Asia, along with great difficulty in attracting talented scientists and engineers.
- European economies will take much longer to recover from the current recession, and will find other nations taking economic value away from Europe.
  - The EU HPC supply chain will grow very slowly and more foreign companies will gain ground.

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  - Europe and the EU Member States could lose industrial competitiveness, innovation capabilities, and jobs.

- The smaller and less affluent EU Member States would lose the ability to access and benefit from large HPC systems. This would widen the digital divide in Europe, to the detriment of the smaller countries.

- Europe's existing strengths in hardware, software, and other HPC-related technologies could diminish or disappear from lack of advancement.

There Are Major Opportunities for Europe in HPC

The transition period from petascale to exascale computing is creating a major opportunity for HPC-related innovations and new software. The most important HPC-related opportunities for Europe include:

- Capture global leadership in scientific and industrial areas where Europe is already strong. In particular:

  - Weather and climate research, clean and sustainable energy, automotive and aerospace design engineering, bio-life sciences (e.g., creation of digital cells and organisms and the virtual physiome), particle physics, cloud computing, molecular dynamics/modeling of materials, and exascale applications across a wide spectrum of disciplines.

  - These are all scientifically and economically important areas in which Europe has substantial strengths today that provide the basis for pursuing global leadership by 2020.

- Pursue global leadership in key technologies as the HPC market undergoes the powerful shift to exascale computing speed. The increasing commoditization of highly parallel HPC hardware systems has greatly improved their price/performance while making them harder to use efficiently.

  - This has shifted the burden of innovation much more onto the software side.

  - Europe's considerable strengths in algorithm development, parallel programming, and domain applications, especially but by no means exclusively in the targeted leadership areas, creates the opportunity for Europe to pursue global leadership in sustained petascale and exascale computing on real-world applications.

- By rewriting important software applications, especially in the targeted leadership areas. IDC believes that in the next five years many HPC applications will need to be fundamentally rewritten so they can efficiently exploit HPC systems that will soon feature 1 million processor cores or more.

  - Europe's expertise in algorithm development and parallel programming, as mentioned in the preceding, closely related opportunity, will be enormously useful for this critical task.

  - At a minimum, Europe should pursue global leadership in rewriting software codes important for the targeted leadership areas.

- Another critical issue to tackle in order to seize these opportunities is the need for increased HPC training and education in exascale HPC. This encompasses multiple dimensions:

  - Initial and lifelong training in HPC-related technologies, providing a training testbed development environment/ecosystem, support to users for the efficient use of HPC resources, support to European industrial users and SMEs in the petascaling and exascaling of important applications.

A Vision for EU HPC Leadership by 2020

The HPC strategy recommended in this report is aimed at progressively realizing a distinct leadership for Europe by 2020. Over 200 HPC experts across the EU have provided ideas, insights, and suggestions in the creation of this report. The vision proceeds directly from Europe's unique circumstances and strengths in science, engineering, and technology — and from the ability of the EU Member States to join forces to accelerate Europe's scientific advancement and economic competitiveness.

The Proposed Vision Statement for EU HPC Leadership by 2020

> *Provide world-class HPC expertise and resources to make EU scientists, engineers, and analysts the most productive and innovative in the world in applying HPC to advance their research, in pursuit of scientific advancement and economic growth*

The vision includes these attributes:

- Delivering world-class research and innovation, and creating positive economic/societal impacts by exploiting computational science

- Developing leading-edge next-generation simulation software, libraries, and software that can efficiently and effectively exploit current and future HPC architectures — making EU researchers and businesses the most productive and innovative in the world

- Supporting the development of a sustainable/strategic supplier base for the supply of high end HPC components and systems integration capabilities

- Sustaining a world-class skills base through undergraduate, postgraduate, and professional development

Benefits From This Strategy by 2020

The benefits/returns for these investments will be substantial in many areas, including:

- Substantially contributing to the acceleration of economic growth in European economies by 2020 (adding as much as 2%–3% to Europe's GDP by 2020)

- Making the EU a hotbed for scientific and engineering research

- Further invigorating EU academic and research institutions by making EU researchers the most productive and innovative in the world

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- Expanding the HPC ecosystem across the EU and creating a vibrant HPC supplier economy

What the EU Could Accomplish by 2020 With This Strategy

By 2020, the EU HPC strategy has the potential to enable the following progress:

- Europe is recognized as a hotbed for new science and engineering research, especially in critical domains the HPC strategy has targeted for world leadership.
    - The continuing growth of Europe's scientific leadership, especially in the fields targeted by the strategy, has made Europe the primary source of theoretical and experimental advances in these fields.
        - More and more scientists migrate to Europe to advance their research and to participate in collaborations that require access to the world-leading HPC hardware/software resources and expertise that reside in Europe.
    - Scientists and engineers are moving to European countries in larger numbers than ever before. This is occurring especially in the fields the HPC strategy targeted for world leadership.
    - European universities are growing with EU and international students across all scientific domains, as people want to be part of the new renaissance in scientific discovery in the application of HPC modeling and simulation, the third pillar of science.
        - Europe's leadership has reversed the "brain drain" by attracting the top scientists/researchers from throughout the world, especially in the targeted fields.
- Europe's leadership in the targeted areas has created many new jobs in science and industry, and has caused the national economies to grow faster. Europe's move to the forefront of progress in other areas has also preserved many existing jobs in both science and industry.
    - Thanks to the expanded HPC strategy, Europe has benefitted from a substantial, sustainable net gain in job creation, employment, and improved economic competitiveness. The impact of the HPC strategy could be in billions of euros a year, potentially increasing Europe's GDP by 2%–3% in 2020.
    - Europe is the world leader in the scientific/industrial domains targeted for leadership: weather and climate research, clean and sustainable energy, automotive and aerospace design engineering, bio-life sciences (e.g., creation of digital cells and organisms and the virtual physiome), particle physics, cloud computing, molecular dynamics/modeling of materials, and exascale applications, across a wide spectrum of disciplines, such as astrophysics, quantum chemistry, nanoscience, advanced combustion modeling, weather and climate research, and aerospace design.

- European industry, benefitting from the scientific advances and from being able to solve challenging research problems on large EU HPC systems, leads the world in the targeted areas.
- Europe has at minimum kept pace with the rest of the world in scientific and industrial domains not explicitly targeted for global leadership. Europe continues to remain at the forefront of scientific and industrial progress across the full spectrum of scientific and engineering domains.

- Europe is the world leader in important HPC technologies, especially those designed to support the leadership areas. In particular, Europe leads the world in scalable algorithms and software applications in the targeted areas, and in tools to make HPC systems easy to use and to make researchers highly productive and innovative.
  - Europe has funded and operates two to three highly productive and innovative exascale-class supercomputers that are built to excel in a number of the key targeted leadership areas. Europe has funded and operates 10 to 20 other large supercomputers as well.
  - For cost-effectiveness, the supercomputers in Europe make maximum use of commodity components and systems that are widely available on the world market. European experts augment these components and systems with purpose-built technologies in order to meet Europe's unique requirements for world leadership in the targeted areas.
  - Europe partners with technology vendors based in Europe and elsewhere, as needed, to secure and sustain its hardware and software technology leadership, including the purpose-built technologies, on behalf of European science and industry.
  - Through advanced networking, Europe makes these unique supercomputing resources more widely and more easily available for European scientific and industrial research projects, and also for important, prestigious global collaborations.

Scientific productivity refers to the ability to provide scientific researchers with HPC resources that enable the researchers to accomplish more in a given timeframe. Increasing productivity is important because scientists are typically highly paid and in scarce supply.

Recommended Action Plan for HPC Leadership by 2020

Six major actions are required to achieve this plan:

1. First is the need for expanding the number, size, and access to HPC resources across the EU (including broader access to the tools by all EU researchers including those in industry). An expanded PRACE can address this requirement. Figure 1 shows the current mix of European supercomputer purchases by country.

2. Second is to provide peer-reviewed access to large supercomputers for industrial research projects.

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3. Third is to create a set of HPC exascale development lab/testbed centers (techno-pools) — a new type of productivity center — to make HPC users more productive and innovative by creating the world's best tools, training, and development environment. This requires a new initiative.

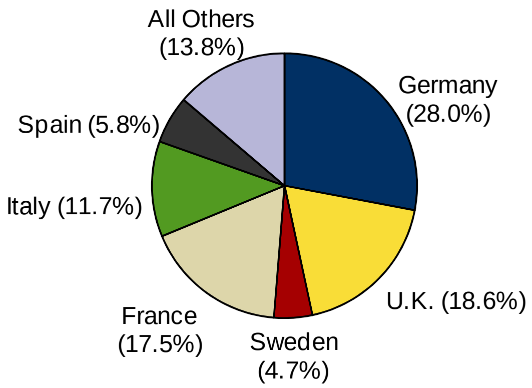
4. Fourth is to attract more students into scientific, engineering, and HPC fields and to attract more experts from around the world to join in EU projects. This requires additional funding and a new "magnet" program.

5. Fifth is the need to increase funding in developing next-generation exascale software and infrastructure.

6. Sixth is to target a few strategic application areas for global leadership.

FIGURE 1

EU Total High-End Supercomputer Revenue Mix by Country, 2009



Source: IDC, 2010

In addition, there are a number of core recommended implementation principles:

- Work to make HPC a higher priority on the EU's research agenda
- Expand PRACE to address a broader role in making HPC a powerful tool for EU researchers
- Expand HPC training with a focus on software usage
- Promote public-private partnerships to advance competitiveness
- Support for industrial initiatives and expanded use of HPC resources by both science and industry
- Support grid and cloud computing initiatives to support extended collaborations

- Buy rather than develop new exotic custom exascale supercomputers. Develop standards based high end HPC systems and supporting components.

- Establish clear roles and responsibilities between the EU and Member States

All of the above actions support the goal of making Europe the strongest in applying HPC tools for advancing science, engineering, and analysis in pursuit of scientific advancement and economic growth.

In addition, the EU could develop a new concept in software, and drive to make the EU the leader in HPC software that is beyond the best easy-to-use software and is viewed as "exciting-to-use" software. The concept is to make it so highly productive and innovative for researchers that it's not just easy to use, but exciting to use. This will also attract new people and talent to HPC.

Alternative Scenarios and the Recommended Investment Level

It is recommended that the EU and Member States fund this strategy at the "Full Leadership level."

Four alternative scenarios are evaluated in this report:

- Full leadership funding to reach a leadership position by 2020

- Funding to reach the major goals by 2020

- Partial funding to start on a better path

- Minimal funding, close to today's levels to keep from falling too far behind

IDC recommends that the EU and the Member States make HPC a higher priority and step up to the "Full Leadership Level" or at least the "Funding to Reach Major Goals Level." This would require net *additional investments* reaching €500–€600 million a year within five years.

Investments need to start quickly and reach the desired levels within five years. Then investments in HPC need to grow by 10% a year to keep Europe in a leadership position.

Table 2 compares the EU supercomputer spending as a ratio of GDP compared with other countries. To catch up to U.S. levels requires an approximate doubling in yearly supercomputer spending for the base systems.

TABLE 2

GDP and Supercomputer Spending by Country (GDP: €000,000; Sales €000)

	GDP (1)	Average Supercomputer Sales Over Last Five Years (2)	Supercomputers as a Percentage of GDP	Compared to the U.S. = 100%
U.S.	10,949,000	979,126	0.0089%	100%

TABLE 2

GDP and Supercomputer Spending by Country (GDP: €000,000; Sales €000)

	GDP (1)	Average Supercomputer Sales Over Last Five Years (2)	Supercomputers as a Percentage of GDP	Compared to the U.S. = 100%
Europe	10,201,000	502,074	0.0049%	55%
Japan	3,874,000	212,070	0.0055%	62%
China	3,651,000	52,050	0.0014%	16%
Korea	614,070	51,569	0.0083%	93%
Hong Kong	160,200	11,886	0.0074%	83%
Singapore	140,500	12,525	0.0100%	112%

Notes: (1) source: CIA World Factbook, 2009, (2) five-year average yearly spending.

Source: IDC, 2010

Recommendations

The EU should make the proposed organization changes and investments, and drive HPC leadership to reach the stated objectives by or before 2020. One of the cornerstones of the strategy is making HPC highly productive and innovative to EU researchers. This requires having greatly enhanced HPC resources, more broadly delivered, and major R&D investments to make HPC easier to use. If successful, the EU should push HPC productivity to an even higher level — making it "exciting-to-use."

In addition, the EU should prepare for becoming the new hotbed for scientific advancement, including broader-scale programs throughout its educational and research institutions to increasingly attract top researchers from around the globe, e.g., through broad incentives.

1.0 STUDY METHODOLOGY

1.1 Study Background

Supercomputing has become a key element for the competitiveness and innovation in knowledge-based economies. But in recent years, Europe has under-invested in supercomputing (also referred to as high-performance computing, HPC), both in annual spending on computing resources and in research investments, while other nations' investments grew even during the economic recession.

European stakeholders from industry, research, and academia believe that Europe has a chance to jump back to the forefront of development for the next generation of HPC-based research, and for the applications and other software technologies required for the transition to petascale and exascale computing. To achieve these goals and to foster world-class ICT infrastructures for European science and research, as requested by the communication on e-infrastructures, the European Commission asked IDC to develop a Strategic Agenda for European Leadership in Supercomputing by 2020, which is presented in this report.

The Strategic Agenda builds on the in-depth analysis of the strengths and weaknesses of the European HPC industry and market, developed by IDC's multidisciplinary team, with the support of a Technical Strategic Committee composed of experts from the European HPC community, and with the insights gathered from a large community of stakeholders.

This report identifies the key challenges faced by the EU scientific and research community, the relevance of HPC for scientific and economic leadership, the needs for policy action in this field at the EU level, the potential returns of a proactive HPC strategy and a vision of supercomputing leadership in 2020. This is completed by recommendations of the actions to be undertaken, based on alternative scenarios.

The ultimate goal of the HPC 2020 Strategic Agenda is to guide EU investments in this area and to suggest a framework for cooperation between the European Commission and the Member States, enabling the development of HPC world-class infrastructures, supporting Europe's ability to meet the scientific and engineering challenges of the 21st century.

1.2 Study Methodology and Research Approach

This study was conducted under the SMART 2009/0055, contract number 2009/S99-142914, for the project entitled "The Development of a Supercomputing Strategy in Europe." This is the D3 Final Report, and it contains Work Product 3, as described in the contract. This report is a follow-on to the Interim Report, "Development of a Supercomputing Strategy in Europe," by IDC EMEA, the multinational market research and consulting company specialized in the ICT markets, on behalf of DG Information Society and Media of the European Commission. The Interim Report presents the main results of WP1 — Market Analysis and WP2 — Technology Requirements.

This Final Report contains IDC's recommendations for the development of a supercomputing strategy in Europe. Over 200 HPC experts across the EU provided

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ideas, insights, and suggestions in the creation of this report and proposal. The recommendations are based on careful consideration of several sources:

- The **extensive field research** IDC conducted for the Interim Report of this study (downloadable at www.hpcuserforum.com/EU). Throughout the process, over 200 EU individuals were contacted for their ideas, suggestions, and opinions about this critical area. As described in the Interim Report, the initial field research for this project included the following components:
  - **Broad survey of the European HPC stakeholders.** In February 2010, IDC distributed an extensive, custom-designed questionnaire to 321 targeted HPC community members representing all EU countries, 11 other European countries, as well as a few key individuals in Canada, Japan, and the U.S. (in order to capture perspectives on European HPC from other regions of the world). The primary survey questionnaire is in the appendix of this report, along with the list of organizations that were invited to participate in the survey or otherwise contributed ideas, suggestions, and recommendations. To encourage candor, IDC assured survey respondents that their comments would remain anonymous.
  - **In-depth interviews with HPC leaders.** During February and March 2010, IDC also conducted in-depth interviews, in person or by phone, with national funding agencies of EU Member States; representatives of European HPC programs (PRACE, DEISA, et al.); senior officials of HPC centers in Europe; other HPC industry experts in Europe, the U.S., and Japan; and senior officials of HPC vendors in Europe, the U.S., and Japan. These interviewees included some of the most well respected, highly knowledgeable individuals in the European and worldwide HPC communities. The interviews typically lasted an hour or longer each. To encourage candor, IDC assured interviewees that their comments would remain anonymous.
  - **Four HPC European case studies.** IDC also interviewed and developed case studies on four leading European HPC centers, including CINECA, the Italian national supercomputing center for science and research; HLRS (High Performance Computing Center Stuttgart, in Germany); SARA Computing and Networking Services; and CERN, the European organization for nuclear research based in Switzerland. The case studies are meant to illustrate the situations and challenges faced by leading European HPC centers, of which there are many others.
  - **The Technical and Strategy Committee (TSC).** Because of their close understanding of relevant research programs, HPC centers, vendors, and users within the HPC market in Europe, the five individuals in this group provided invaluable consultation to IDC in the formation of both the interim report and this report. The TSC members are Hervé Mouren and Christian Saguez, Ter@tec; Arndt Bode and Herbert Huber, Leibniz-Rechenzentrum/LRZ Munich; Friedel Hossfeld, Forschungszentrum Jülich; and Richard Blake, Daresbury Laboratory.
  - **Special EU HPC Web site.** To enable comments from anyone in the HPC community, IDC also designed and deployed a special Web site (www.hpcuserforum.com/EU) that will remain live through the duration of this project and beyond. IDC emailed the more than 3,300 individuals on its European and worldwide HPC community contact lists, inviting them to visit

the Web site and post comments. Plans call for the Interim Report, Final Report, and other relevant documents to be posted on this public Web site for comment as well.

- **Additional in-person and phone interviews.** After the European Commission approved publication of the Interim Report on the special Web site, IDC conducted additional in-person and phone interviews with European HPC users and with HPC vendors selling their products in Europe. The goal of these additional interviews was to discuss the perspectives, opportunities, and issues that emerged from the field research and were documented in the Interim Report, in order to further inform IDC's recommendations for the development of a supercomputing strategy in Europe.

- **Opinions from the Technical and Strategy Committee.** With the field research findings of the Interim Report in hand, the TSC members, acting in their consultative role, provided their opinions for IDC's consideration on the development of a supercomputing strategy in Europe. These opinions appear in this Final Study Report.

- **HPC conference sessions.** In order to gather additional perspectives for this Final Study Report, members of IDC's HPC team also attended the DEISA PRACE Symposium 2010 (Barcelona, Spain, May 10–12, 2010), the International Supercomputing Conference (Hamburg, Germany, May 30–June 3, 2010), and TER@TEC '10 (Palaiseau, France, June 15–16, 2010). The IDC team members had useful discussions with many attendees at these meetings.

- **IDC presented the initial findings at ISC10** and invited participants to provide their input. In total, IDC talked with more than 200 individuals in Europe, as well as others from the rest of the world.

- **IDC HPC research studies, including 25 years of technical server shipment data.** Each year, IDC conducts 10–12 major HPC-related research studies, most of them worldwide in scope and including interviews with members of the HPC community in Europe. IDC brought recent studies to bear on behalf of this report. The most relevant studies are described in the "IDC Research Summary" portions of the Working Groups section of the Interim Report. In addition, IDC typically organizes two HPC conferences in Europe each year and two in the U.S., called HPC User Forum meetings (www.hpcuserforum.com). The results of these conferences, especially presentations by leaders from Europe's HPC community, also informed this report.

In total, over 200 European HPC experts participated in this research and study.

1.3 Report Layout

This strategic agenda report is divided into these primary sections:

- Executive summary

- Study methodology

- The need for an HPC strategy

- The strategic vision

- Why action is required
- The recommended strategy and actions
- Additional strategic principles and actions
- Investments required and alternative scenarios
- Conclusions, risks, and additional recommendations

2.0 THE NEED FOR AN EXPANDED HPC STRATEGY HEADING TOWARD 2020

As detailed in the Interim Report for this project, recent worldwide studies by IDC have consistently shown that HPC has become indispensable for both scientific advancement and economic competiveness. Europe needs to have the infrastructure to access computing systems covering a large spectrum of needs. It is worthwhile both to multiply the number of centers with average computing power and to have a policy for providing access to some very high-performance supercomputers that are uniquely capable of supporting breakthrough achievements in science and engineering.

The former age of lone scientists working in isolation with the traditional methods of theory and physical experimentation is being replaced by a new era in which teams of scientists or engineers collaborate across distances using HPC-based computation and networking. More Nobel Laureates are moving to employ these computational science methods in their research. And on the commercial side, in an IDC study 97% of large companies worldwide that had adopted HPC said they could no longer compete or survive without it.

Today, to Out-Compete is to Out-Compute

HPC-based modeling and simulation is becoming a necessity for competing with other advanced economies and is a powerful tool for competing with nations having lower labor costs, especially as labor and equipment costs for physical experimentation have skyrocketed in the past decade. That is why today major nations and global regions are vying for HPC leadership as a prerequisite for scientific and economic leadership.

Europe has played an important role since HPC's beginnings and possesses a wealth of HPC-related experience and talent, but in recent years Europe has under-invested in HPC and is falling behind other regions of the world. In order to catch up and keep pace with competing nations and regions, Europe needs to both increase its HPC investments (specific investment levels are proposed below), and find ways to apply HPC in a more productive and innovative manner. And while continuing to support all scientific disciplines and domains, Europe needs to also target specific scientific, industrial, and technology areas to stress with its HPC investments — important areas in which Europe is already strong and has the potential to attain global leadership by 2020 (candidate areas are also described below).

2.1 The Importance of HPC for Scientific Advancement and Industrial Competitiveness

During the past 30 years, HPC, also called technical computing and supercomputing, has contributed enormously to scientific and industrial innovation, national and regional security, and the quality of human life. HPC-based modeling and simulation has become firmly established as the third branch of scientific inquiry, complementing traditional theory and experimentation. Yet few people outside of the global HPC community are aware of HPC's varied contributions or its impact on their daily lives.

How many people know, for example, that HPC plays an integral part in designing the vehicles they drive and the airplanes they fly in, locating and extracting the fuel that

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powers these vehicles and heats their homes, developing life-saving new drugs and medical treatments, and producing the weather forecasts they rely on to plan for daily activities and severe weather that can devastate lives and property?

These and other HPC abilities have become increasingly important not only for the well-being of individuals, but also for the scientific and economic competitiveness of entire nations and global regions. For example:

- Nobel Prize winners are starting to rely on HPC for their research.
- In November 2009, the Japanese government rejected a budget-cutting panel's recommendation to sharply cut funding for HPC. Japanese Nobel Laureates helped win the day by testifying that HPC is crucial for continued scientific advancement and Japan's standing in the global scientific community.
- An IDC study for the Washington, DC-based Council on Competitiveness revealed that 97% of tier 1 industrial companies that have adopted HPC now consider it indispensable for their ability to innovate, compete, and survive.
- In his July 2009 address to the nation, Russian President Medvedev warned that unless Russia invested significantly more in HPC, in five years "our products will not be competitive or of interest to potential buyers." Russia has substantially boosted its HPC funding since then.
- In his State of the Union speech, U.S. President Obama named supercomputing as one of only three areas destined for increased funding rather than recession-driven budget cuts. During the 2007–2009 period that included the global recession, North American investments in supercomputer-class systems jumped 38.5%.
- China is firmly committed to pursuing world leadership in HPC. In June 2010, Chinese supercomputers captured the number 2 and number 7 positions on the closely watched list of the "World's Top 500 Supercomputers" (www.top500.org). Only one U.S. supercomputer, and no European HPC systems, ranked ahead of the top Chinese machine.

It is crucial for Europe to embrace this underlying paradigm shift in order to retain its competitive edge. In February 2010, the Report of the *Expert Group* on Research Infrastructures of the European Commission, "A Vision for Strengthening World-Class Research Infrastructures in the ERA," was released. It reviews and reexamines the role of research infrastructures within the European Research Area (ERA) at large, and provides further recommendations emphasizing the crucial role of e-infrastructures in order to meet the global challenges.

The scale of these challenges requires HPC infrastructures which are beyond the resources available at the national or regional levels in Europe. They require collaborations which involve the very best scientific and technical expertise. This strategic view of HPC for the research community and the EU led to the creation of a new e-Infrastructure, PRACE, Partnership for Advanced Computing in Europe, which is supported by the Capacities Program of the 7th Research Framework Program. The PRACE initiative, which was launched in 2008, laid a sound foundation for the establishment and future development of world-class HPC infrastructures for European researchers in computational science and engineering.

In summary, HPC is important because it has proved to be a substantial multiplier of scientific and economic investments, a major productivity tool for researchers. HPC is valuable because it can often produce scientific and industrial solutions faster, less expensively, and with higher quality than traditional theory and experimentation alone. This is critical for global competitiveness. HPC is also valuable because it can help address "grand challenge" societal problems that are impractical (e.g., severe weather prediction) or simply impossible to test (e.g., future climate changes, star formation) or to evaluate with "live" physical experimentation. The Intergovernmental Panel on Climate Change (IPCC) and ITER programs are prime examples of HPC's crucial role in supporting large-scale scientific collaborations.

Corroboration From Field Research

In the extensive field research IDC conducted for the Interim Report component of this study, every one of the survey respondents said that HPC is "extremely important" or "important" for both scientific and industrial leadership. The following quotes are representative, although a few respondents appropriately cautioned that HPC alone is not a panacea for research excellence.

Scientific Advancement

"HPC is a major tool for most scientific activities."

"The number of researchers who have migrated from the two traditional methodologies to computer modeling has become so significant that scientific leadership cannot be achieved without a significant presence in HPC."

"[HPC-based] simulation is the third research method besides theory and experiment."

Industrial Competitiveness

"Applied research utilizing HPC is extremely important for industrial competitiveness."

"[HPC is] extremely important for industry sectors such as aerospace, oil and gas, energy, chemistry and life sciences."

"Future drug development and personalized medicine will heavily rely on HPC and simulation-based research."

Table 3 shows where HPC is used today by European users in science and industry.

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TABLE 3

EU Total HPC Purchases (€000) by Industry/Application Segments

Application	2009	Percentage of HPC
University/academic	278,036	16.6%
Bio-sciences	265,509	15.8%
Computer-aided engineering	252,487	15.1%
Government lab	226,579	13.5%
Defense	155,639	9.3%
Electronic design analysis	115,781	6.9%
Geosciences and geo-engineering	96,894	5.8%
Weather	70,561	4.2%
Digital content creation and distribution	69,348	4.1%
Chemical engineering	48,493	2.9%
Economics/financial	48,018	2.9%
Mechanical design and drafting	29,774	1.8%
Technical management	11,285	0.7%
Software engineering	2,563	0.2%
Other	6,138	0.4%
Total revenue	1,677,105	100.0%

Source: IDC, 2010

2.2 Why Use of HPC is Expanding

As noted above, HPC has contributed enormously to the advancement of science and industry. This section describes a few of the many examples of HPC's contributions.

HPC and Science

In addition to its many past contributions to science, HPC today plays a crucial role not only at the national and regional levels, but in multiregional projects of great importance for society.

- **The Intergovernmental Panel on Climate Change** (IPCC) is the leading body for the assessment of climate change, established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socioeconomic consequences. HPC modeling and simulation have been indispensable for the IPCC's work.

- **HPC modeling and simulation are also at the heart of the ITER project**, which brings together the People's Republic of China, the European Atomic Energy Community (via EURATOM), the Republic of India, Japan, the Republic of Korea, the Russian Federation, and the United States of America in an international collaboration to establish fusion as a new source of energy.

- **HPC is also crucial for the Airbus initiative in Europe.** HPC plays a critical role in designing airplanes that are more fuel efficient, more environmentally friendly, and available in the global market place faster.

HPC and Industry

From its roots in government and academic research, HPC-based modeling and simulation spread out into large industry starting in the late 1970s. Since then, HPC has enabled automakers around the world to reduce the time for developing new vehicle platforms from an average 60 months to 24 months, while greatly improving crashworthiness, environmental friendliness, and passenger comfort. With help from HPC, airframe manufacturers such as Airbus and Boeing have saved billions of euros by dramatically reducing the number of physical prototypes needed for satisfactory designs of new airplanes.

But that's not the end of the story. In recent years HPC use has become more pervasive than even many members of the worldwide HPC community may realize, as these further examples illustrate:

- **Healthcare.** In the early 1990s, a hospital in Germany began routinely using HPC to predict which expectant mothers would require surgery for Caesarian births, with the goal of avoiding traditional, riskier last-minute decisions during childbirth. A Washington, DC hospital routinely employs HPC to "read" digital mammograms with better-than-human accuracy to spot early signs of breast cancer (microcalcifications). Hospitals in Europe and the U.S. have begun to use HPC in surgical training, especially to convey the "feel" of various procedures as experienced by veteran surgeons (haptics). Researchers at EPFL in Switzerland, in the U.K., and elsewhere are en route to creating functional computer models of the human brain to aid in neurological studies.

- **Consumer products.** HPC plays an important role in the design of automobiles, cell phones, dishwashers, and a whole host of other consumer products.

- **Humanities.** Scientists at Reading University in southern England have been using a supercomputer called "ThamesBlue" to model the evolution of words in English and the wider family of Indo-European languages over the last 30,000 years. University of Cyprus researchers are using supercomputers to construct digital 3D models of historic architecture. Other academics are putting HPC into service in sociology, archeology, and other disciplines.

2.3 Industry Needs Advanced HPC to Stay Competitive

Many small and medium businesses (SMBs) have to integrate the use of HPC technology to be competitive today. They will need to expand its use in the very near future in order to remain competitive. A majority of them are working for larger industrial groups that are progressively imposing the use of numerical design and simulation tools in their tenders. Those that are not able to meet this requirement will progressively disappear. Access to HPC is vital for them, and it should be available easily and at reasonable cost. As most of the SMBs have limited or no modeling capacity, there is a clear need for intermediate structures with real business knowledge in specific domains and having the mathematics and software tools to realize the complete modeling of a given problem.

2.4 The Value of HPC to the EU

The primary rationale for an enhanced HPC strategy is the immense return-on-investment possible for the EU, its researchers, and the population at large. By investing more heavily and in a smart way, the EU can use HPC as a primary tool for advancing science and getting EU economies back into a healthy growth mode. HPC can also provide protection from other nations that are targeting the EU's substantial markets.

The economic returns 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)

The HPC Supply Chain

Within this project, IDC interviewed 45 vendors of HPC hardware systems, software, storage, and services. We talked with major vendors multiple times in most cases, and we talked with vendors headquartered in North America, Europe, and Asia. The vendors' perspectives can be summarized as follows:

- Most of the vendors, no matter where their headquarters, already sell products and/or services in Europe and have a high degree of interest in the EU HPC strategy and the overall future of Europe as an HPC market.
  - Most felt that they would like Europe and the EU to invest more into HPC by buying more products and services and by funding targeted R&D programs.
  - Foreign HPC suppliers with operations in Europe are also very willing to invest in making products and services that better meet the needs and requirements of the European market.
  - The good news is that the supply chain is in place and willing to act quickly, once the EU decides to apply increased resources.
- Vendors headquartered outside of Europe want to ensure continued open access for their products in European markets. Some vendors expressed concern about

what they see as a growing tendency toward protectionism in European HPC procurements.

- Europe-headquartered software vendors in many cases have achieved success on a global scale, but Europe-based hardware system vendors have not had time yet to expand their selling efforts beyond Europe. There was some concern among the hardware vendors that Europe should conduct open procurements only to the extent that other regions, especially the U.S. and Japan, also conducted open procurements where European hardware vendors could compete on equal terms.

- Some non-European vendors, including IBM, Cray, and Intel, have already established European collaborations aimed at making exascale computing a reality.

Key industries in the HPC supply chain include:

- System vendors

- Software providers

- Service companies

- Research institutions and joint R&D centers

Industries That Leverage HPC to Improve Their Products and Services

Europe has many industries that can be expanded and improved by an increase in HPC access and by having better and more productive and innovative ways to use HPC systems. If the EU and Europe decide to follow this strategy, these and other industries across the EU could see substantial growth:

- The manufacturing sector, including automobiles, aerospace, IT products, cell phones, and other consumer products. For example:

  - HPC enables incremental improvements, such as cost savings or time to market, in existing commercial processes. An example of this is Airbus' increasing use of digital simulations and experiments to replace more expensive and time-consuming physical modeling.

  - HPC enables transformational improvements in the creation of new products or services. An example of this is development of the next generation of storage technologies which would not be possible without HPC.

- The energy sector including traditional and new forms of energy

- The bio-life science sectors, including chemicals

- The financial sector, including economic and financial modeling, and business intelligence modeling

- IT services providers including everything from small software houses to large cloud providers

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Scientific and Engineering Research Returns From a Broader HPC Strategy

The returns to end users are critical in enabling advanced scientific and engineering research. Measuring the actual value of academic research is notoriously difficult and so, within the time available for this project, a number of incremental improvements were investigated as well as transformational improvements. For incremental and transformational improvements the project team, in association with the advisory team, investigated a number of different products and services developed using HPC. Each case confirmed that HPC has become a decisive tool for both the research and development of new products and services. But in addition, most of these organizations felt that to be successful in the future, they will need to broaden the use of HPC in order to keep up with the competition.

Respondents were asked to compare the value of using non-HPC alternatives. 100% of the sites surveyed said that once HPC is used in a process, it becomes a fundamental requirement. In a few cases, smaller SMEs said that they could try going back to just using workstations, but it would be painful.

3.0 THE VISION FOR EUROPEAN HPC LEADERSHIP

3.1 The HPC Vision

The HPC strategy is aimed at progressively realizing a distinct leadership vision for Europe by 2020. The vision proceeds directly from Europe's unique circumstances and strengths in science, engineering, and technology — and from the ability of the EU Member States to join forces to accelerate Europe's scientific advancement and economic competitiveness.

The Overall Vision for EU HPC Leadership by 2020 is as follows:

> *Provide world-class HPC expertise and resources to make EU scientists, engineers, and analysts the most productive and innovative in the world in applying HPC to advance their research, in the pursuit of scientific advancement and economic growth.*

The vision includes these attributes:

- Delivering world-class research and creating positive economic/societal impacts by exploiting HPC
- Developing leading-edge next-generation simulation software, libraries, and software that can efficiently and effectively exploit current and future HPC architectures — making EU researchers and businesses the most productive and innovative in the world
- Supporting the development of a sustainable/strategic supplier base for the supply of HPC components and systems integration capabilities
- Sustaining a world-class skills base through undergraduate, postgraduate, and professional development

3.2 Potential Benefits of Implementing This Strategy

By 2020, the EU HPC strategy has the potential to enable the following progress:

- Europe's leadership in the targeted areas has created many new jobs in science and industry, and has caused the national economies to grow faster. Europe's move to the forefront of progress in other areas has preserved many existing jobs in both science and industry.
  - Thanks to the expanded HPC strategy, Europe has benefitted from a substantial, sustainable net gain in job creation, employment, and improved economic competitiveness. And because the HPC strategy also supports SMBs and small/medium science (Member States), the job creation and preservation have a deeper impact on Europe's scientific and industrial sectors and extend more broadly across larger and smaller EU Member States.

Europe's leadership in the targeted areas has created many new jobs in science and industry, and has resulted in faster growth in the national economies.

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- Europe is the worldwide leader in the scientific/industrial domains targeted for leadership: weather and climate research, clean and sustainable energy, automotive and aerospace design engineering, bio-life sciences (e.g., creation of digital cells and organisms and the virtual physiome), particle physics, cloud computing, molecular dynamics/modeling of materials, and exascale applications, across a wide spectrum of disciplines.

- European industry, benefitting from the scientific advances and from being able to solve challenging research problems on large EU HPC systems, leads the world in the targeted areas. Industry enjoys peer-reviewed access to EU tier 0 HPC systems for challenging industrial research problems. As a result, in the targeted sectors Europe leads the world because it has the ability to deliver superior products to the global market faster than non-European competitors.

- Europe has at minimum kept pace with the rest of the world in scientific and industrial domains not explicitly targeted for global leadership. Non-targeted domains have continued to have substantial access to tier 0 HPC systems and related resources. Because of this, Europe continues to remain at the forefront of scientific and industrial progress across the full spectrum of scientific and engineering domains.

Europe is the world leader in important HPC technologies.

- Europe is the world leader in important HPC technologies, especially those designed to support the leadership areas. In particular, Europe leads the world in scalable algorithms and software applications in the targeted areas, and in tools to make HPC systems easy to use and to make researchers highly productive and innovative.

  - Europe has funded and operates two to three highly productive and innovative exascale supercomputers that are purpose built, from a hardware and software standpoint, to excel in a number of the key targeted leadership areas. Europe has funded and operates 10–20 other large supercomputers as well.

    - For cost-effectiveness, the supercomputers in Europe make maximum use of commodity components and systems that are widely available on the world market. European experts augment these components and systems with purpose-built technologies in order to meet Europe's unique requirements for world leadership in the targeted areas.

  - Europe has created multiple partnerships and collaborations around the world in support of making its HPC solutions world class and highly productive and innovative for European researchers. Europe partners with technology vendors based in Europe and elsewhere, as needed, to secure and sustain its hardware and software technology leadership, including the purpose-built technologies, on behalf of European science and industry.

  - Through advanced networking, Europe makes these unique supercomputing resources more widely and more easily available for European scientific and industrial research projects.

Europe is recognized as a hotbed for new science and engineering research.

- Europe is recognized as a hotbed for new science and engineering research, especially in critical domains the HPC strategy has targeted for world leadership.

- Scientists and engineers are moving to European countries in larger numbers. This is occurring especially in the fields the HPC strategy targeted for world leadership. European universities are swelling with EU and international students across all scientific domains, as people want to be part of the new renaissance in scientific discovery as Europe applies HPC, the third pillar of science, better and more broadly than anywhere else on earth.

- Europe's leadership in the targeted areas has reversed the "brain drain" by increasingly attracting the top scientists/researchers from throughout the world. The continuing growth of Europe's scientific leadership, especially in the fields targeted by the strategy, has made Europe the primary source of theoretical and experimental advances in these fields.

  - More and more scientists migrate to Europe to advance their research and to participate in collaborations that require access to the world-leading innovative HPC hardware/software resources and expertise residing in Europe.

3.3 Objectives of the HPC Strategy

- Seize the opportunities presented by the emerging era of petascale/exascale computing to advance Europe's ability to pursue breakthrough scientific and engineering innovation.

- Provide the computational tools needed to increase the scientific and economic competitiveness of Europe and the EU Member States in the global market place, across a broad spectrum of scientific and industrial domains.

- Help advance Europe to a position of world leadership in select domains of great scientific, economic, and/or technical importance. These should be domains where Europe already has considerable strengths to build on.

- Help make Europe increasingly attractive for important scientific collaborations with non-European nations and global regions.

- Ensure appropriate access to HPC resources not just for worthy "big" science and engineering projects, but also for worthy small and medium science (Member States) and SMEs.

- Expand training on the use of HPC and greatly expand the training and development of new software.

- Create and maintain an appropriate balance along multiple dimensions:

  - The role of the EU versus the Member States

  - The role of large versus smaller Member States

  - The requirements of science versus industry

  - Open procurement versus providing advantages for EU-based HPC vendors

  - Buying HPC systems from abroad versus developing a new European HPC architecture

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4.0 WHY HPC POLICY ACTION IS IMPORTANT

As indicated in an earlier section ("The Importance of HPC for Scientific and Industrial Competitiveness"), high-performance computing is integrally linked to government policy in the U.S., Japan, Russia, and China, to name a few. Some EU Member States have clearly delineated national HPC policies, and the EU, acting on behalf of all the Member States, is home to the PRACE program and actively sponsors other collaborative HPC-related programs and initiatives.

In all of these cases, policy action was needed to legitimize, prioritize, and drive the HPC initiatives. Without the policy actions, these important HPC initiatives would almost certainly have failed due to inadequate stature, urgency, funding, and participation.

4.1 Recommended EU HPC Policy Actions

For the EU HPC strategy to achieve its important scientific and economic objectives by 2020, the EU needs to adopt a policy on behalf of the Member States that accomplishes the following things:

- Recognizes HPC's important, growing role in driving scientific advancement, economic competitiveness, and regional security for Europe
- Elevates the stature and expanded mission of HPC within the EU to an appropriate level by creating an EU Coordinating Office for High Performance Computing (or other appropriate name), as a widening of the PRACE program and its existing pan-European service mission
- Delineates the EU's expanded role in HPC, as needed to drive the EU HPC strategy on behalf of the Member States
- Targets funding levels sufficient to implement the EU HPC strategy on a sustained and secure basis through 2020, by augmenting currently planned funding levels as needed

4.2 Additional Benefits if Action is Taken by the EU

The longer-term benefits (by 2020) of taking policy action on HPC are described at the start of this section of the report, in "The Vision for European HPC Leadership." In general, countries and global regions are investing more in HPC because HPC can affect the balance of economic and political power, as described in *Massive HPC Systems Could Redefine Scientific Research and Shift the Balance of Power Among Nations* (IDC #219948, September 2009).

HPC-driven innovation has become a prerequisite for:

- Scientific leadership
- Industrial leadership
- Economic advancement

HPC-based modeling and simulation has become a fundamental driver of scientific and engineering discovery in many disciplines and fields. It is often referred to as the third pillar of the scientific method (along with theory and experimentation). Supercomputers are a tool for researching areas in ways that were previously impossible to accomplish. HPC enables dramatically faster, less costly time-to-solution and time-to-discovery.

HPC Investment and Economic Return

The linkage between HPC and economic return is analogous to linking R&D investments to economic successes. At a macroeconomic level, it can be shown that the most scientifically and economically successful countries invest the most in R&D and also in HPC. The increasing tilt toward HPC as an R&D method is related to the fact that the costs of experimental ("live") science and engineering research have skyrocketed in the past decade. This has made HPC increasingly attractive from an investment basis, not to mention HPC's proven ability to enable faster, higher-quality solutions. Scientific R&D savings are more difficult to quantify, but in the automotive and aerospace industries, HPC has dramatically reduced the time-to-market and increased the safety and reliability of new vehicle designs. Some of these firms have cited savings of €40 billion ($50+ billion) or more from HPC usage.

4.3 Potential Risks if No Action is Taken

In the extensive field research IDC conducted for the Interim Report, survey respondents from national funding agencies, HPC centers and research programs, and vendor companies in Europe clearly articulated the consequences if the EU does not take additional steps to develop leading HPC capabilities. The respondents almost universally portrayed the consequences as dire for both Europe as a region and the EU Member States, especially the smaller ones. IDC agrees that the main foreseeable consequences are as follows:

- **Europe could become inferior to the U.S. and Asia in science.** Failure to expand the EU HPC strategy to keep pace with the rest of the world could cause Europe to become a second-class region for science. It could also leave each EU member state to compete on its own, resulting in less ambitious, more fragmented scientific initiatives and outcomes. Smaller EU Member States would likely suffer most from this scenario.

- **Europe and the EU Member States could lose industrial competitiveness and jobs.** The existing EU HPC strategy already lags the U.S. and Japan in providing industry with access to world-class HPC resources. If nothing is done to remedy this situation, Europe and the Member States could fall seriously behind these and other nations in industrial innovation and economic competitiveness. In a nutshell, other nations and global regions could have a major advantage in bringing more advanced, higher-quality products to market in shorter timeframes than European companies. And because HPC is a major weapon against countries with lower labor costs, failure to provide adequate access could result in the permanent loss of European industrial firms and jobs.

- **Europe and the EU Member States could experience an escalating brain drain to the U.S. and Asia, along with great difficulty in attracting talented scientists and engineers.** The Europe-to-U.S. brain drain is already occurring, including scientists relocating to work at U.S. national laboratories with the best HPC resources. This brain drain would likely escalate if Europe failed to keep its

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HPC resources on a par with those of the U.S. and Asia. If Europe's current deep pool of scientific and engineering talent is allowed to drain away, it might take a decade or more to restore it even with the best of efforts and funding. It makes far more sense to address the brain drain now.

- **Europe and the Member States could become increasingly reliant on the U.S. and Asia for scientific, industrial, and technological advances.** If Europe fails to keep pace in HPC with the U.S., Japan, and others, Europe might be forced to import scientific, industrial, and technological advances from other areas of the world — without having much except money and political favors to offer in exchange.

- **The smaller and less affluent EU Member States could lose the ability to access and benefit from large HPC systems. This could widen the digital divide in Europe, to the detriment of the smaller countries.** If Europe failed to keep pace in HPC with the U.S., Japan, and others, the smaller and less affluent EU Member States would likely suffer the most. Unlike Europe's wealthier states, the smaller countries typically cannot afford to fund world-class HPC systems on their own and rely to a greater extent on access to tier 0 EU HPC systems. It's easy to see how failure to expand the EU HPC strategy could widen the digital divide between richer and less-affluent Member States.

- **Europe's existing strengths in hardware, software, and other HPC-related technologies could diminish or disappear from lack of advancement.** It almost goes without saying that Europe's existing world-class skills in HPC-related technologies would also erode without continuing access to world-class HPC systems.

5.0 THE RECOMMENDED ACTION PLAN AND STRATEGY

IDC recommends the following HPC strategy for the EU to pursue on behalf of the Member States. This strategy takes into consideration Europe's current status in HPC as well as the known HPC plans of other contenders for HPC leadership, especially the United States, China, and Japan. This strategy optimizes the return-on-investment for Europe in attaining a higher level of scientific advancement as well as driving economic growth.

The surveys and discussions with European HPC experts provided a large number of ideas, suggestions, and insights. The many options were evaluated and ranked based on their ability to address the key objectives in the most cost-effective and time-effective way. The assessment criteria included:

- Contribution to the primary European HPC objectives (growth, competitiveness, jobs, sustainable development, etc.)
- Contribution to the strategic HPC objectives
- Business value (and industrial relevance)
- Scientific value and the ability to advance research across the EU
- Feasibility (level of risk in terms of success and time needed to realize commercial effects, probability of success, etc.)

5.1 Overall Strategic Approach: Action Plan for HPC Leadership by 2020

To reach the vision and objectives for leadership, the EU and member nations need to make additional investments with a clear focus on increasing innovation in a number of critical areas:

1. First is the need for expanding the number, size, and access to HPC resources across the EU (including broader access to the tools by all EU researchers in science and industry). An expanded PRACE can address this requirement. The investments required to fully implement this plan would be on the order of doubling current HPC system investments over the next five years and adding a sizeable additional amount of funding in the targeted areas.

2. Second is to provide peer-reviewed access to larger supercomputers for advanced industrial research.

3. Third is to create a set of HPC exascale development lab/testbed centers (techno-pools) — a new type of productivity center — to make HPC users more productive and innovative by creating the world's best tools, training, and development environment. This new initiative is what can make Europe leap ahead of other countries by increasing the productivity of HPC users, increasing the talent level of existing HPC users, developing new HPC experts, and creating an entirely new level of the EU HPC ecosystem.

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4. Fourth is the need to increase funding in developing next-generation exascale software. The need to create the ability to use highly parallel HPC systems via new algorithms, new software tools, new applications, and extensive testing and development. This also requires investments in the above three areas, plus a change in mindset that allows HPC industry and code developers to use shared HPC resources in the development testbed centers.

5. Fifth is to attract more students into scientific, engineering, and HPC fields and to attract more experts from around the world to join in EU projects. This requires additional funding and a new magnet program. This requires both of the above initiatives, along with a broader focus on making science and engineering an exciting area for students. Europe can become the central point in the world in this area by taking the leadership role in making HPC the most useful and productive and innovative.

6. Sixth is to target a few strategic application areas for global leadership.

In Addition, There are a Number of Core Recommended Implementation Principles

- Work to make HPC a higher priority on the EU's research agenda
- Expand PRACE to address a broader role in making HPC a powerful tool for EU researchers
- Expand HPC training with a focus on software usage
- Promote public-private partnerships to advance competitiveness
- Support for industrial initiatives and expanded use of HPC resources by both science and industry
- Support grid and cloud computing initiatives to support extended collaborations
- Buy rather than develop new exotic custom exascale supercomputers. Develop standard-based high end HPC systems and supporting components.
- Establish clear roles and responsibilities between the EU and Member States

All of the above actions support the goal of making Europe the strongest in applying HPC tools for advancing science, engineering, and analysis in pursuit of scientific advancement and economic growth.

5.2 Expand and Broaden PRACE to Administer the EU HPC System Strategy

The EU can accomplish these goals via a new HPC organization or an expansion of an existing organization. By starting with an existing organization, much time can be saved, but the EU may decide that it needs a new organization. IDC recommends that the EU expand the mission, stature, and funding of the PRACE program to make it the central EU organization responsible for pursuing the mainstream system acquisition and operating the EU HPC strategy on behalf of, and in collaboration with, the Member States. In addition, the expanded PRACE coordinating organization for HPC should oversee the HPC exascale development lab/testbed centers, run EU industry workshops on applying HPC to gain competitive advantage, and coordinate with the Member States to drive the HPC leadership initiatives (see "The Expanded PRACE Management Board" at the end of Section 5.2).

The creation of an EU HPC system strategy elevates HPC to an appropriate, larger role within Europe. An expanded central organization is needed to pursue the strategy and to signal the EU's increased commitment to HPC leadership. Although IDC's field research showed that Europeans generally rank U.S. and Japanese HPC programs ahead of any in Europe, PRACE emerged as the top-ranked EU HPC program and is widely respected within Europe.

To date, PRACE has effectively been limited to a pan-European HPC service mission, that is, to providing HPC resources across Europe, and almost exclusively to scientific researchers. IDC recommends that PRACE's mission be expanded to having chief responsibility for administering the EU HPC strategy that includes not only service provision but also the pursuit of global leadership in specific scientific and engineering domains. Hence, PRACE's role vis-à-vis European industry would also increase substantially.

Expanding PRACE's role in this way would not disrupt PRACE's current momentum, as would the creation of a new organization to administer the EU HPC strategy while PRACE continued its established main mission of service provision. IDC believes that expanding PRACE's mission as recommended would also cause Europeans to rank PRACE even higher among the world's most effective HPC research programs over time.

IDC also recommends that the EU consider giving PRACE a new name, such as the EU Coordinating Organization for High Performance Computing or something similar (e.g., Coordinating Agency of Partnerships in Europe for Advanced Computational Engineering and Science), to reflect the organization's expanded mission and stature on behalf of the Member States. The PRACE name could be retained within the organization for the existing program activities.

The Expanded PRACE Management Board

It is recommended that the expanded PRACE board includes the existing PRACE leadership, with the addition of HPC champions from a number of additional countries and institutions.

5.3 Substantially Increased Funding for HPC Systems is Needed

Europe Has Been Under-Investing in HPC Systems Lately

Europe has been under-investing in HPC, especially for larger HPC systems needed to support leadership initiatives. During the economically challenging 2007–2009 period, purchases of supercomputer-class systems priced above €375,000 ($500,000) increased 38.5% in North America, 284% in Japan (a figure heavily skewed by a few major upgrades), stayed flat in the rest of the Asia/Pacific region, but declined by more than 9% in the EMEA region, which consists almost entirely of Europe. Europe lost ground to other world regions, especially North America, during this period. Note that Europe in this context refers to the combined spending of the EC and the Member States. IDC's figures are derived from the shipment records of HPC hardware system vendors that IDC collects on a quarterly basis. The figures reflect actual prices paid by buyers, rather than list prices.

Supercomputer-Class Systems

During the period 2007–2009 that includes a period of global economic recession, European spending for supercomputer-class systems priced at $500,000 (€375,000) and up declined by 9.3% from the 2007 level of €692 million, while worldwide spending in this category grew by 25.6% and North American spending increased by 38.5%.

- To stay even with worldwide growth, Europe would have had to spend €692 million x 1.256 in 2009, or €869 million. Actual 2009 European spending in this category was €628 million. Therefore, to stay even with the worldwide growth rate, Europe would have had to spend an additional €241 million in 2009.

- To stay even with North America's 38.5% growth rate, Europe would have had to spend €958 million in 2009, or an additional €330 million (€958 million minus €628 million).

- Although with a more focused strategy of NOT investing in core exascale hardware R&D, Europe can catch up without spending the same level as in the U.S. A yearly increase in spending of €150 million within five years would help to close the HPC system gap.

High-End Supercomputer-Class Systems That Sell for $3 Million (€2.25 Million) or More Each

This subdivision of the supercomputer-class segment is the most relevant for HPC leadership. European spending in this bracket, 2007–2009, dropped 0.4% from the 2007 level of €277 million, while worldwide spending grew 209% and North American spending grew by 237%.

- To stay even with worldwide growth, Europe would have had to spend €277 million x 2.09 in 2009, or €579 million. Actual 2009 European spending in this bracket 2009 was €278 million. Therefore, to stay even with the worldwide growth rate, Europe would have had to spend an additional €301 million in 2009. This is more than double the amount Europe spent in this category.

- To stay even with the North American growth rate, Europe would have had to spend €658 million in 2009 for computer systems, or an additional €401 million (€658 million minus €257 million). Although Europe can choose to purchase and not develop early exascale systems, and save substantially, it still needs to increase its spending for large supercomputers by at least €200 million per year.

Early Exascale Initiatives Will Require Substantial R&D Funding and Very High System Costs

Though the petaflop era in computing is just dawning, initiatives are already under way in the U.S., Europe, and Asia aimed at the next major milestone — the thousand-fold leap to exascale computing speed (10^{18} operations/second) before 2020. Problems have been identified that need this much horsepower, and the U.S. Department of Energy has put the price tag for the multiyear development of a single exascale computer at between $1.5 billion and $2 billion.

A principal objective for the EU HPC strategy is to advance Europe's standing in HPC by 2020, the early exascale era. Europe's R&D funding requirement could vary greatly, depending on whether Europe decides to develop its own custom exascale supercomputer design (not recommended) or decides to purchase an exascale system based on an existing design (procurement funding), and free up more funding for software and other critical areas.

The first exascale systems will likely be targeted or optimized to work on a narrow, select set of applications. By doing this, both suppliers and users can reach the exascale era sooner and at the same time see that certain key applications can perform well at this scale. Later on, more general purpose exascale systems will become available, but for the first few years the largest systems will have a more limited application range than in the past.

For example, in the exascale panel session at the June 2010 International Supercomputing Conference (ISC) in Hamburg, Thomas Schulthess, director of the Swiss National Supercomputing Center (CSCS), noted that each of today's largest supercomputers excels on a narrow range of applications and the breadth-of-applicability of exascale systems will be even narrower. The clear implication, as other panelists confirmed, is that the targeted applications should be selected before the large-scale supercomputer is developed, and the computer and the applications should be designed together ("co-designed") rather than separately, as has often happened to date. The EU could collaborate with other nations in making these large R&D system investments, instead of taking on billion dollar HPC research programs.

The EU Should Purchase, Not Develop exotic custom Exascale or Near-Exascale Supercomputers

IDC recommends that Europe (through the EU) fund the purchase of an exascale or near-exascale supercomputer to provide unrivaled sustained performance on a limited range of important applications where Europe has the potential to lead the world. In particular, the application areas should be the ones that the EU decides on as the areas for EU leadership. At least two or three flagship projects targeting supercomputers in the hundred of petaflops performance regime by 2016 and then in the near exaflops performance regime by 2020 should be started by the EU.

The benefits of this strategic recommendation include:

- Europe will possess the necessary HPC resources that are highly cost-effective to support world leadership in the targeted application domains, which have been selected because of their scientific and economic importance.
- These resources will help to attract the most creative scientists and researchers working in the targeted application domains, both from within Europe and from elsewhere in the world. The computers will also help to create, and attract participants for, high-profile collaborations within Europe and with non-European nations and global regions. (The Large Hadron Collider is an analogous example on a larger investment scale.)
- These supercomputers will also help foster the growth of an "ecosystem" of European technology vendors, especially in the targeted application domain.

Exascale Versus Near-Exascale Investment

As noted earlier, the United States expects to invest $1.5–2.0 billion (€1.1–€1.5 billion) or more to develop a single exascale supercomputer before 2020 (most likely by 2018). To do the same, Europe would need to invest a similar amount.

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- IDC recommends that Europe (EU) could save additional money by purchasing (not developing) two to three near-exascale systems in this timeframe rather than purchasing an early peak exascale system. And by purchasing these systems a year or so after the first exascale version of the product has been installed, Europe (EU) could save could save money without sacrificing progress on the scientific and engineering codes intended for exascale computing. Waiting a year or so would substantially reduce the technical challenges (e.g., hardware/software scaling) and associated costs, such that an investment on the order of €150 million ($200 million) per system would likely suffice. The resultant supercomputers would still sustain unrivaled performance in the targeted application domains, and still attract the best researchers and collaborations in that domain. In addition, Europe can purchase a much larger number of exascale-class (i.e., near-exascale) supercomputers within a given budget profile.

- Europe should invest at levels approaching those of the United States for broader purpose systems (whose gross domestic product closely resembles Europe's). The money "freed up" by not developing an early full exascale system could be used to substantially boost funding for software, HPC development testbeds, and for the procurement of broader-purpose HPC systems on the open market to support a wider range of scientific and industrial projects and initiatives.

5.4 How Much Does Europe Need to Invest to Catch Up With the Rest of the World?

Because no single HPC processor or system architecture is best for all scientific and engineering applications, it is important for European researchers to have access to multiple types of supercomputers, including clusters of shared memory compute nodes and massive parallel processing systems.

Table 2 (in the Executive Summary) compares GDP and average supercomputing for a number of countries and with Europe as a whole. Compared with the U.S., Europe needs to almost double its historic supercomputing spending as a percentage of GDP. (Incidentally, the U.S. is not alone in outspending Europe in relation to GDP. Korea, Hong Kong, and Singapore have also been spending close to double the percentage of GDP that Europe has been spending.)

IDC recommends that Europe apply a very cost-effective approach to funding its HPC supercomputers *by not developing custom exascale systems*. This will save over a billion euros in costs, and will provide funds for more systems and for R&D in other areas. An increase of €250 million a year for new large systems (built up over a five-year period), followed by an increase of 10% per year, should be sufficient.

Spending €150 million extra per year for large systems, and €100 million per year for smaller supercomputer systems, would work well.

- Spending €150 million extra per year for large systems and €100 million per year for smaller supercomputer systems would work well.

5.5 A Critical New Part: Create New HPC Exascale Development Lab/Testbed Centers

In addition to the basic need for expanding the number of HPC systems and providing dramatically broader access to the systems, the EU should establish an entirely new type of HPC environment.

These new HPC exascale development lab/testbed centers are needed to address these weaknesses in HPC today:

- Most large HPC systems are very hard to use by all but the most talented experts.
- The productivity in using highly parallel systems is very low, no matter which metrics are used:
  - Time to get an application up and running versus the usefulness of the results
  - Time to optimize codes versus the speed-up obtained
  - Percentage of the system that can be effectively used by a user's job
- There are a limited number of scientists, engineers, and analysts in the EU, while other countries such as China and India have strong growth in graduates in these areas, making the productivity of these experts a critical deciding factor in the advancement of science and research.

5.6 What the New HPC Exascale Development Lab/Testbed Centers Would Look Like

It is recommended that the EU establish a number of new centers with the focus on developing better HPC software, tools, applications, etc., as well as training researchers to make them highly productive and innovative. The focus is to make these systems and centers work on developing better HPC, and not running user jobs. They could be located within existing centers, but a key is to have a broad group of experts, teachers, users, designers, etc. all share the same center, projects, and goals.

There have been a number of smaller-scale examples of HPC testbeds, but none has been done on the scale proposed here and with the broader strategic goals proposed.

The HPC exascale development lab/testbed centers (techno-pools) concept:

- The testbeds would focus entirely on the advancement and usage of HPC software and hardware technologies, rather than conducting science and engineering work.
- The testbeds would be dedicated HPC centers with the goals of helping users, researchers, and companies make their codes and products highly scalable and highly productive and innovative.
- These HPC systems would only be used in a test and development mode. They may crash hourly as new algorithms, new codes, or even new hardware is being tested, optimized, and made resilient.
- The expanded PRACE coordinating organization should manage the large EU HPC exascale development lab/testbed centers.
- The systems need to be large, but not extremely large. IDC envisions the largest single system at a typical HPC development lab/testbed center as on the order of

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one-tenth of a peak exaflop, with a purchase price on the order of €10 million to €20 million.

- The HPC development testbeds should have major training and teaching responsibilities. They should offer classes in all forms of advanced HPC, again with a focus on making users and products more productive and innovative. This requires a strong technical staff, along with teachers and HPC experts across multiple domains.

- They would support individual users and researchers across the EU. For example, if scientists have ideas for how to make their codes run at a larger scale, they could make use of the testbed systems and staff to figure out new algorithms, test them at scale, make improvements, and then take the results back to their home organizations. They would be allowed to do this at no charge, but would not be allowed to use the center resources for regular job runs. The PRACE systems and other computers across the EU would be used for regular job runs.

- They would also support the broader EU vendor community and ecosystem. For example, if a EU vendor decides to research a new interconnect for exascale systems, they could use these HPC development testbeds for testing out the new interconnects by physically installing the new hardware, and then running tests, debugging, and making their product more resilient. The EU should help support the broader HPC ecosystem by making these resources "free to all, for development and testing work only."

The EU should help support the broader HPC ecosystem by making these resources "free to all, for development and testing work only."

- In order to provide the broadest and most useful test and development environment:

  - One could be a large x86 cluster, running the best-in-class HPC parts with higher-performance interconnects and a very complete software stack.

  - One could be a very large cluster, built with the cheapest parts and without any special interconnects. This would also provide a close approximation to running jobs in a cloud environment.

  - Another system could be based on a more custom design, perhaps around an exascale type architecture.

  - Another system could be a cluster with a large number of GPUs.

- A fast way to develop the critical expertise is to create a larger and more complete ecosystem — grouping in the same place users and providers, computer experts, teachers, from industry and academy, to create the proper technological dynamic and to ensure the fast spread in industry and research. This is an optimized way to accelerate both development and usage, which are strategic for European competitiveness and innovation and will become an engine for growth indirectly through an increase in competitiveness and directly through the development of these new activities.

5.6.1. Possible Locations of the HPC Exascale Development Lab/Testbed Centers

The larger testbeds will require a large staff of HPC experts, computer scientists, researchers, and teachers. In addition, they require full support of a complex HPC computer center. Four likely locations include:

- At major academic institutions that already have a strong starting set of HPC talent
- At some of the tier 0 PRACE centers, but as a separate computer center
- At a vendor HPC lab or center in Europe
- A few could be at new centers with a dedicated focus area

In addition, it would be useful to have 10 to 12 additional smaller HPC development testbeds across Europe that are tightly tied into the three to five larger testbed centers. The size of these centers would be much smaller, perhaps with systems in the €1–€5 million range.

5.7 The Need for Attracting Top Scientific Talent Via a "Magnet" Program

To accomplish the major objective on making Europe the hotbed for scientific research, the EU needs to fund a number of HPC magnet programs to attract top scientists, recent graduates, and other researchers to European institutions. The magnet program should include:

- Funding of highly prestigious positions/seats at top EU educational institutions. These need to include sizeable research grants to attract the top talent.
- Creating a new degree-like position between a PhD and a professor, and inviting selected top researchers and top new graduates to attend these degree programs at no cost.

These positions need an exciting title and full press coverage. The goal should be to start ASAP with tens of these new positions, growing quickly to hundreds per year.

Note: In some respects, the proposed HPC magnet programs resemble the existing "people" programs of the ERC, Marie-Curie, and Capacities/RI transnational programs in Europe. None of these programs specifically focuses on HPC, however.

5.8 The Need for Adequate Funding of Exascale Software Development

In order to achieve the goals, there is a major requirement for investing in new software, new tools, and rewriting and improving existing software. Most HPC experts believe that the world of HPC has to change along many dimensions on the road to exascale. Most also believe that many things became broken well before the petascale era, but now the disconnects between what users can actually do and the capability of the hardware is so vast that a revolution is required.

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This is what creates a sizable opportunity for the EU to establish leadership and generate major scientific and economic advances. To accomplish this requires software investments at the PRACE level, at the national level, at the individual centers, as well as within the proposed new HPC development testbeds. The total investment in software needs to grow by a similar order of magnitude that the hardware investments need to grow (see the next section for estimated funding levels).

One of the major challenges is how to evolve existing applications so that they can exploit 1,000 to 10,000 processors without requiring a complete redesign of the codes. The EU needs to think through its strategy for stimulating the wider uptake of simulation and modeling in general, and then accelerating the impact of HPC in transforming the scale and scope of scientific and engineering research. The first area to address is the increase of processing capacities based on new architectures that integrate multicore CPU processors and GPUs. One major result of this disruption is that the IT world is becoming parallel from laptop to supercomputer.

5.9 The Need for Expanded HPC Training With a Focus on Software Usage

The investments required for scientific and economic success include many areas in addition to the cost of the computers. One of the most critical areas is the experts, including the scientists and researchers as well as the experts in using the supercomputers. There is a growing worldwide shortage of HPC talent due to a combination of an aging workforce and fewer new graduates in various HPC fields (see the soon to be published DOE HPC Talent study at www.hpcuserforum.com).

HPC leadership, however defined, is unattainable without an adequate number of properly trained personnel, including computational researchers, system administrators, technologists, and all the others who help make up the HPC ecosystem. In HPC User Forum meetings and at other HPC conferences in Europe, North America, and elsewhere during the past decade, HPC leaders say they expect their growth plans to be limited by a shortage of available, qualified personnel.

In Europe, there is a tendency to support the procurement of HPC systems by national programs, but these programs often neglect the necessity to have enough qualified personnel to use, run, maintain, and enhance the systems but also for user support, porting of applications, and development of new applications and techniques.

The HPC personnel shortage that affects Europe and North America to a great extent, and the Asia/Pacific region to a lesser extent, is no accident. The United States is the world's largest HPC market and historically has been the largest university educator of the global HPC workforce. When HPC funding from the U.S. government and closely allied nations declined after the end of the Cold War, the HPC market entered a period of slowdown from which it did not start to recover until about 2002, when the fast rise of HPC clusters caused a five-year spurt of average 20% annual revenue growth.

The period of HPC slowdown, occurring as it did alongside the explosive growth of Internet companies, helped to transform the image of HPC into that of a dying, "old technology" market. The number of university programs in computational science and related fields plummeted, as did HPC-related internship and postgraduate fellowship opportunities. Young people who might have chosen an HPC career a decade earlier all too often opted instead for employment with a "new technology" Internet or gaming company. As a result, a high proportion of today's graying HPC workforce is within a decade of retirement age and educational institutions are not producing enough HPC-trained graduates to replace them.

Fortunately, HPC centers in Europe and elsewhere have begun to address the labor shortage in collaboration with academia through new curricular and internship offerings, and through accelerated on-the-job training, but there is still a long way to go — especially in light of the challenges needed to harness the potential of petascale and exascale computers. And this opens a major opportunity for the EU to take a leadership role.

5.10 Advanced Software Training is Critical to Improve HPC Productivity

Increased HPC training and education in exascale HPC in Europe is greatly needed, and has to fulfill several basic requirements:

- Create an adequately trained European workforce by offering contiguous bachelor/master/PhD programs in informatics, software engineering, computational sciences, and electrical engineering

- Support specifically European industrial users and SMEs in the petascaling of important applications

- Create similar offerings for lifelong learning for academia as well as for industrial participants

- Support users in skills for adaptation of existing application algorithms and the creation of new algorithms and codes that make efficient use of resources as a specific European strength

The educational offerings should be organized along the following guidelines:

- HPC and the efficient use of system resources by applications are an effort which is basically of interdisciplinary nature. It requires the cooperation of mathematicians for algorithm design, evaluation, and optimization, of informaticians for the design, implementation, and use of integrated hardware/software systems including all aspects of massive parallelism and scalability issues in operating systems, programming languages, and compilers, optimizers, middleware for reliability, load balancing, multithreading, as well as tools for performance analysis, debugging, visualization, and optimization, and finally of the application area specialist. Educational offerings must reflect this interdisciplinary approach in courses such as computational science and engineering, computational physics, and computational "xyz" in general.

- It is important that educational offerings are oriented both toward academia (to support future R&D in the field) and to an even larger extent toward practical applications of HPC. The offerings should therefore include specific case studies, labs, and implementations which foresee cooperation with the different areas of application (in industrial and academic environments).

- Specific support should be given to European SMEs that do need to have access to the newest HPC technology at low cost. Practical training for existing system

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technologies and application programs, and support for the porting of applications to new HPC architectures, should also be given.

- The high quality of educational offerings should be obtained by honors programs that include additional skills in education. Special emphasis should also be given to the international exchange of students and subjects.

- In general, a large spectrum of offerings ranging from full programs (bachelor, master, PhD) to smaller entities such as tutorials, workshops, and in-house training should be provided.

A practical example for an educational offering as a full program organized according to the above recommendations is the Bavarian Graduate School of Computational Engineering (BGCE, www.bgce.de). An example for smaller entities is the offering by the members of Gauss Centre for Supercomputing (www.gcs.de).

5.11 Potential Domains for Scientific and Engineering Leadership Areas

One of the strongest messages from the field research IDC did for the Interim Report is that the EU HPC strategy should continue to support all disciplines but should single out a limited number of scientific, engineering, and technology domains to pursue for global leadership by 2020. These should be areas in which Europe already has considerable strength, creating the basis for future leadership.

Based on the field research, subsequent discussions with HPC leaders in Europe and elsewhere, and the findings of other recent IDC HPC studies, these are the domains that Europe should consider for leadership pursuits.

Criteria for Selecting World Leadership Domains

Scientific, engineering, and technology domains selected for the pursuit of world leadership should meet these criteria:

- The domain should have strong current and/or potential importance, both from a research and economic standpoint. Ideally, the domain should address one or more major ("grand challenge") societal problems.

- Progress in the domain should benefit multiple scientific disciplines and economic sectors.

- Europe should already have considerable strength within the domain, creating the potential for assuming world leadership by 2020. This strength should exist within many EU Member States, both large and smaller.

- Leadership in the domain, once achieved, should be sustainable for a reasonable period of time and with reasonably affordable investment.

Findings From Field Research

The extensive field research IDC carried out for this study and documented in the Interim Report showed that the HPC-enabled scientific and engineering areas most often proposed by survey respondents for leadership were as follows:

- Clean and sustainable energy (including nuclear reactor design/operation, oil and gas exploration, smart electrical grids, clean water, fusion energy, and other alternative energy research)
- Climate modeling and severe weather forecasting
- Physics (e.g., the Large Hadron Collider)
- Aerodynamics and other automotive/aerospace methods
- Chemistry, pharmaceutical, and other bio-life sciences research

The survey respondents saw the technical areas of expertise most needed by HPC user organizations as falling into these main categories:

- Expertise in parallel programming for highly parallel HPC systems
- Expertise in creating advanced software algorithms
- The ability to port and optimize applications for new hardware architectures, including heterogeneous architectures that include newer processor types

Suggested Target Domains

Not all of the domains identified in the field research fit the selection criteria equally. When the criteria are taken into consideration, IDC recommends the following domains as candidates to target for world leadership by 2020 (as also noted earlier in this report):

- **Weather and climate research.** Europe already has world-class, and arguably world-leading, expertise in this increasingly important field. Weather and climate research affect many other scientific and engineering fields, including economic planning, agriculture, aviation, tourism, energy research (e.g., the carbon cycle), and even automotive engineering (e.g., emissions).

  Europe's high standing in these fields is a shining example of success based on free market principles. The EU should not attempt to meddle with this success, but should actively support Europe's weather and climate research communities with appropriate peer-reviewed access to tier 0 HPC resources and continued support for collaborations within this community.

- **Clean and sustainable energy,** including nuclear reactor design/operation, oil and gas exploration, smart electrical grids, clean water, fusion energy, and other alternative energy research. This domain is a natural partner for weather and climate research. Europe already has world-class strengths in this domain, which covers a lot of scientific and economic ground and may become the most important domain of all in the not-too-distant future.

  - Europe is already the most "green-conscious" region of the world.
  - Europe is a global leader in the design and operation of nuclear power plants, an area of expertise that largely disappeared in the United States and now needs to be rebuilt.
  - The first experimental fusion energy reactor (ITER project) is scheduled to go into operation in France.

- Within Europe there are large-scale wind turbine farms and other leading-edge alternative energy sites in operation or in the planning stages.

- Europe has amassed considerable scientific and engineering expertise in this field.

- **Automotive and aerospace design, and bio-life sciences.** Europe today has world-class capabilities in the related fields of automotive and aerospace design engineering, including computational fluid dynamics (CFD) and computational structural analysis expertise and software creation. Europe also has world-class strengths in the bio-life sciences sector. In addition, an IDC study for the Washington, DC-based Council on Competitiveness showed that European best-in-class automotive and aerospace companies typically have pushed HPC usage much deeper into their organizations on average than U.S. tier 1 firms — more frequently extending its use from traditional upstream applications in R&D and design engineering into high-value downstream uses, such as manufacturing and production. The study also found that the European automotive, aerospace and bio-life sciences firms more often require their suppliers to use HPC than occurs in North America.

  Although much of the activity in these domains will continue to take place in the national HPC centers, particularly where industrial participation is concerned, the EU should provide peer-reviewed access to tier 0 HPC centers for scientific and industrial research in these fields, and should promote appropriate collaborations between tier 0 centers and tier 1 national centers.

  EU support for the European Aeronautic Defense and Space Company (EADS) is an existing initiative that will presumably continue.

- **Particle physics and related fields.** Europe's investment in the Large Hadron Collider (LHC) at CERN has already set the stage for global leadership in particle physics, and in HPC-based model and simulation to support this work. The LHC is already attracting top particle physicists from throughout the world — a good example of how the "brain drain" can be reversed in Europe's favor. Even before the availability of the LHC, European particle physicists at CERN and other institutions were on a par with the best in the world.

- **Modeling of materials/molecular dynamics.** The Car-Parrinello method that is central to molecular dynamics research was invented in Europe and molecular dynamics is used in many scientifically and economically important fields, including materials science (development of new materials, aging of materials), alternative energy (improved design for solar cells, wind turbines, etc.), drug discovery and other biomedical research, nanotechnology, product engineering, and more.

Technology Leadership Areas

In support of leadership in the scientific and engineering domains, IDC recommends that the EU HPC strategy target global leadership in the following HPC technology areas. Europe has world-class strengths in all of these areas today, and each of these areas will become far more crucial for leadership by 2020. The European Exascale Software Initiative (EESI) was founded to help organize Europe's efforts in these areas, in part by bringing together "islands" of software talent within Europe to create the critical mass needed to address the daunting challenges associated with developing exascale software.

- **Leadership in making large-scale HPC highly productive and innovative to users.** Including all types or HPC users, researchers, and students.

- **Highly scalable algorithms and software applications,** especially related to the targeted scientific and engineering domains, but by no means limited to these domains.

- **Leadership in parallel programming of future-generation, heterogeneous supercomputers.** Future-generation supercomputers will employ up to 1 million or more processor cores and multiple types of processors/coprocessors. The ability to create programs that efficiently exploit these highly parallel, heterogeneous supercomputers will be extremely valuable.

- **A highly scalable, narrow-purpose HPC hardware/software system,** co-designed with the scalable software to enable world-leading sustained performance on the targeted applications. This exascale system would be based on commodity components and an architecture available in the global market, but would need to be augmented with purpose-built software (and perhaps also hardware) to support leading performance in the targeted application domains.

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6.0 RECOMMENDED STRATEGIC PRINCIPLES AND SUPPORTING ACTIONS

In addition to the primary strategic actions there are a number of strategic principles and supporting actions required.

6.1 Stakeholders and Organization Structure Options

HPC 2020 Action Plan: Stakeholder Roles and Responsibilities

To succeed, the goals of the Strategic Agenda must be shared by the main stakeholders, and the roles and responsibilities for the implementation of the Action Plan need to be clearly defined. There are potential tensions between the different stakeholder interests along multiple dimensions, including:

- The balance of responsibilities between the European Commission and the Member States concerning coordination, strategic choices, funding provision, monitoring and control.
- The different positioning of large Member States compared with small Member States in terms of the potential research areas, benefits, and motivations to invest in HPC.
- The requirements of science versus industry, and different Member States' opinions about the rules of access and use of shared HPC infrastructures.
- The implications of a coordinated European HPC procurement policy for the European industry (should it be favored or not) and specifically for some Member States' HPC industries, and the pros and cons of a pre-commercial European procurement policy.

6.2 Governance and Organization Options Explored and Recommended

The focus here is to suggest the appropriate governance mechanism for the HPC Strategic Agenda to achieve an optimal balance between the main stakeholders, suggesting some operational solutions with their pros and cons.

First of all, there should be a clear policy decision at the European Union level about the need for a HPC Strategic Agenda and the strategic goals that it should pursue. The evidence presented by this study of the value added of an initiative at the EU level, the potential benefits and the potential risks if no action is taken, can provide a basis for this policy decision. In any case it is important that the Member States governments provide a clear political support at the highest possible level to the HPC 2020 Agenda and agree on the overall strategic goals, level of funding, timing, and main milestones. The European Commission can define the mechanisms for the monitoring, assessment, and periodic revision of the Strategic Agenda, in cooperation with the Member States governments. The main decisions about the amount of funding and cost sharing between the EC and the Member States should be taken at this level.

The implementation of the Action Plan will require the establishment of a coordinating body at the EU level. There are several options for this coordinating body; the following ones were analyzed and evaluated on the basis of meeting the suggested goals:

- A new PRACE, but with an extended mission and expanded structure, goals, and responsibilities. The main pros are the ability to exploit the current momentum and the already existing community of stakeholders; the cons are that it would be necessary to handle a transition to a new coordination and management model, reaching out to other Member States. This would be the fastest approach to getting an organization structure in place.
- A new organization, created from the merging of existing initiatives at the European or national levels. This approach could strengthen the scientific aspect of the initiative but would take longer to take off because of the need to reconcile different experiences in a single model. In addition, it would require a whole set of negotiations and organization design that could take many years.
- A permanent organization such as a European agency, for example similar to ENISA (the European Network and Information Security Agency), with the responsibility to run and provide HPC infrastructures and services. This last option would provide a strong managerial and organizational structure, centralized governance with a stronger role for the European Commission, but may require higher investments and a much longer time to be established.

IDC recommends the first option — an expanded PRACE — as the most feasible and the fastest option, because of the consensus gathered by the stakeholders surveyed, and because of the possibility of exploiting its current momentum.

IDC recommends the first option — an expanded PRACE — as the most feasible and the fastest option.

6.3 Need to Establish Clear Roles and Responsibilities (EU and Member States)

The governance of the new coordinating body should enable stronger coordination between the Commission and the Member States than the current PRACE. This should take into account different levels of engagement and of investment by less involved Member States (for example the smaller Member States), defining for example more and less active membership profiles and HPC sharing mechanisms.

The European HPC infrastructure recommended by the Strategic Agenda will be a layered infrastructure, including tier 0 HPC centers, collectively funded and shared, and tier 1 centers at the national level.

Roles and Responsibilities

This section proposes an effective division-of-labor between the EU and the Member States as Europe prepares to pursue a stepped-up HPC strategy and world leadership in targeted domains by 2020. The recommended division-of-labor includes three categories:

- EU-only responsibilities
- Member States-only responsibilities
- Joint EU-Member States responsibilities

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According to IDC analysis, and based on our vision of the optimal balance of tasks between the EU level and the Member States level, the division of responsibilities could be as follows.

Responsibilities: EU Coordinating Body/Organization

The field research conducted for the Interim Report showed strong consensus for an EU HPC strategy to enable Europe to compete with other global regions in a way that no single EU member state could afford to fund and sustain. Europe's existing PRACE program was widely (though not universally) seen as having established a useful model (tier 0, 1, and 2 centers) and basis for a stepped-up EU HPC strategy that would, however, need to augment PRACE's current service-provision mission and funding.

In recognition of HPC's importance for European scientific advancement and economic competitiveness, establish a new organization (suggested names: EU Coordinating Office for High Performance Computing, or EU Coordinating Office for Computational Science and Engineering, or equivalent name) to carry out the stepped-up EU HPC strategy. This could be a renaming of PRACE to reflect its expanded mission and stature, with the PRACE name retained for existing activities within the new organization. (In any case, it is critically important not to affect the momentum and plans already established by the PRACE program.)

IDC recommends that the EU/Expanded PRACE have primary responsibility for the following functions and activities related to HPC:

- To implement the action plan, be responsible for the collection, administration, and spending of joint-funding projects.
  - Carrying out the stepped-up EU HPC strategy on behalf of the Member States and driving toward the goals of this strategy, including coordination with the Member States, along with the pursuit and administration of increased funding needed to implement the stepped-up EU HPC strategy.
  - To coordinate and advance existing EU collaborations with non-EU governments and organizations, and work to establish useful new collaborations with non-EU governments and organizations in the interest of the Member States.
  - To promote and support the training and hands-on experience of human resources in the HPC field.
  - To act as an arbiter for possible conflicts or difficulties arising from the exploitation of the shared HPC infrastructures.
  - Define the details of the cost sharing balance based on the principles decided at the policy level.
- To manage the tier 0 HPC centers.
  - Including the establishment and coordination of external peer review panels for allocating access for scientific and industrial research projects to tier 0 HPC center resources, and the establishment and administration of policies and procedures for providing industry with more-limited paid, non-peer-reviewed access to these resources as appropriate.

- To coordinate, facilitate, and oversee the collaborations between tier 0 HPC centers and nationally funded tier 1 HPC centers. Also work to provide access to tier 0 HPC center resources, as appropriate, for international and regional HPC-based collaborations taking place within the EU.

- Ideally, the EU and the national government should split funding for the tier 0 centers (for example, on a 50/50 basis), and funding should cover both the initial investment and operations.

- To operate the larger EU HPC exascale development lab/testbed centers.

- To invest in the magnet and software development programs.

Responsibilities: Member States Only

The Member States have worked hard to establish the existing nationally funded HPC tier 1 (and tier 2) centers, and to acquire HPC systems, employees, networks of internal/external relationships, and other valuable assets. The EU HPC strategy needs to respect and enhance these activities, and not disturb what the Member States have built and accomplished. The Member States should maintain semi-autonomous control over their HPC centers and activities, within the framework of the commonly agreed coordination process.

But for the common EU HPC strategy to succeed, the Member States need to assume certain responsibilities for the common good. IDC therefore recommends that the Member States continue to carry out the following responsibilities:

- To administer and control access to tier 1 national HPC centers and other HPC facilities and activities within their borders

- To set up and operate the national (techno-pools)

- To fund the growth in national centers

- To invest in the magnet and new software development programs

- To promote and support the training and hands-on experience of human resources in the HPC field

Responsibilities: EU and Member States Acting Together

IDC recommends that the following responsibilities be carried out by the EU and the Member States, acting in close collaboration:

- Promote and support a closer collaboration of Europe's scientific and engineering community around the cutting-edge use of HPC, in order to contribute to the creation of a more powerful "critical mass" of talent and research capability.

- Promote and support the dissemination of scientific and engineering knowledge and of the results of HPC-based research among and within the EU Member States, alleviating the "digital divide" in the process.

- Support funding for procurement of large supercomputers at tier 0 HPC centers.

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- Support increased collaboration between all EU HPC centers. More active collaborations have benefits that are important for the Member States and for Europe's ability to compete on a global scale.

6.4 Need to Provide Broader Access to Users in Both Science and Industry

- **Access should be increased for both science and industry.** Scientific access to tier 0 HPC resources is the most important and will use most of the cycles, but some industrial problems are also significant and can be as challenging as scientific problems. If industry can't access tier 0 centers, it will have nowhere to go to solve these economically important problems and European industrial competitiveness will suffer. Advancements in basic science are valuable in their own right. It is also important to encourage the progression that leads from basic scientific research to industrial research as a prerequisite for economic success. PRACE has set the stage for industrial access with its well-attended industry workshops. Future PRACE calls-for-proposals should expressly invite proposals from industry as well as science.

- **Scientific access should continue to be primarily on a peer review basis.** In an ideal world, all scientific access to tier 0 centers would be based strictly on peer review, such that if proposals from small Member States were judged the most worthy, those proposals would always be awarded substantial access. Basing all allocations purely on peer review would accelerate the integration of Europe's science community and its important work. But the political reality is that larger states that make larger contributions to the PRACE program expect greater access for their researchers in return, under the principle of "juste retour." Although trying to eliminate this principle today is impractical, the largest PRACE contributors should continue to seek ways to move increasingly toward allocations based purely on peer review. In the meantime, after-the-fact accounting review should continue to see which countries use the resources most.

- **Industry access should also be based on peer review.** Unpaid access to tier 0 HPC centers should be awarded only to industrial research proposals whose authors agree to publish at least a meaningful part of the results at the conclusion of the project or within a specific, relatively brief period afterward (say, within six to 12 months).

  If the EU and/or the tier 0 hosting centers decide to allocate some time on the HPC resources for non-research-oriented industrial work, industry should be charged for this time — perhaps not at full market rates, but at a level high enough to cover the basic system costs. Otherwise, experience shows that industry will come to see the tier 0 resources as "cheap" access and will not use the resources well.

  As is the case with scientific researchers, the tier 0 centers should expect to help industrial researchers to develop algorithms and map their problems onto the tier 0 supercomputers. As noted earlier, much of the industrial access in Europe will continue to be done on the tier 1 national centers. It will be important for the tier 0 and tier 1 centers to coordinate so that worthy industrial research proposals are awarded time at the appropriate facility.

6.5 Buying Rather Than Building Exotic Custom Exascale Supercomputers

Twenty-five years ago the HPC market was driven by high-end custom computers, built primarily in the U.S. and Japan. U.S. and Japanese vendors were forced to innovate heavily because there were few standard component technologies for them to buy in the open market.

The steady march of commoditization has made it possible for nations and regions of nearly all sizes to enter the global race for HPC (i.e., scientific and engineering) leadership, assuming they have the financial means and willpower to fund petascale/exascale systems. Today, the global HPC market is dominated by commodity clusters that are based on standard x86 processors, standard operating systems, and the standard MPI message-passing protocol. Even many of the most powerful contemporary supercomputers are based on these commodity technologies, with custom technologies (e.g., interconnects, heterogeneous processors) selectively added on to boost performance.

For the most part, HPC commoditization has been a good thing:

- It has led to more affordable, easily deployable systems, making the benefits of HPC accessible to many more users. In the process, this has grown the HPC server market from a €1.5 billion space 25 years ago to one that IDC forecasts will reach €8.3 billion in 2013 (by 2013 the market for all HPC products and services is expected to exceed €17 billion).

- Commoditization has also eased the creation and implementation of industry standards that have greatly advanced collaboration among HPC users.

- A major downside of commoditization and the standardization it makes possible is that it becomes more difficult to shift to a new paradigm if the existing one begins to hit a wall, as is happening today (e.g., the "memory wall" and the "parallel programming wall"). IDC research studies have consistently shown that few HPC users are ready to shift to a new paradigm that would require learning a new programming language, such as PGAS, and rewriting applications software.

  - This downside has led to large computers with 100,000 or more processors and soon over a million processors in one system, while most HPC user codes only scale to 8 processors today, and 90% scale to under 1,000 processors. So system productivity is at a low point and getting worse.

Europe should also plan to acquire supercomputers that are heavily based on commodity technologies — augmenting these selectively with custom technologies as needed (e.g., IBM BlueGene) — rather than attempting to design a new supercomputer architecture from the ground up. This approach has important advantages:

- First and foremost, this approach supports the primary objective of an expanded EU HPC strategy, which is to help advance science and engineering. Advances in new custom HPC technologies are an important but secondary consideration.

- It will allow Europe to exploit the attractive price/performance of commodity-based supercomputers. This price/performance is based on the economies of scale of the standard component technologies used in these systems.

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- It will avoid the enormous expense needed to develop component technologies, such as processors, interconnects, and system software.

- It will allow Europe to benefit from efforts around the world to advance HPC hardware, software, energy efficiency, and industry standards.

- It will encourage European HPC hardware and software vendors to create products/solutions that can compete effectively in the worldwide market. The European HPC market is not large enough to sustain these vendors as growing, thriving companies over time.

- In addition, many U.S. HPC system vendors are already opening up HPC R&D centers across the EU, which the EU can leverage.

In summary, Europe should continue to provide its scientific and engineering communities with the best supercomputers and other HPC resources, no matter where in the world they come from, without providing special advantages to EU-based vendors. This will serve to maintain Europe's status as perhaps the most open, competitive HPC market place in the world. Compared with the U.S., EU buyers have a much broader selection of HPC products to choose from, e.g., can you imagine a U.S. buyer trying to buy a large Chinese or Russian built HPC supercomputer?

In cases where non-European markets are less open to EU-based HPC vendors, as is arguably the case with public sector markets in the U.S. and Japan, the EU should press for equal treatment of its vendors in those markets rather than creating special advantages for domestic vendors in European procurements. Creating special advantages for EU-based vendors does not serve the interests of science and engineering progress. Often when protectionism has occurred in the worldwide HPC market, science and engineering have been the losers.

As noted elsewhere in this report, Europe should plan to augment commodity-based supercomputer technologies with custom ("purpose-built") technologies in designing the exascale or near-exascale supercomputers that will support European primacy in the targeted leadership areas. Because enabling scientific and engineering leadership is the main objective for this supercomputer, the EU should also conduct a procurement that is open to vendors from throughout the world.

It might be argued that because China has said it intends to design its own supercomputers from the ground up, Europe should do the same. The argument here is that HPC technology is strategic and Europe (or China) cannot afford to have it controlled by another country or region. But China is coming from a history of not being allowed to acquire powerful supercomputers from other countries, and presumably China does not want to be in this dependent situation in the future. In sharp contrast, Europe has arguably been the most open, competitive HPC market in the world. IDC believes it is highly unlikely that political differences would emerge to bar the sale of U.S. and Japanese supercomputers in Europe between now and 2020. In addition, the high cost of building custom new supercomputers results in a very poor ROI, with the first systems often costing 2x the cost of buying the second or third system.

6.6 The EU Should Continue to Support Grid and Cloud Computing to Increase Collaborative Research

The EU HPC strategy needs to continue support for grid and cloud computing as ways to encourage the growth of collaborative and distributed scientific and engineering research. The approach to research, especially in science, has changed dramatically in recent decades. Increasingly, lone scientists working in isolation have been replaced by teams of scientists collaborating over distances. Grid and cloud computing models help to support some of the newer modes of collaborative research.

In the field research IDC conducted for the Interim Report, European respondents named DEISA as one of the top HPC programs in Europe. DEISA, based on agreements among large HPC centers in Europe, provides a distributed, grid-based infrastructure for supercomputing applications in Europe.

CERN, home of the world's biggest particle accelerator (LHC), recently announced that with Platform Computing's help it is developing what may be the world's biggest scientific computing cloud to distribute data, applications, and computing resources to scientists in Europe and around the world. In February 2010, NASA announced plans to build a cloud environment with a Web portal to enable researchers to run climate models on remote systems provided by NASA. This will save NASA from having to help users build the complex models correctly on their local systems. Boeing and other companies have been remotely accessing the big supercomputer at Tata's CRL location in Pune, India, for several years. Therefore various forms of cloud computing are inching their way into the HPC market.

Because of security, data, cost, and other concerns with public clouds, most of the action today is in private ("internal") clouds such as the CERN and NASA examples, where the computing resources are owned and managed by the organization using them. Public clouds can allow HPC sites to leverage existing computer infrastructure and personnel, to balance workloads for efficient use of HPC resources, and to enforce data privacy, policies, and directives.

Many HPC users and jobs require higher performance features and capabilities than currently offered by most cloud providers today. But some HPC organizations, especially in the engineering services, oil and gas, financial services, and digital content creation sectors, are actively exploring and in some cases already using public clouds to handle workloads or portions of workloads that aren't very latency-dependent. "Surge" or overload work is another reason for turning to public clouds for tier 1 organizations, and for SMEs, public clouds promise to avoid capex that would have been needed to buy and support their own servers.

IDC expects cloud computing to remain at an early adoption stage in 2010, with the majority of the activity on the private cloud side. But advanced cloud initiatives like those at CERN and NASA will be used, when ready, for production scientific work and will almost surely advance the boundaries of cloud computing, at least in certain targeted areas.

6.7 Need to Promote Public-Private Partnerships to Advance Competitiveness

We recommend that as part of its mission, the proposed expand PRACE (perhaps to be called the EU Coordinating Organization for High Performance Computing) actively encourage the formation of public-private partnerships in the HPC domain. Funding for the partnerships could come from multiple potential sources. It was beyond the scope of this report to evaluate these potential sources, but we recommend that this evaluation take place.

As the examples below support, public-private partnerships that pair industry with university HPC resources are already well under way in a number of EU Member States. As part of the HPC strategy for Europe, the EU should actively promote the formation of public-private partnerships, to advance industrial competitiveness and to tighten the linkage between European science and industry. In pursuit of these objectives, the following actions are recommended:

- The EU should study existing public-private partnerships involving HPC, such as the examples below and others, in order to support one or more model for these collaborations.
- The EU should create a framework that any Member State or local government can use to promote the formation of public-private partnerships within its boundaries, or extending beyond its boundaries. The framework should include appropriate legal guidelines.
- The EU should serve as a clearinghouse for information on public-private partnerships involving HPC.

Examples of Public-Private Partnerships That Work Well

Example #1: HWW (Stuttgart, Germany)

HLRS provides HPC services for academic and applied research. HPC services provided to industry are organized through two organizations: HKZ-BW and HWW GmbH. T-Systems, T-Systems SfR GmbH, and Porsche AG provide co-funding and expertise for these collaborations. The Automotive Simulation Center Stuttgart (ASCS) is the organization through which HLRS provides HPC services to the wider automotive industry. The center has a focus on engineering and material science and a strong focus on physics.

HLRS participates in a commercial joint venture company, HWW Betriebs-GmbH, whose partners are debis Systemhaus, Porsche AG, the state of Baden-Wuerttemberg, and Stuttgart University, with T-Systems also involved as the marketer of HLRS computing resources and services to industrial users. HWW stands for Hochleistungsrechenzentrum für Wissenschaft und Wirtschaft, the High Performance Computing Center for Science and Industry.

HLRS Director Dr. Michael Resch explained the rationale for forming the HWW public-private partnership: "Although it's unusual for German universities to align themselves this closely with industry, in this case there were important advantages:

- First, our main goal was to bundle together the resources of the academic research community and industry. By doing this, they can operate a large number of systems with a small number of people. They have half a dozen system administrators running nine to 10 supercomputers today. They can make the most of taxpayers' money and leverage resources on behalf of our users.

- Second, HLRS gains by adding industrial users, and industry gains by giving their users access to advanced HPC resources and expertise.

- The third advantage is that partnering in a commercial venture told all parties that this had to be a serious collaboration. HWW is about risk-sharing."

Example #2: Automotive Simulation Center Stuttgart (ASCS)

An innovative public-private partnership aimed at advancing the automobile industry through HPC called Automotive Simulation Center Stuttgart was founded at the University Stuttgart.

Composed of software designers, scientists and researchers, and top automobile manufacturers, ASCS will combine the expertise of key scientists and industry representatives with leading-edge supercomputing technologies to conduct research aimed at developing quiet, low pollution vehicles; creating products for the market that reduce fuel consumption, lower CO_2 emissions, and enhance safety; increase cost efficiency; and speed time to market with new products.

The founder members of the ASCS are the University of Stuttgart in Germany; the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS); automobile manufacturers Porsche, Daimler, and Opel; supercomputing expert Cray; software vendors Abaqus, Altair Engineering, DYNAmore, Engineous Software, and Intes; the Virtual Dimension Center Fellbach; and the full-service vehicle supplier Karmann. Other companies, and the University of Karlsruhe, also joined ASCS.

"The University of Stuttgart brings expertise from several sides; for example, along with the High-Performance Computing Center [HLRS], the new Cluster of Excellence for Simulation Technology is involved," said Wolfram Ressel, rector of the University of Stuttgart. "The experts who work for the cluster of excellence will help to integrate still isolated numerical approaches in the development of advanced simulation technologies."

ASCS is bringing together industry experts and top scientists with the aim of developing products and energy-efficient technologies as well as enhancing product development and optimization practices for the global automobile industry.

The initial funding for the project was provided by the Ministry of Science of the Federal State of Baden-Wuerttemberg and the University of Stuttgart. The ultimate goal is to establish ASCS as a non-profit organization to be funded through membership fees and third-party contributions.

Example #3: Plans for the New Hartree Centre

The Hartree Centre (http://www.cse.scitech.ac.uk/events/Hartree_Summary/) will be a new kind of computational sciences institute for the U.K. It will bring together academic, government, and industry communities, and focus on multidisciplinary, multiscale, efficient, and effective simulation.

The Hartree Centre is being realized as one of a number of Technology Gateway Centres that form part of STFC's strategy for the development of the Daresbury and Harwell Science & Innovation Campuses. Capital funding for the first three of them, including £50 million (€62 million) from the Large Facilities Capital Fund to build and

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equip the Hartree Centre, was approved by DIUS on July 14, 2008. Detailed science and business cases are being developed for submission to the Department for Business, Innovation & Skills (BIS). In 2008 they ran a series of initial workshops in several different subject areas (see below). They plan to work with both the industrial and academic communities to build an exciting science program that supports a step-change in knowledge exchange and economic impact.

The vision for the Hartree Centre combines an innovative approach to computational science research that will be funded through a program of grants, knowledge exchange, and service activities. Some of the key elements of the Hartree Centre approach will be:

- A small number of focused, medium- to long-term, grand challenges in a highly collaborative structure, bringing together the skills of leading U.K. and international research groups and the STFC

- Extended and dedicated access to large-scale computational resources

- A coordinated program of algorithm and software development, driven by the needs of the grand challenges, with input from both commercial and non-commercial application software developers, software tool developers, computer science and numerical algorithms experts, and computational scientists

- Space to host extended visits from U.K. and overseas academics and students' additional funding from the center in the form of research grants and funded sabbaticals to extend access to petaflop scale computational hardware

- A training facility offering courses in theory, computational science, and engineering and advanced computing to augment postgraduate courses and industrial staff training

- The support of knowledge exchange in conjunction with a wide range of commercial and industrial partners

Example #4: Ter@tec

Ter@tec is a European initiative based in France whose objective is to build the first "technopole" in Europe dedicated to simulation and HPC. One characteristic of Ter@tec is that it regroups a large number of industrial companies, users, and providers, and the major R&D centers, public and private.

Ter@tec is building the Ter@tec Campus (15,000 square meters of offices and labs), close to the Very Large Computing Center (several petaflops, including the future French PRACE system).

It represents more than 1,000 people and its plans include:

- The Exatec HPC Lab, created by Intel with French partners, and focused on exascale hardware and software optimization

- The Bull-CEA Extreme Computing Lab on architecture performance and development

- The new HPC Master that opens in October 2010 and will be the first of its kind

- A System Engineering Lab to develop the future tools and methods for engineering simulation and modelization
- Systems and software companies (ISVs, Scilab Entreprises, etc.), and an office structure dedicated to host European and U.S. technological companies
- Technology platforms that will allow technical and industrial users, especially SMEs, to access HPC platforms, software, and expertise to be used in their own developments

6.8 The Need for Clear Milestones

To be successful, the EU and Europe need to implement the strategy wisely. First, the EU and member nations, along with suppliers, need to establish the funding process, bodies, and management structure for the increased funding levels.

- PRACE is already established and in place, so its structure should be leveraged to the fullest.
- The HPC exascale development lab/testbed centers (techno-pools) should be jointly funded by the EU, member nations, individual institutions, and HPC suppliers. The large EU testbed centers should be part of an expanded PRACE, and the smaller ones should be within the Member States.
- In the first two years the funding and structure needs to be finalized, and new HPC systems should already be in the proposal stage.
- Within four years, a number of new systems should already be installed and at least three HPC exascale development lab/testbed centers (techno-pools) should be operational.
- Within five years, the funding levels should have reached the full target levels.
- By 2020, the primary goals should be at least 75% achieved:
  - Europe is recognized as a hotbed for new science and engineering research, especially in critical domains the HPC strategy has targeted for world leadership.
  - Europe's leadership in the targeted areas has created many new jobs in science and industry, and has led to fast growth in the national economies. Europe's move to the forefront of progress in other areas has preserved many existing jobs in both science and industry.
  - Europe is the world leader in important HPC technologies, especially those designed to support the leadership areas. In particular, Europe leads the world in scalable algorithms and software applications in the targeted areas, and in tools to make HPC systems easy to use and to make researchers highly productive and innovative.

7.0 INVESTMENTS REQUIRED — AND INVESTMENT SCENARIOS

In order to achieve the desired results, the EU and member nations need to establish a higher level of funding for HPC. This will likely require a major political push to raise the awareness and importance of HPC to science, the economy, and society overall.

7.1 Scenarios Explored

This section looks at three funding areas and explores three alternative funding scenario levels.

The four general funding areas are:

- HPC supercomputer systems/centers
- New HPC exascale development lab/testbed centers (techno-pools)
- Advanced HPC software and tools
- New scientific talent magnet programs

Four funding scenarios were explored:

- Full leadership funding level
- Funding to reach major goals level
- Partial funding level
- Minimal increase funding level

The range in funding levels varies from a low level of increase in HPC funding (almost no new EU funding, limited increase in national funding levels, no coordination role of the European Commission, but only intervention of the European Commission needed to recommend that national research programs could be strengthened and better targeted) to a very high level of European Commission Commitment needed in both funding and coordination (high EU co-funding and strong leadership of the European Commission).

The investments required for scientific and economic success include many areas in addition to the cost of the computers. The most critical area is the human experts, including the scientists and researchers as well as the experts in using the supercomputers. There is a growing worldwide shortage of HPC talent due to a combination of an aging workforce with fewer new graduates in various HPC fields (see the forthcoming DOE HPC talent study at www.hpcuserforum.com).

7.2 Funding Levels for Additional HPC Systems

Based on the interim report analysis of the EU's HPC historic funding, HPC funding compared with other countries, and HPC funding compared with GDP, Europe has a major need to increase its purchases of supercomputers by around 100% over the next five years. *This would increase funding from today's €200–€250 million a year to closer to €450–€500 million a year for supercomputers* costing over $3 million each (U.S. dollars).

A larger increase would provide a greater buffer for leadership, but the funds may be better applied to other areas once this new level is reached.

Investment requirements are growing quickly for the largest HPC systems:

- In the 1970s and early 1980s — the price of the largest supercomputers was $25 million (€19 million)
- In the 1980s and 1990s — the price of the largest supercomputers was $35 million (€26 million)
- In the late 1990s — the price of the largest supercomputer was $100 million (€75 million)
- In 2000, the Earth Simulator and DARPA set a level of $250–$300 million (€150–€200 million)
- Now some are looking at $1 billion (€750 million) for a single system (including development R&D costs)

The bad news is that Europe has been falling behind in making the required investments to acquire the largest computers. A number of countries are now building multiple very large systems in the $75-million-plus range. This is one-tenth of what others plan to spend on the largest HPC systems.

7.3 Funding for New HPC Exascale Development Lab/Testbed Centers (Techno-Pools)

The HPC testbeds don't need to be anywhere as large as the tier 0 PRACE centers, but do require many things beyond just the computer center. They also require large technical staff, class rooms, offices, and other support infrastructures.

A large testbed center would require funding of around €10–€15 million for the HPC system, and would likely cost close to €15 million a year for operations. Smaller testbed centers would be about a third to a half of this cost. Scenario 1, full funding, assumes that there would be four new major HPC exascale development lab/testbed centers created, at an annual total cost of around $30 million.

The good news is that many HPC vendors may supply hardware and software as being part of the testbed center, therefore significantly reducing total costs.

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7.4 Funding for Highly Scalable Software and Tools

Historically software costs for applications and middleware (but not for operating systems) have tracked hardware spending at a 75%–85% level. Going forward, this ratio is likely to grow for the next decade in favor of increases on the software side. What is included here are the costs that buyers and users are paying for software.

To address the software needs, as described previously, would require higher funding for software R&D, but these increases promise to yield some of the highest returns. Other countries are considering exascale software R&D investments in the $250-million-plus range (over a five-year period). Scenario 1 assumes that the EU invests enough in HPC software development to really "change the game" as far as international leadership is concerned, and invests at an increased rate of €150 million a year, in addition to the software investments in the testbeds (building up to this level over the next five years).

Investments are needed in multiple software areas:

- System tools to make systems easier to use and more productive and innovative
- Application redesign, optimization, and scaling
- Algorithm development

In addition, the EU could develop a new concept in software, and drive to make the EU the leader in HPC software that is "exciting to use." The concept here is to make the software so highly productive and innovative for researchers that it's not just easy to use, but exciting to use. This will also attract new people and talent to HPC.

7.5 Implementation Scenarios: Alternative Funding Scenarios/Approaches

Four funding scenarios were explored:

- Full leadership funding level
- Funding to reach major goals level
- Partial funding level
- Minimal increase funding level

Table 4 shows the yearly rate of funding *increases* required by year five. The increases can be made in a gradual growth mode over the next five years, and then the new level needs to be moderately grown in subsequent years (10% a year). These investments include all types of HPC areas, and are all in addition to current HPC investments being made across Europe.

TABLE 4

Alternative HPC Funding Scenarios: Yearly Funding Additions by Year Five

(Millions of euros added per year)

	Full Leadership Funding Level	Funding to Reach Major Goals Level	Partial Funding Level	Minimal Increase Funding Level
HPC system funding increases (tier 0 systems)	150	120	70	40
HPC system funding increases (tier 1 systems)	100	90	50	10
HPC development testbeds (H/W)	50	40	25	0
HPC development testbeds (people)	75	60	35	0
Exascale software development	150	125	55	25
Scientific talent magnet program	75	60	25	0
Total yearly funding increase	600	495	260	75

Note: These figures include HPC funding paid by the EU, by Member States, and contributions by vendors.

Source: IDC, 2010

The funds should come from a number of sources, including the EU, Member States, and vendors/users. Vendors are likely to cover the cost of a sizeable portion of the testbed hardware and exascale software development and could sponsor parts of the magnet program. It would be useful if the EU could cover close to 50% of the tier 0 and tier 1 hardware system costs and software development costs, with the Member States contributing the other 50%. The Member States should cover a sizeable portion of the staffing cost and the small to medium-sized systems. Industrial funds could come from two sources: a) HPC suppliers providing hardware, software, and people, plus funds; and b) from industrial end users paying for time on the systems. A funding distribution example is shown in Table 5.

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TABLE 5

Potential Funding Sources for the Full Leadership Funding Scenario #1

(Millions of euros added per year)

	EU	Member States	HPC Suppliers and Industrial Users	Total
HPC system funding increases (tier 0 systems)	55	55	40	150
HPC system funding increases (tier 1 systems)	35	35	30	100
HPC development testbeds (H/W)	10	10	30	50
HPC development testbeds (people)	20	20	35	75
Exascale software development	55	50	45	150
Scientific talent magnet program	25	30	20	75
Total yearly funding increase	200	200	200	600

Note: These figures include HPC funding paid by the EU, by Member States, and contributions by vendors/users.

Source: IDC, 2010

7.6 Evaluation of the Scenarios

Potential GDP Economic Impacts

This section is based on a high-level analysis of the two extreme funding scenarios (#1 and #4). Investments in R&D and HPC are critical for economic growth in many sectors, but the economic growth will normally lag investments by five years or more. These comparisons assume that all parts of this proposal are put in place within a reasonable amount of time for Scenario 1. The GDP impacts are based on 2020.

European GDP improvements will come from a number of different areas:

- Directly from industries that use the improved HPC infrastructure and tools to make better and more competitive products and services
- Directly from European HPC suppliers of the targeted new technology areas (and for related HPC suppliers)
- Indirectly from scientific advances, although these take longer to show up in economic terms (and are not included in this evaluation)

Scenario 1, the full leadership funding level, has the potential to dramatically impact the GDP in many EU countries and in many industries. In addition, it will directly grow the broader HPC supplier sector across Europe. Many industries in Europe will see direct benefits from this strategy, including automotive, aerospace, oil/gas, bio-life sciences, finance, movie design, pharmaceuticals, IT, and chemicals.

Approximately 27% of overall EU GDP is currently in industry (versus services and agriculture) and a strong HPC strategy could increase industry growth by 6%–8% in

2020 and potentially as high as 10% in 2025. This would result in an increase in GDP growth for all Europe by 2% in 2020 and 3% in 2025 as the strategy and investment impacts materialize.

- In addition, Europe could see a 0.5%–1% growth in GDP just from the HPC sector by 2020.
- This is in addition to a return to historic European yearly GDP growth of 2%–3%.

In Scenario #4, the minimal increase funding level, European economies will see little change from new HPC investments and will struggle longer to recover from the recession. In addition, by 2020 additional scientific and economic ground will be lost to foreign competitors. In 2009 overall European GDP fell 4%, after yearly growth in the 2%–3% range for 2005–2007. The impact of minimal HPC investment increases in HPC could be as strong as causing GDP to still be slightly negative even in 2020.

Full Leadership Funding Level

This is the recommended funding level scenario and would provide the best chance of reaching all or at least most of the strategic leadership goals by 2020. It would also provide more HPC resources and tools to increase the rate of scientific advancement and economic competitiveness across Europe. It is also the most costly scenario.

Benefits would include:

- Europe is recognized as a hotbed for new science and engineering research, especially in critical domains the HPC strategy has targeted for world leadership.
- Europe's leadership in the targeted areas has created many new jobs in science and industry, and has resulted in faster growth in the national economies. Europe's move to the forefront of progress in other areas has preserved many existing jobs in both science and industry.
- Europe is the world leader in important HPC technologies, especially those designed to support the leadership areas. In particular, Europe leads the world in scalable algorithms and software applications in the targeted areas, and in tools to make HPC systems easy to use and to make researchers highly productive and innovative.

Funding to Reach Major Goals Level

Under this scenario, the majority of the critical strategic goals would be reached, but not as quickly or as fully as under the first scenario. By 2020, the primary goals should be at least 75% achieved:

- Europe is starting to be recognized as a hotbed for new science and engineering research.
- Europe's leadership in the targeted areas has created new jobs in science and industry, and has resulted in faster growth in the national economies. Europe's move to the forefront of progress in other areas has preserved many existing jobs in both science and industry.
- Europe is up with the world leaders in important HPC technologies, especially those designed to support the leadership areas. In particular, Europe is gaining a

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lead in scalable algorithms and software applications, and in tools to make HPC systems easy to use and to make researchers highly productive and innovative.

Partial Funding Level

This option is better than doing nothing, but will push the achievement of the primary goals out to at least 2025, and some of the primary goals are unlikely to be achieved. For example, being the leader in the targeted domains will change to being strong (but not a leader).

The negative results of this approach would include:

- Europe will lose ground as a scientific and research powerhouse.
  - Europe and the EU Member States could experience a continuing brain drain to the U.S. and Asia, along with difficulty in attracting talented scientists and engineers.
- European economies will take longer to recover from the current recession, and will find other nations taking economic value away from Europe.
  - The EU HPC supply chain will grow slowly and more foreign companies will gain ground.
  - Europe and the EU Member States could lose industrial competitiveness and jobs.
- Europe's existing strengths in hardware, software, and other HPC-related technologies would diminish.

Minimal Increase Funding Level

This will at least keep Europe from falling behind too quickly, and could provide help in one or two areas. This scenario drops the HPC development testbeds and drops the magnet program. The major risk is that other countries will target the key areas and by 2020 Europe will be seen as a follower and not as a leader in many areas.

The negative results of this approach would include:

- Europe will lose ground as a scientific and research powerhouse.
  - Europe could become inferior to the U.S. and Asia in science and become increasingly reliant on the U.S. and Asia for scientific, industrial, and technological advances.
  - Europe and the EU Member States could experience an escalating brain drain to the U.S. and Asia, along with great difficulty in attracting talented scientists and engineers.
- European economies will take much longer to recover from the current recession, and will find other nations taking economic value away from Europe.
  - The EU HPC supply chain will grow very slowly and more foreign companies will gain ground.

- Europe and the EU Member States could lose industrial competitiveness and jobs.

- The smaller and less affluent EU Member States could lose the ability to access and benefit from large HPC systems. This could widen the digital divide in Europe, to the detriment of smaller countries.

- Europe's existing strengths in hardware, software, and other HPC-related technologies would diminish or could disappear from lack of advancement.

Priorities and Funding

In summary, the highest priorities within the recommended EU HPC leadership strategy are as follows:

- Recognize HPC's crucial role in enabling scientific leadership and economic competitiveness, as has already happened within the governments of the U.S., Japan, China, Russia, and other competing areas of the world.

- Substantially increase funding, especially for HPC system procurements, in order to keep pace with and not fall farther behind the rest of the world. To accomplish this, the EU essentially needs to double 2009 HPC expenditures in a phased-in manner, as suggested elsewhere in this report.

- As part of the increased funding, direct extra attention toward a limited number of areas where Europe is already strong and should drive toward world leadership. The recommended areas are described in this report.

- Expand the mission of the PRACE program beyond pan-European service provision, by making PRACE the centerpiece of a new EU organization responsible for driving the EU HPC leadership strategy in collaboration with, and on behalf of, the Member States.

- In recognition of HPC's importance for European scientific advancement and economic competitiveness, establish a new organization (suggested names: EU Coordinating Office for High Performance Computing, or EU Coordinating Office for Computational Science and Engineering, or equivalent name) to carry out the stepped-up EU HPC strategy. This could be a renaming of PRACE to reflect its expanded mission and stature, with the PRACE name retained for existing activities within the new organization. (In any case, it is critically important not to disturb the momentum and plans already established by the PRACE program.)

7.7 The HPC Supplier Value Beyond the Server

The value of fully investing in HPC to drive leadership in Europe has a major direct economic benefit for European suppliers. Table 6 shows that the worldwide purchase value for HPC software for just supercomputers (systems priced at €375,000 and up) was €1.8 billion in 2009 (counting both application software and middleware software), close to the level of supercomputer system purchases of €2.5 billion. So the economic return from having a leadership role in high-end HPC software is sizable.

TABLE 6

Worldwide HPC Revenue (€000) for Server, Storage, Service, and Software Forecast in the Supercomputer Segment, 2008–2013

	2008	2009	2010	2011	2012	2013	CAGR 09–13
Compute	2,014,596	2,527,058	2,718,264	2,909,471	3,100,677	3,291,884	6.8%
Storage	1,551,239	1,819,481	2,011,516	2,182,103	2,356,515	2,534,751	8.6%
Service	523,795	581,223	638,792	698,273	775,169	855,890	10.2%
Application software	1,390,071	1,667,858	1,848,420	2,080,272	2,232,488	2,403,075	9.6%
Middleware	141,022	161,732	176,687	218,210	238,752	263,351	13.0%
Total	5,620,723	6,757,352	7,393,679	8,088,329	8,703,602	9,348,951	8.5%

Source: IDC, 2010

Note: Software revenues are contained in both the application software line and the middleware software line in Table 6.

8.0 CONCLUSIONS, RISKS, AND ADDITIONAL RECOMMENDATIONS

8.1 Key Recommendations

First, Adopt a Clear and Concise HPC Vision

Provide world-class HPC expertise and resources to make EU scientists, engineers, and analysts the most productive and innovative in the world in applying HPC to advance their research, in pursuit of scientific advancement and economic growth.

Key Recommended EU Actions to Make Europe Stronger in HPC Include

- First is the need to expand the number, size, and access to HPC resources across the EU (including broader access to tools by all EU researchers). An expanded PRACE can address this requirement.
- Second is the need to provide peer-reviewed access to large supercomputers for advanced industrial research.
- Third is to create a set of HPC exascale development lab/testbed centers (techno-pools) — a new type of productivity center — to make HPC users more productive and innovative by creating the world's best tools, training, and development environment. This requires a new initiative.
- Fourth is to attract more students into scientific, engineering, and HPC fields, and to attract more experts from around the world to join EU projects. This requires additional funding and a new magnet program.
- Fifth is the need to increase funding in developing next-generation exascale software.
- Sixth is to target a few strategic application areas for global leadership.

In Addition, There are a Number of Core Recommended Implementation Principles

- Work to make HPC a higher priority on the EU's research agenda.
- Expand PRACE to address a broader role in making HPC a powerful tool for EU researchers.
- Expand HPC training with a focus on software usage.
- Promote public-private partnerships to advance competitiveness.
- Support for industrial initiatives and expanded use of HPC resources by both science and industry.
- Support grid and cloud computing initiatives to support extended collaborations.
- Buy rather than develop new custom exascale supercomputers.
- Establish clear roles and responsibilities between the EU and Member States.

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In addition, the EU could develop a new concept in software, and drive to make the EU the leader in HPC software that is beyond the best easy-to-use software and is viewed as "exciting-to-use" software. The concept is to make it so highly productive and innovative for researchers, that it's not just easy to use, but exciting to use. This will also attract new people and talent to HPC.

8.2 EU HPC Expert Views on the Value That EU Action Adds

EU survey respondents' opinions on how the EU Member States should collaborate toward the goal of conducting research at sustained petascale and exascale speeds included:

- The Member States should form multinational projects focused on specific scientific or technology issues.
- The Member States should formalize ("institutionalize") their existing HPC partnerships.
- The EU should establish an independent new body dedicated to carrying out the HPC strategy — an EU HPC center — with sustained, multiyear commitment and funding.
- Don't neglect collaborations with non-European countries such as the U.S. and Japan.

8.3 Additional EU Actions That Should be Considered

- The EU should consider launching a new organization similar to the U.S. Council on Competitiveness (www.compete.org) that would help promote HPC and connect industry, academia, governments, and suppliers.
- The EU and the Member States could launch an "INCITE"-like program by expanding the PRACE program to include access for peer-reviewed industrial research.

8.4 Risks Without EU Involvement

The primary risks include:

- Europe will lose ground as a scientific and research powerhouse.
  - Europe could become inferior to the U.S. and Asia in science and become increasingly reliant on the U.S. and Asia for scientific, industrial, and technological advances.
  - Europe and the EU Member States could experience an escalating brain drain to the U.S. and Asia, along with great difficulty in attracting talented scientists and engineers.
- European economies will take much longer to recover from the current recession, and, more importantly, will find other nations taking economic value away from Europe.

- The EU HPC supply chain will grow very slowly and more foreign companies will gain ground.

- Europe and the EU Member States could lose industrial competitiveness and jobs.

- The smaller and less affluent EU Member States could lose the ability to access and benefit from large HPC systems. This could widen the digital divide in Europe, to the detriment of smaller countries.

- Europe's existing strengths in hardware, software, and other HPC-related technologies could diminish or disappear from lack of advancement.

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A.0 APPENDIX

A.1 EU SUPERCOMPUTING STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS

This section provides an analysis of Europe's strengths, weaknesses, opportunities, and threats (SWOT analysis) with respect to HPC, and more specifically with respect to high-end supercomputing that is most important for scientific advancement and economic competitiveness.

A.1.1 Europe's HPC Strengths

Europe's greatest HPC strengths, in relation to other global regions, are as follows:

- **A world-class scientific and engineering community.** Europe already possesses the most important prerequisite for HPC leadership: scientific and engineering communities equal in quality and stature to any the world. Without this invaluable asset, leadership-class HPC initiatives would be hollow exercises. Within Europe there are scientists recognized as leaders in a wide range of disciplines, and European engineering expertise is second to none in economically important, HPC-dependent fields such as aerospace, automotive, and energy research, as well as life sciences (e.g., creation of digital cells and organisms and the virtual physiome) and other domains.

- **Deep, diverse HPC user experience.** Europe's experience with HPC dates back to the very beginnings of the supercomputing era. Since then, Europe has amassed enormous experience applying HPC to a wide spectrum of applications in government, academia, and industry. This is in contrast, for example, to China, whose hands-on HPC experience today is far more limited in duration and scope. Europe's deep, diverse HPC user experience provides a strong foundation for scientific, industrial, and technology advancement involving HPC.

- **Knowledge transfer to industry.** Though Europe has not yet opened up tier 0 HPC systems to industry, within multiple Member States there is a strong track record of transferring scientific knowledge to industry, and this can act as a multiplier in domains targeted for world leadership. In some EU Member States there are frameworks for strong collaboration between academia and industry (e.g., the HWW for-profit venture that pairs the University of Stuttgart with T-Systems, Porsche, and others to pursue automotive engineering research). In the U.S. by contrast, academic faculty tend more to found startup companies to sell these concerns to larger firms. In the European examples, universities more often hire experts from industry to conduct engineering research, and new knowledge can be transferred from academia to industry widely and at no appreciable cost. This allows new knowledge to be developed and disseminated by universities on a continuing basis, without the limiting need to buy the knowledge from a commercial startup when the startup is ready to sell it.

- **The world's most open, competitive major HPC market.** The primary goal of any HPC leadership strategy should be to advance scientific and engineering innovation, rather than HPC technology leadership for its own sake. From that perspective, one of Europe's great strengths has been not having one or more dominant HPC hardware system vendors. This has enabled European HPC buyers to conduct open, highly competitive global procurements aimed at acquiring the best supercomputers on the most favorable terms for their scientific and engineering users, without needing to give special consideration to Europe-based vendors.

The U.S. and Japanese public-sector markets historically have sometimes exhibited protectionist behavior toward each other's HPC hardware systems, and it remains to be seen whether Europe-based supercomputer vendors would encounter protectionism should they attempt to sell into the U.S. or Japanese public-sector markets.

- **HPC software expertise within vendors and academia.** Although European HPC hardware system vendors (e.g., Bull, Eurotech) are not meaningful competitors yet in the global HPC market place beyond Europe, a number of Europe-based HPC software vendors have gained strong worldwide installed bases, especially in engineering-related software, and within Europe's universities there is world-class expertise in key software areas needed for HPC leadership, including algorithm development. At some point before 2020, it is likely that some key software codes will need to be rewritten to take advantage of petascale/exascale HPC hardware systems, and algorithm development will play a crucial role in this rewriting process.

- **PRACE, DEISA, and other European HPC research programs have laid a strong foundation for an expanded, leadership-oriented EU HPC strategy.** Due to the diverse cultural and legal traditions of the European Member States and the national orientation of their research strategies, integrating their activities in the area of computational science and engineering into a well coordinated, internationally competitive HPC ecosystem presented a gigantic challenge to which Europe had to respond. Through PRACE, Europe established a successful model to do this. The achievements of the PRACE initiative in its preparatory phase (2008–2010) and the follow-up PRACE implementation have created a sound foundation for establishing a sustainable HPC ecosystem in Europe. The field research IDC conducted for the Interim Report showed that Europe's HPC community generally ranks U.S. and Japanese HPC research programs ahead of any in Europe. But PRACE and DEISA topped the rankings of European programs, and many respondents singled out PRACE as having established a strong basis for an expanded, leadership-oriented EU HPC strategy. They viewed the hierarchy of tier 0 EU HPC centers, tier 1 national centers, and tier 2 smaller centers as an effective model for providing HPC access in Europe. With PRACE's established credibility and momentum in mind, IDC elsewhere in this report recommends that PRACE evolve into the central organization for carrying out the expanded EU HPC strategy. DEISA, a partnership among HPC centers rather than nations, has advanced the boundaries for networked access to large HPC centers and scientific collaboration across distances. Other European HPC research programs have made other important contributions.

A.1.2 Europe's HPC Software Strengths

Europe has a long and strong history of software experience and capabilities. Appendix A.5 lists a number of software suppliers and organizations in Europe. The Interim Report identified the IT market segments that have an important role in the

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supply chain for the development of systems software, tools and applications for HPC. In the Interim Report, the size of the HPC software market in Europe is addressed in detail. Highlights include the following:

- The worldwide market for HPC software — including application software and the wide variety of system software, libraries, and tools collectively described as middleware — amounted to about €3 billion in 2009 and is projected by IDC to exceed €4 billion in 2013. Europe's share of this market in 2009 was about €800 million, or about 26% of the worldwide market.

- The worldwide software market associated with high-end supercomputers (priced at $3 million/€2.25 million and above) amounted to about €813 million in 2009 and is expected to exceed €1.25 billion in 2013. Europe's share of the 2009 market was about €105 million, or about 13%. IDC predicts that Europe's share in 2013 will grow to about 20% as Europe invests more in high-end HPC software and as the world increasingly taps into Europe's expertise in HPC software development.

Despite Europe's minority position as a purchaser of HPC software, Europe possesses substantial HPC software development talent that can be applied for more efficient exploitation of petascale and exascale supercomputers.

A.1.3 Europe's HPC Weaknesses

Here are Europe's most important liabilities in pursuing an EU HPC leadership strategy:

- **Europe has been under-investing in HPC at a time when other nations are ramping up.** Europe has been under-investing in HPC, especially for larger HPC systems needed to support leadership initiatives. During the economically challenging 2007–2009 period, purchases of supercomputer-class systems priced above €375,000 ($500,000) increased 38.5% in North America, 284% in Japan (a figure heavily skewed by a few major upgrades), stayed flat in the rest of the Asia/Pacific region, but declined 9% in the EMEA region, which consists almost entirely of Europe. Clearly, if the figures focused on 2009–2010, they would show a rapid increase in China's HPC investments as well. One of the strategies recommended in this document quantifies the investment levels needed for Europe to catch up and keep pace with the rest of the world.

- **Europeans rank U.S. and Japanese HPC research programs ahead of Europe's.** In the field research IDC conducted for the Interim Report, the survey respondents most often named U.S. and Japanese programs as the most successful in the world, especially America's SciDAC and INCITE programs and Japan's Keisoku program. In fact, non-European HPC research programs occupied the top six positions in the ranking, with the PRACE program seventh. Despite this, there was considerable respect for PRACE and DEISA, with other European HPC programs less often singled out for praise. IDC believes that expanding the mission and stature of PRACE could elevate the program in Europeans' future ranking of the world's most successful HPC research programs.

- **European HPC research programs lag in providing access for industry.** The PRACE program, for example, recently announced a call for proposals to use the first PRACE-sponsored supercomputer, nicknamed JUGENE and installed at the

Forschungszentrum Juelich (Juelich, Germany). The call explicitly stated that "only proposals from academia are eligible." Barring advanced research projects submitted by industry from the peer review process stands in sharp contrast to the U.S. Department of Energy's INCITE program, which has been awarding millions of hours on its largest supercomputers for peer-reviewed advanced industrial research projects for five years, or to the access industrial users have had to Japan's largest government-funded supercomputers. In general, industrial access to EU tier 1 supercomputers has remained at an early stage compared with the U.S. and Japan. It is promising, however, that PRACE and other programs intend to increase access for industry, and the PRACE Industry Seminars have been well attended. The EU needs to support industrial access to tier 0 centers as an important part of EU HPC strategy, since without this access industrial firms will have nowhere to go to solve their most daunting, economically important problems.

- **Coordinating an EU HPC strategy with 27 Member States and others is inherently challenging.** Unlike the U.S., Japan, or China, the European Commission must obtain fundamental agreement and sustained collaboration for its HPC strategy from multiple nations — 27 Member States, along with closely affiliated nations such as Norway and Switzerland. Given this added challenge, it is impressive that the consensus underlying PRACE and other programs has been so strong to date. This was also reflected in the field research done for the Interim Report, where there was nearly universal recognition of the need for a common HPC strategy at the EU level.

- **Different funding sources inhibit collaborations between tier 0 and tier 1 HPC centers.** While it is vital that the national governments continue to operate tier 1 centers autonomously, collaboration between tier 0 and tier 1 centers can be in the best interests of both parties but are inhibited today by rules stemming from their different funding sources. More should be done to facilitate collaboration.

- **The European HPC market is limited in size.** Europe accounts for only about 25% of the worldwide market for HPC hardware systems and for overall HPC spending (hardware systems, storage, services, and software). This means that Europe-based HPC vendors generally cannot thrive and continually fund world-class innovation unless they match competitors that have access to the larger worldwide market. A number of Europe-based software vendors have been successful at this, but Europe-based HPC hardware vendors have not yet reached this stage. In any case, the limited size of Europe's HPC market constitutes a barrier for Europe-based vendors in comparison with U.S.-based vendors that have access to a considerably larger domestic market as a launching pad for worldwide selling.

- **Shortage of qualified HPC job candidates.** This is a weakness that Europe shares with North America and many other areas of the world. In our European HPC User Forum meetings and elsewhere, HPC center directors frequently say that their plans are being inhibited by a lack of qualified job candidates. Universities have not been producing an adequate number of HPC-trained graduates, especially in highly desired job categories such as parallel programming, system administration, and algorithm development. Over time, more universities need to recognize that HPC is the third branch of scientific inquiry and integrate HPC training directly into science and engineering curricula, rather than offering it as separate elective coursework.

- **The tradition of short-term research programs from the national governments and the European Commission do not provide enough of a solid foundation** for an effective, robust, and flexible first-class research e-infrastructure for HPC. Europe's HPC strategy needs long-range guarantees for funding and the stability of research strategies on the national and EU level in order to reach and preserve its competitiveness.

A.1.4 Europe's HPC Opportunities

Europe's most important HPC-related opportunities are as follows:

- **Capture global leadership in scientific and industrial areas where Europe is already strong.** As described earlier, these areas include weather and climate research, clean and sustainable energy, automotive and aerospace design engineering, bio-life sciences (e.g., creation of digital cells and organisms and the virtual physiome), particle physics, cloud computing, molecular dynamics/modeling the properties of materials, and exascale applications, across a wide spectrum of disciplines. These are all scientifically and economically important areas in which Europe has substantial strengths today that provide the basis for pursuing global leadership by 2020.

- **Pursue global leadership in key technologies as the HPC market undergoes the powerful shift to exascale computing speed.** During the past decade, so-called clusters — HPC systems heavily based on commodity technologies that are freely available in the global market place — have become the dominant species of supercomputers. The increasing commoditization of highly parallel HPC hardware systems has greatly improved their price/performance while making them harder to use efficiently. This has shifted the burden of innovation much more onto the software side. Europe's considerable strengths in algorithm development, parallel programming, and domain applications, especially but by no means exclusively in the targeted leadership areas, creates the opportunity for Europe to pursue global leadership in sustained exascale computing on real-world applications. The parallel programming expertise resident within Europe will also be useful for exploiting contemporary and future-generation supercomputers that are increasingly heterogeneous in design, that is, HPC systems employing more than one type of processor to solve problems.

- **Rewriting important software applications, especially in the targeted leadership areas.** IDC believes that in the next five years many HPC applications will need to be fundamentally rewritten so they can efficiently exploit HPC systems the largest of which will soon feature 1 million processor cores or more (today's largest supercomputers employ up to about 250,000 processor cores). Europe's expertise in algorithm development and parallel programming, as mentioned in the preceding, closely related opportunity, will be enormously useful for this critical task. At a minimum, Europe should pursue global leadership in rewriting software codes important for the targeted leadership areas.

- **Growing the EU-based HPC vendor community by awarding contracts for pre-competitive, enabling technologies.** Keeping Europe at the forefront of science and engineering argues strongly for HPC procurements that treat all competing vendors equally, no matter where in the world they are based. But the EU may want to provide advantages for EU-based vendors in procurements to

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develop pre-competitive, enabling HPC technologies — as a way to help the EU-based HPC community grow in size and experience.

A.1.5 Europe's HPC Threats

Important threats to the development of a leadership-oriented HPC strategy for Europe include the following. The threats generally fall into two categories: internal threats within Europe and external threats from outside of Europe.

Internal Threats

- **Failure to appropriately recognize and support the importance of HPC within the EU.** Political support for HPC is substantially greater in the U.S. and Japan, for example, as reflected in the fact that the EU — whose GDP is about the same as that of the U.S. — invested only about half as much as the U.S. in HPC in 2009. For the EU HPC strategy to succeed in boosting Europe's scientific leadership and economic competitiveness, the European Commission needs to elevate HPC to an appropriate status within the organization.

- **Targeting inappropriate leadership goals.** The extensive field research IDC conducted for the Interim Report revealed the following priorities for the goals the EU HPC strategy should pursue:

  - Making world-class HPC resources more widely available to the EU scientific and engineering communities

  - Advancing scientific leadership by using HPC to solve some of the world's most challenging problems

  - Making HPC more readily available for the first time to small and medium-sized businesses

  - Having many very large supercomputers, that is, being at or near the top of the top 500 list of the world's most powerful supercomputers (www.top500.org)

  - Building an EU-based HPC vendor community with world-class capabilities

  In addition, survey respondents stressed the importance of pursuing global leadership in only a limited number of scientific and engineering areas, while continuing to provide support across all disciplines.

  In sum, there was a strong consensus among the survey respondents — a consensus IDC agrees with — that an important threat to the success of any EU HPC strategy would be to focus on low-priority goals, especially numbers 4 and 5, that do not directly contribute to the advancement of science, engineering, or HPC technology development.

- **Failure to provide a central authority at the European level to carry out the HPC strategy.** In the field research IDC conducted for the Interim Report, European respondents made it clear that the EU needed to drive a European HPC strategy because no Member State acting alone could afford to compete for leadership with the U.S., Japan, or China. Yet there was reluctance to relinquish authority to a centralized authority lacking technical expertise in computational science and engineering. It will be crucially important to have a central authority

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at the European level drive the HPC program, but not to assume responsibility for certain matters requiring technical proficiency. For example, this body should have the authority to administer the peer review process for allocating time on EU HPC resources, but should assign the peer review task itself to qualified outside experts. An appropriate division of labor between the EU and the Member States is proposed elsewhere in this report.

- **The financial crisis in the national economies.** In the midst of a serious European and global economic crisis, HPC must compete for funding with other key priorities. It is important for both the EU and the national governments to recognize — as has already happened in the U.S., Japan, China, and Russia — that HPC is a crucial part of the solution to the economic crisis. The EU HPC strategy aims to do this by boosting Europe's economic competitiveness and prosperity, by moving Europe to global leadership in targeted scientific and industrial areas and thereby preserving many existing jobs and creating many new jobs. It is with these goals in mind that the U.S. increased HPC funding 38.5% in 2009, the most difficult year of the global economic recession.

- **Competition among the Member States to host and use the EU tier 0 HPC centers.** To an important extent, the PRACE program to date has been based on the principle of juste retour, in which the Member States contributing the most money for the tier 0 centers have expected to host the centers and use them to the greatest extent, in order to "get their money's worth." This principle has been modified somewhat through after-the-face accounting to create a more accurate balance between payment and usage. It will be important over time to create a new formula that balances juste retour against the value of better integrating the European science community and providing the most worthy proposals with adequate resources, no matter which country the proposals come from.

- **Focusing on developing a European supercomputer from the ground up.** It makes little sense for Europe to try to fund the development of a new exascale supercomputer architecture based on all-European components by 2020, given the time needed for this huge task (more than 10 years), the money needed (certainly in excess of €10 billion), and the high risk that it might still not be competitive with 2020-era supercomputers that heavily leverage commodity technologies available in the global market place. It is recommended that the EU approach its exascale needs by exploiting commodity technologies and augmenting these only as needed to run targeted leadership applications with unrivaled performance.

External Threats

External threats, other than those faced by HPC strategies the world over — highly parallel programming, power and cooling, and so on — come mainly in the form of countries that will be competing with the EU for HPC leadership in this decade. The best way to fend off these threats is for the EU to develop a distinct HPC leadership strategy that targets leadership in areas different from those others that are most important for other nations, areas in which the EU has special strengths today on which to build.

- **United States.** Today, at the dawn of the petascale computing era (10^{15} operations per second), the U.S. is the world leader in HPC by almost any measure — including the twice-annual list of the world's 500 fastest supercomputers (www.top500.org), where in November 2009 the U.S. held 55%

of the spots on the list, Europe 31% (up from 29% six months earlier), and China, Japan, and India together just 8%. The current U.S. primacy is no accident, but the result of a deliberate, multiyear effort to regain global HPC leadership after Japan seized it for several years (2002–2004) with its surprisingly powerful "Earth Simulator" climate-modeling supercomputer that required five years of development and about €245 million ($350 million) in funding.

In response to this perceived threat to national security, scientific, and industrial competitiveness, the U.S. government sharply increased funding for HPC systems development and purchases, especially through the Department of Energy's Advanced Simulation and Computing (ASC) program and the Defense Advanced Research Projects Agency (DARPA) High Productivity Computing Systems (HPCS) program. Since 2002, the U.S. government has summoned the political will to invest well over $1 billion (€700 million) in aggregate HPC funding to recapture worldwide leadership. The U.S. is actively considering the need to spend at least that amount again to fund the development of a single exascale computer (10^{18} operations per second) for delivery in the second half of this decade.

- **Japan.** In recent years, Japan has slipped from contention for worldwide HPC leadership and had none of the top 10 entries on the aforementioned November 2009 ranking of the world's top 500 supercomputers. But Japan remains a technical powerhouse for HPC development and the country's Keisoku project, organized to produce a 10-petaflop HPC system in 2011–2012, had U.S. officials worried for a time. In 2009, the Japanese government rejected a budget-cutting panel's proposal that would have slashed funding for supercomputing projects, including Keisoku, to almost nothing. Instead of accepting the drastic recommendation of the Government Revitalization Unit's budget-cutting panel, the government reduced the supercomputing budget by only about 15%, from the original €206 million ($295 million) request to about €175 million ($251 million). In the context of Japan's troubled economy, that represents a strong vote of confidence in the importance of high-performance computing and a repudiation of a high-ranking panel member's public comments questioning HPC's ability to make Japan more competitive.

- **Russia.** Interestingly, the debate in the Japanese government began soon after Russian President Medvedev declared that without investment in HPC, "in five years our products will not be competitive or of interest to potential buyers." Vladimir Putin subsequently allocated €26 million ($37 million) for supercomputer procurements. Following that, Russia has begun spending a larger amount than that for HPC systems, including a new system with 414 teraflops of peak computing power deployed in April 2010 at Moscow State University.

- **China.** China surprised the world by seizing the number 2 and number 7 spots on the June 2010 list of the world's top 500 supercomputing systems. China plans to develop its own supercomputing systems from the ground up, but its situation is very different from that of Europe. Until recently, China was not allowed to purchase large HPC systems from abroad, and China does not want to be in this dependent situation again. In contrast, Europe has arguably been the most open, competitive HPC market in the world, with access to systems from across the globe. In addition, the top 500 list is not a good indicator of a supercomputer's actual performance on real-world applications. IDC believes that despite China's impressive rankings on this list, China is not yet competitive with the world's most effective supercomputers.

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- **India.** Through our experience holding 2007 HPC User Forum conferences in India, in conjunction with the Indian Institute of Technology (New Delhi) and the Indian Institute of Science (Bangalore), along with intensive market tracking, IDC has a good sense of government funding patterns in that country. India to date has opted to fund multiple small to midrange HPC centers in various parts of the country, rather than concentrating funding on one or more large center. This approach may reflect political realities as much as budgetary constraints. In any case, as a consequence of this policy the largest supercomputer in India today is not government funded but a commercial system at Tata's Computational Research Laboratories (CRL) site in Pune, India.

A.1.6 Main HPC Technical Barriers That Need to be Addressed

Many standard computer codes do not scale to work on large numbers of processors. There is a pressing need to develop the next generation of theory, algorithm, and computational codes that will operate on hundreds of thousands, or millions, of processors. In order to develop the next generation of applications the EU will need to bring together applications domain experts, numerical analysts, HPC technologists and systems software experts to deliver these solutions. To capitalize on the power of current and future high-performance computing, system models must be developed that integrate predictive simulations at many different length and time scales (for example, a simulation of a human lung which includes models of atomic level processes all the way up to macroscopic gas flow). Complexity, realism, and an understanding of trends, sensitivities, and variability will require the coordinated efforts of experts in many domains.

The chief technical barriers impeding HPC progress include:

- **Highly parallel programming and the need to rewrite applications.** Rampant hardware parallelism from burgeoning core counts and system sizes is racing ahead of programming paradigms and the time available to programmers. Alternative "manycore" processors and heterogeneity are adding to the programming challenge. The parallel performance "wall" will reshape the nature of HPC code design and system usage.

Partitioned global address space (PGAS) languages have the potential to transform highly parallel programming, but as noted earlier, relatively few users have moved to PGAS languages yet. Most of the solutions available in 2010 are less revolutionary but also have interesting potential. They include software products that hide the parallel hardware behind optimized application-specific libraries (Star-P, Acceleware), optimize intra-node performance for multicore (Acumen), abstract from distributed parallel hardware (ScaleMP, PGAS languages), and address processor heterogeneity by extending the x86 ISA within the compiler to include parallel accelerators (e.g., Convey Computer). As multicore/manycore parallelism and heterogeneity advance, eventually something will need to give. HPC programmers will need more efficient programming paradigms, more innovative approaches for redesigning applications, more balanced hardware architectures, or all of the above.

- **HPC system imbalance and the "memory wall."** Clusters based on commodity components are now the dominant species of HPC systems, capturing about two-thirds of all system revenue in 2009. Since the emergence of HPC clusters only about a decade ago, users and vendors have enabled most HPC applications to run satisfactorily, and in some cases with impressive performance, on these cost-effective systems comprised of independent computers coupled together with software and networking technologies. But IDC research consistently shows that clusters remain difficult for users to manage and efficiently exploit.

For at least the near-term future cluster complexity will continue to grow, driven by ballooning system sizes, processor counts, and heterogeneity, as well as novel environments (e.g., grids). Cluster complexity will outrace hardware and software vendors' evolutionary progress in taming it. Alternative processor technologies will accelerate performance on certain classes of applications and HPC management software with rising sophistication will help to administer clusters, but neither of these technologies is designed to overcome the growing "memory wall" that limits the efficiency of most HPC architectures, especially clusters. And the limited scalability of most HPC codes, particularly ISV applications, will increasingly lag the multicore/manycore parallelism of clusters and other HPC systems. In short, no developments on the near horizon promise to make clusters simple to manage and to exploit with high efficiency.

- **Energy efficiency and availability.** Power and cooling has become a top concern among HPC datacenters, as confirmed by two recent IDC studies. Increases in HPC system sizes have escalated energy requirements, such that the largest systems already consume as much electricity as a small city and their successors promise to use even more. At the same time, energy prices have risen substantially above historic levels, although prices have dropped from their 2008 highs. The third element in this "perfect storm" is the challenge of making HPC processors more energy-efficient without overly compromising performance — the holy grail of HPC. And these power and cooling developments are occurring at a time of increased sensitivity toward carbon footprints and global climate change.

  Where efficiency is concerned, most exascale computing initiatives are aiming to develop exascale systems that fit into the same power and space envelopes as today's petascale computers, though the exascale systems will be about 1,000 times faster. The challenges associated with doing this are daunting and as yet unsolved. One large HPC center already consumes 25MW, is in the midst of constructing a 100MW replacement facility, and has drawn up plans to build a 250MW center later on. This center may not be able to obtain that much power from the local power company and has said it may need to "go off the grid" by building a small nuclear reactor.

- **Fault tolerance and resilience.** Looking at the exascale performance regime, an approach based on fault avoidance schemes will be required since for these systems the mean time between failure (MTF) will be in the same range as the time which is required to write an application checkpoint to a non-volatile storage medium. Hence the applications, the run time environment, and the corresponding hardware will have to be able to go on without disruption even if individual components do fail.

- **Storage and data.** For decades now, but especially during the rapid rise of clusters since 2002, HPC vendors and users have aggressively advanced the processor peak performance of their systems while paying less attention to HPC storage and I/O capabilities. The areal densities of magnetic disks have increased dramatically, but improvements to disk I/O performance and access density (the ability of many concurrent users to access stored data quickly) have

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greatly lagged advances in disk capacity and processor speeds. And as HPC users have deployed ever-larger parallel servers for their application workloads, this fundamental imbalance — the gap between the server and storage sides of HPC — has grown worse. As a result, today storage and data management are major issues for many HPC users.

Extracting knowledge and information from the data along with visualization and networking. These centers will be generating huge amounts of data that will either have to be analyzed on-site, migrated to user institutions, or stored in large datacenters.

Today's unbalanced HPC systems are exacerbating the storage challenges by generating unprecedented data volumes. Assuming the bytes-per-dollar ratio in the HPC submarket is the same as in the overall storage systems market, the HPC sector's aggregate storage capacity will grow by 2011 to roughly 6.5 exabytes. The roadmaps of HPC cluster vendors indicate that in relation to this data explosion, tomorrow's HPC systems will be even more unbalanced ("flopsided") than today's.

A.2 A SAMPLE OF APPLICATIONS TARGETED FOR EXASCALE PERFORMANCE LEVELS

Below is a partial list of applications that have been targeted by HPC users for multipetascale and exascale performance levels.

- Weather forecasting
- Climate modeling
- Astrophysical simulation
- Quantum chemistry
- Plasma physics
- Advanced combustion modeling
- Nanoscale material science
- Molecular nanotechnology
- DNA sequence analysis
- Protein folding simulations
- Full genome comparisons
- Proteomics and toxicology
- Metabolism and therapies
- "Designer drugs"
- National and regional scale economic modeling
- Real-time medical imaging

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A.3 INTERIM REPORT KEY FINDINGS THAT SUPPORT THE STRATEGY

The key findings described in the Interim Report are as follows. These findings represent the preponderance of opinion among the survey/interview respondents, the vast majority of whom (86%) were Europeans. Respondents included HPC users in government, academia, and industry; HPC vendors; national funding agencies with HPC oversight; representatives of HPC research programs; and a smaller number of HPC experts from outside of Europe for additional perspective.

- HPC use is indispensable for advancing both Europe's scientific and industrial competitiveness.

- The primary goal of any EU HPC strategy should be to advance scientific and industrial innovation, not HPC for its own sake.

- Europe should use HPC to pursue scientific, industrial, and technical leadership in a few important domains where Europe is already strong, while not ignoring any other domain or discipline.

- Europe has been under-investing in HPC. During the economically challenging 2007–2009 period, purchases of supercomputer-class systems priced above €375,000 ($500,000) increased 38.5% in North America, 284% in Japan (a figure heavily skewed by a few major upgrades), stayed flat in the rest of the Asia/Pacific region, but declined 9% in the EMEA region, which consists almost entirely of Europe. Europe lost ground to other world regions, especially North America, during this period.

- An EU-level HPC strategy is needed, because no European nation acting alone can afford to compete in HPC with the U.S., Japan, or China.

- HPC research funding in Europe includes a diversity of EU, national, and regional programs, and few countries have a coherent HPC development strategy.

- HPC stakeholders from research, industry, and academia rank U.S. and Japanese HPC research programs ahead of Europe's research programs.

- There is strong support for expanding Europe's PRACE research program to respond to growing scientific and industry demand for HPC capacity.

- The transition to petascale and exascale computing creates opportunities for Europe's scientific and computing communities to return to the forefront of development for the next generation of research and HPC software technologies.

A.4 EXASCALE ACTIVITIES IN EUROPE AND AROUND THE WORLD

The recommended EU HPC strategy extends out to 2020, which is the start of the exascale era in supercomputing. The EU strategy is aimed at leadership in the early exascale era, and it is therefore useful to describe exascale initiatives that exist today in Europe and elsewhere. This list does not claim to be exhaustive, but it should provide a good sense of what is out there today.

- **Global: International Exascale Software Project (IESP).** The original impetus for this project came from Dr. Jack Dongarra, University of Tennessee, and the project quickly became international in scope, including Europe. IESP's goal, as its name suggests, is to explore and address the challenges associated with developing software that can efficiently exploit future exascale supercomputers. IESP has held workshops in North America, Europe, and Asia.

- **Europe: European Exascale Software Initiative (EESI).** In May 2010, the European Commission announced that it will fund this 18-month project aimed at coordinating European input into the International Exascale Software Project. In essence, EESI plans to construct a European roadmap for petascale and exascale computing. EESI will build on some of the accomplishments of the HPC Europe, ESFRI, and PRACE programs.

- **Europe: Exascale Research Initiative.** In September 2009, Cray announced the Exascale Research Initiative, a collaboration with the Swiss National Supercomputing Center (CSCS), the University of Edinburgh (EPCC), and the University of Lugano to explore new ideas and technologies needed to deliver a supercomputing system capable of sustaining exaflop application performance.

- **Europe: Exascale Innovation Center.** In March 2010, IBM and the Forschungszentrum Juelich announced the Exascale Innovation Center, to develop hardware and software for an exascale supercomputer by 2020. The plan is to develop a prototype computer by 2015 for deployment in 2019.

- **Europe: ExaCluster Laboratory.** On May 31, 2010, Forschungszentrum Jülich, Intel, and ParTec signed a multiyear agreement to create a new ExaCluster Laboratory (ECL) on the campus of Forschungszentrum Jülich. The lab will explore the key challenges of building exascale computing systems; it will initially employ about a dozen researchers, expecting to triple the staff over time. It will investigate systems management software for large heterogeneous supercomputers with a focus on scaling, including open exascale runtime system software, software tools, and simulation software.

- **Europe: Flanders ExaScale Lab.** Based at the IMEC research facilities in Leuven, Belgium, this collaboration between Intel and five Flemish universities aims to develop software to run on future Intel-based exascale computer systems. The lab will be part of the Intel Labs Europe network.

- **Europe: The Exatec HPC Lab.** Created by Intel with French partners, this initiative is focused on exascale hardware and software optimization.

- **U.S. Department of Energy (DOE).** Within the DOE, both the Office of Science and the National Nuclear Security Administration have begun initiatives focused on exascale supercomputing in this decade. IDC believes that the DOE will seek in excess of $5 billion (€3.75 billion) to develop multiple exascale computers.

- **U.S. Department of Defense.** The Defense Advanced Research Projects Agency (DARPA) recently launched its Omnipresent High Performance Computing program, which will focus on developing the hardware and software design for an exascale computer, along with power management and efficiency, file systems, input/output (I/O), and resource management. This program targets a prototype exascale system by 2018.

- **HP: Exascale Computing Lab.** The goal of this initiative, which takes place within HP Labs, is to "build compute fabrics for next-generation IT solutions utilizing a cross-layer, inter-disciplinary approach across conventional divisions — of CPU, system, and datacenter; compute, storage, networking, and packaging; hardware, firmware, systems, and software; over performance, power, availability, and manageability; with cost-effectiveness and agility."

A.5 EU-BASED HPC SOFTWARE VENDORS

HPC software is created by a variety of sources, including universities and government organizations as well as commercial enterprises. Europe has considerable strengths in each of these domains and across many organizations. For reference, a partial list of EU-based software vendors is given here:

- **Allinea Software** is a leading supplier of tools for multicore and HPC. Its Distributed Debugging Tool (DDT) and Optimization and Profiling Tool (OPT) are used by universities, government research institutes, and commercial organizations. With new product features aimed at novel computing architectures, and the announcement of new GPGPU features, Allinea is a leader in the tool arena.

- **Bull** (les Clayes Sous Bois, France) is one of the leading European IT companies. Bull has a large team of HPC experts and designs and delivers integrated solutions, from departmental clusters to world-class supercomputers. Bull has a growing number of HPC customers at research centers, universities, and industrial companies.

- Since 1985, the **CADFEM** (Grafing, Germany) has been a leader in ANSYS and competence in CAE in Germany, Austria, and Switzerland.

- **Cluster Resources** (Cambridge, the U.K.) is a leader in unified intelligent automation software for HPC datacenters and cloud computing environments. With more than a decade of experience deploying adaptive operating environments powered by Moab in the world's most advanced datacenters, Cluster Resources delivers software and services that enable organizations to obtain a unified perspective of their resources and optimize service levels through intelligent policy-based governance.

- **ClusterVision** (Amsterdam, the Netherlands) is a specialist in the design, implementation, and support of small- and large-scale computer clusters. ClusterVision's team of experts has designed and built some of the largest and most complex computational, storage, and database clusters in Europe. With a background in applied scientific research and practical experience with a wide range of HPC technologies, the team provides tailor-made solutions. ClusterVision has offices in most major European countries.

- **ESI** is a world leading software vendor for digital simulation of prototypes and manufacturing process engineering in applied mechanics. The key to ESI's success is the use of realistic material physics, providing "as good as real" virtual solutions in order to replace the lengthy trial and error processes on real prototypes.

- **Eurotech** (Amaro, Italy) develops and produces HPC systems and miniaturized computers for pervasive computing applications (NanoPCs) in the defense, security, transport, aerospace, industrial, medical, and research sectors.

- **GNS Systems** (Braunschweig, Germany) offers information technology services for product development and engineering, including the planning, implementation, and operation of complex systems and application infrastructures.

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- **Go Virtual** (Askim, Sweden) provides HP HPC systems, servers, and workstations as well as software from partners including Metacomp Technologies (CFD++ and CAA++), ThermoAnalytics (RadTherm, WinTherm), and Intelligent Light (FieldView).

- **Gridcore** is a privately held company based in Göteborg, Sweden. Gridcore is a worldwide HPC solutions provider that has formed long-term partnerships with companies such as IBM, ANSYS, and Microsoft. Gridcore also owns and operates Gompute, an HPC-on-demand service that operates worldwide.

- **Integrated Engineering Software** is a developer of hybrid simulation tools for electromagnetic, thermal, and structural design analysis. Founded in 1984, Integrated provides integrated two- and three-dimensional simulation software. The products allow engineers and scientists to design, simulate, and optimize complex devices and systems.

- **Kerlabs** (Rennes, France) is a spin-off of INRIA, created in 2006 to develop the Kerrighed.One operating system for clusters.

- **LSI** (Bracknell, the U.K.) is a leading provider of innovative storage, silicon, systems, and software technologies for some of the world's leading OEMs in the storage and networking markets.

- **MEGWARE Computer GmbH** (Chemnitz-Roehrsdorf, Germany) distributes high-performance computing systems and IT equipment to industry, banks, trade, universities, schools, and public facilities. The company's solutions are customized to the specific requirements of a broad range of customers.

- **Mercury Visualization Sciences Group (VSG)**, Mérignac, France, is a leading provider of high-performance 3D visualization toolkits and application software for demanding industrial and scientific applications. Mercury VSG customers are in the geosciences, materials science, oil and gas, manufacturing, and engineering industries.

- **NAG** is a worldwide leader in numerical software and HPC services. NAG serves leading HPC customers such as the HECToR program in the U.K.

- **Nema Labs** (Göteborg, Sweden) offers technology to migrate software to multicore platforms. The FASThread product line is designed to parallelize code automatically and reliably.

- **NICE** (Cortanze, Italy), with its EnginFrame grid portal, aims to increase user productivity through highly customizable, intuitive access to grid-enabled applications and infrastructures.

- The **ParTec Cluster Competence Center** (Munich, Germany) specializes in cluster operating software and support services designed to deliver ground-breaking performance for large-scale supercomputing clusters. Parastation5 is the current release of ParTec's cluster operating and management software.

- **PDE Solutions Inc.** was formed in 1995 by the creators of the PDEase software package. The company provides computational tools for the solution of partial differential equation systems in engineering and science.

- **science + computing ag** (Tübingen, Germany), a subsidiary of the Bull Group, is a service and software company for technical/scientific design and simulation environments (CAD/CAE/CAT). s+c focuses on the operation of complex Unix, Linux, and Windows environments.

- **Scilab** is the free open source software for numerical computation. It is distributed worldwide with more than 70,000 downloads every month coming from more than 80 countries. A new company, Scilab Enterprises, has been created to offer support, migration, development, and integration of specific applications in the companies' technological environments.

- **Ter@tec** is a European initiative based in France whose objective is to build the first technopole in Europe dedicated to simulation and HPC. One characteristic of Ter@tec is that it regroups a large number of industrial companies, users, and providers, and the major R&D centers, public and private. Ter@tec is building the Ter@tec Campus (15,000 square meters of offices and labs), close to the Very Large Computing Center (several petaflops, including the future French PRACE system). It will represent more than 1,000 people and will include:

  - The Exatec HPC Lab, created by Intel with French partners, and focused on "exascale" hardware and software optimization

  - The Bull-CEA Extreme Computing Lab on architecture performance and development

  - The new HPC Master that will open in 2010 and will be the first of its kind

  - A System Engineering Lab to develop the future tools and methods for engineering simulation and modelization

  - Systems and software companies (ISVs, Scilab Entreprises, etc.), and an office structure dedicated to host European and U.S. technological companies

  - Technology platforms that will allow technical and industrial users, especially SMEs, to access HPC platforms, software, and expertise to be used in their own developments

- **T-Platforms** (Moscow, Russia) provides HPC systems, software, storage, and services.

- **transtec** (Tübingen, Germany) provides consultation and integration services for HPC projects, including computer systems, storage, backup, and desktop requirements.

- **X-ISS** is the provider for DecisionHPC and ManagedHPC solutions that monitor and manage heterogeneous HPC environments. X-ISS serves top-tier vendors and customers.

- **Ylichron** (S. Maria di Galeria, Italy) was founded in 2005 as a spinoff company of ENEA (the Italian Agency for the New Technologies, the Energy, and the Environment). The company's main product is the HCE compiler.

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A.6 TERMINOLOGY

Application Workload

IDC uses this term to refer to a set of related scientific or engineering applications, plus the associated infrastructure or support applications (e.g., visualization, data management). Each application workload is characteristic of a market segment. Hence, the application workload for biological sciences differs from that used in chemical engineering or other segments.

Cluster

IDC defines an HPC cluster as a set of independent computers combined into a unified system through systems software and networking technologies. Thus, clusters are not based on new architectural concepts so much as new systems integration strategies. In addition, HPC clusters must use base technologies that are readily available in the open marketplace, such as x86 microprocessors, commercial interconnects (in cases where a cluster includes an interconnect), and a commercial operating system (e.g., Linux or Windows). A system using a base technology that is available to only one or two vendors, such as an IBM POWER processor or the Cray SeaStar interconnect, does not qualify as a cluster in IDC's usage; nor do products employing SMP or MPP architectures that are designed as single systems. Clusters vary greatly in size and range in price from about $25,000 (€19,000) to tens or hundreds of millions of dollars each.

HPC Management Software

The HPC industry has evolved to become characterized by collections of large, parallel cluster systems often tied together and managed as grids. In the process, the software components between HPC applications and HPC operating systems have grown in number and evolved to meet requirements specific to HPC. In this paper, IDC has used the term *HPC management software* to call out these HPC specific requirements. HPC management software is middleware adapted to meet the specific, often more demanding requirements of HPC environments. As presented earlier, it is composed of components in three major subgroups, including software for HPC parallel application development and execution; software for HPC parallel job scheduling, tracking, and infrastructure integration; and software for HPC system monitoring and management.

Supercomputer

In this report, IDC uses the term *supercomputer* in two senses, depending on the context. First, IDC uses the term *supercomputer* to refer to HPC systems priced at $500,000 (€375,000) and above. This use of the term is always associated with one or more numerical values, such as a figure in a numerical table that represents the value of all *supercomputers* sold within the EU in a given year. When the term is not associated with numerical values, it is used as a synonym for an *HPC system* of any type and price. This corresponds to the popular and most pervasive use of the term *supercomputer*.

Technical Computing and High-Performance Computing (HPC)

IDC uses the term *technical computing and high-performance computing (HPC)* to encompass the entire market for computer servers used by scientists, engineers, analysts, and other groups using computationally intensive modeling and simulation applications. Technical servers range from small servers costing less than $5,000 to the large-capability machines valued in hundreds of millions of dollars. In addition to scientific and engineering applications, technical computing includes related markets/applications areas including economic analysis, financial analysis, animation, server-based gaming, digital content creation and management, business intelligence modeling, and homeland security database applications. These areas are included in the technical computing market based on a combination of historical development, applications type, computational intensity, and associations with traditional technical markets.

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