HYPERION RESEARCH

HPC Profiles in Leadership

Barcelona Supercomputing Center

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November 2024

EXECUTIVE SUMMARY

On October 21 and 22, 2024 the 86th HPC User Forum was held at the Barcelona Supercomputing Center. At the Forum BSC presented updates on its facilities, quantum computing, and major research areas. First published in 2017 and revised in 2023, this revision to the HPC Profile in Leadership of the Barcelona Supercomputing Center (BSC-CNS)[1] provides new insights regarding BSC.

The Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS) has long been recognized as one of the leading scientific research and computational science centers in Europe, if not the world. Realizing its mission to "*…research, implement, manage, and transfer technology and knowledge in the area of HPC with the aim of facilitating progress in a variety of scientific fields…*", BSC-CNS has made significant research and scientific contributions to its primary focus areas of computer, life, earth, and engineering sciences.

In addition to supporting the basic and applied research of its users, BSC-CNS also has a mission to transfer its research efforts to industry for successful commercial productization. In 2023 alone, BSC-CNS supported 11 spin-offs, 31 technologies transferred or licensed, 66 new bi-lateral collaborations with industry, and 31 patents approved or pending approval. BSC-CNS has been successful with its research and technology transfer efforts in large part due to its planning and deployment of thoughtfully architected HPC infrastructure.

Also contributing to the success of BSC-CNS are its regional and global partnerships. BSC-CNS has strong relationships with and contributes to various European HPC entities including the European High Performance Computing Joint Undertaking (EuroHPC JU), PRACE, and ETP4HPC. It also has entered into a Memorandum of Understanding (MOU)[2] with the RIKEN Center for Computational Science (R-CCS) in Japan. The MOU outlines a framework to exchange researchers, students, and staff, share scientific and technological research materials, and conduct research collaboration addressing global grand challenges.

Augmenting the focus on indigenous technology is a vision to create an open HPC ecosystem based on open-source software and hardware. With its Laboratory for Open Computer Architecture (LOCA), BSC-CNS will leverage its expertise in various application domains with hardware design capabilities required for software/hardware co-design and the MareNostrum facilities for HPC system deployment.

The future of BSC-CNS is encouraging. Supporting the spectrum from conducting basic and applied research to spawning successful commercial industry start-ups with advances discovered or developed at BSC-CNS, the center is an attractive environment to draw leading scientists and researchers from around the world to augment the talented scientific community within Spain and EU Member States. The anticipated highly efficient nature of MareNostrum 5 may also position BSC-CNS as a global lighthouse center for responsible environmental stewardship for HPC resources.

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BSC-CNS, THE EUROHPC JU, PRACE, AND ETP4HPC

BSC-CNS is both a major beneficiary of and major contributor to the coordinated efforts of various European Union HPC investments and initiatives. These include relationships with EuroHPC JU, PRACE (Partnership for Advanced Computing in Europe), and ETP4HPC (European Technology Platform for High-Performance Computing HPC).

Established in 2018[4] and re-commissioned in 2021, the EuroHPC JU was created to allow the European Union and participating members to coordinate their efforts and pool their resources to make Europe a world leader in supercomputing. The EuroHPC JU awarded the procurement for MareNostrum 5 in June of 2022 to Bull SAS (Eviden) and Lenovo. Representing a total investment of over €151 million covering system acquisition and maintenance, 50% was provided by the EuroHPC JU and 50% from a Spanish-led consortium. MareNostrum 5 will be dedicated to strengthening European medical research through drug research, the development of vaccines, and virus spread simulations, as well as artificial intelligence and big data processing applications. It will also support traditional supercomputing applications, such as climate research, engineering, materials science, and earth sciences.

MareNostrum 5 is a key element of the EuroHPC JU's overarching strategy of achieving EU HPC leadership and placing petascale and pre-exascale supercomputers at sites located across EU member states. PRACE[6] is a 25-country-member organization established to facilitate access to computing and data management resources and services for large-scale scientific and engineering applications at the highest performance level. BSC-CNS, representing Spain, is one of five European supercomputer centers providing access for members of the PRACE network (the others being CINECA representing Italy, ETH Zurich/CSCS representing Switzerland, GCS representing Germany and GENCI representing France).

ETP4HPC[7] is a private, industry-led, non-profit association with a mission to promote European HPC research and innovation to maximize the economic and societal benefit of HPC for European science, industry, and citizens. BSC-CNS co-leads ETP4HPC's Strategic Research Agenda[8].

BSC-CNS RESEARCH AND OPERATIONS ORGANIZATION

BSC-CNS is organized into five core departments: **Computer Sciences, Life Sciences, Earth Sciences, Computer Applications in Science & Engineering (CASE),** and **Computational Social Sciences and Humanities:**

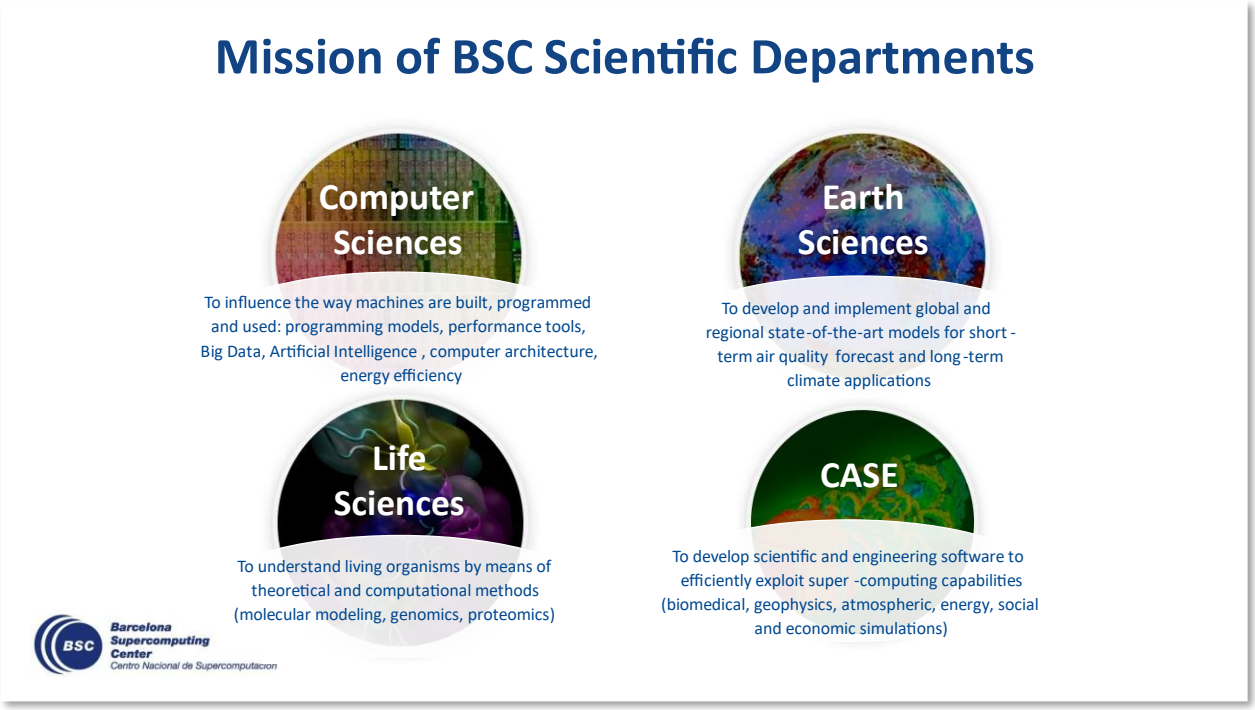
- **Computer Sciences:** The mission is to influence the way machines are built, programmed, and used: computer and system architecture, programming models and performance tools, resource management, big data and artificial intelligence.
- **Life Sciences**: The mission is to understand living organisms by means of theoretical and computational methods (molecular modeling, genomics, proteomics).
- **Earth Sciences**: The mission is to develop and implement global and regional models and data solutions for air quality and climate forecasting and their applications.
- **Engineering (CASE):** The mission is to develop scientific and engineering software to efficiently exploit super-computing capabilities (biomedical, geophysics, atmospheric, energy, social and economic simulations).

- **Computational Social Sciences and Humanities:** The mission of this interdisciplinary field is to model, simulate, and analyze social phenomena to better understand human behavior and society[9].

The mission statements of the BSC scientific departments are shown below in figure 1.

FIGURE 1

The Four Primary Scientific Missions at BSC



Source: Hyperion Research, 2024

BSC-CNS UPDATES FROM THE OCTOBER 2024 HPC USER FORUM

During the October 2024 HPC User Forum, the BSC team provided updates on strategic vision and emerging technology implementation, as well as a tour of the new system. The updates were presented by the following BSC team members:

- Update on BSC Past, Present and Future, Mateo Valero, BSC-CNS
- MN5: Design Choices, Challenges and Future Plans, Sergi Girona, BSC-CNS
- RISC-V and New ISAs, Marc Casas, BSC-CNS
- The DARE RISC-V Initiative, Osman Unsal, BSC-CNS
- AI in Life Science, LLMs and TPC, Jose Carbonell, BSC-CNS

- HPC+AI Workflows at BSC, Rosa M Badia, BSC-CNS
- Optimizing Climate Models with Accelerators and Emerging Technologies, Mario Acosta, BSC-CNS
- Quantum Computing at BSC, Artur Garcia and Alba Cervera-Lierta, BSC-CNS
- Visit of the MN5 Supercomputer, Filippo Mantovani, BSC-CNS

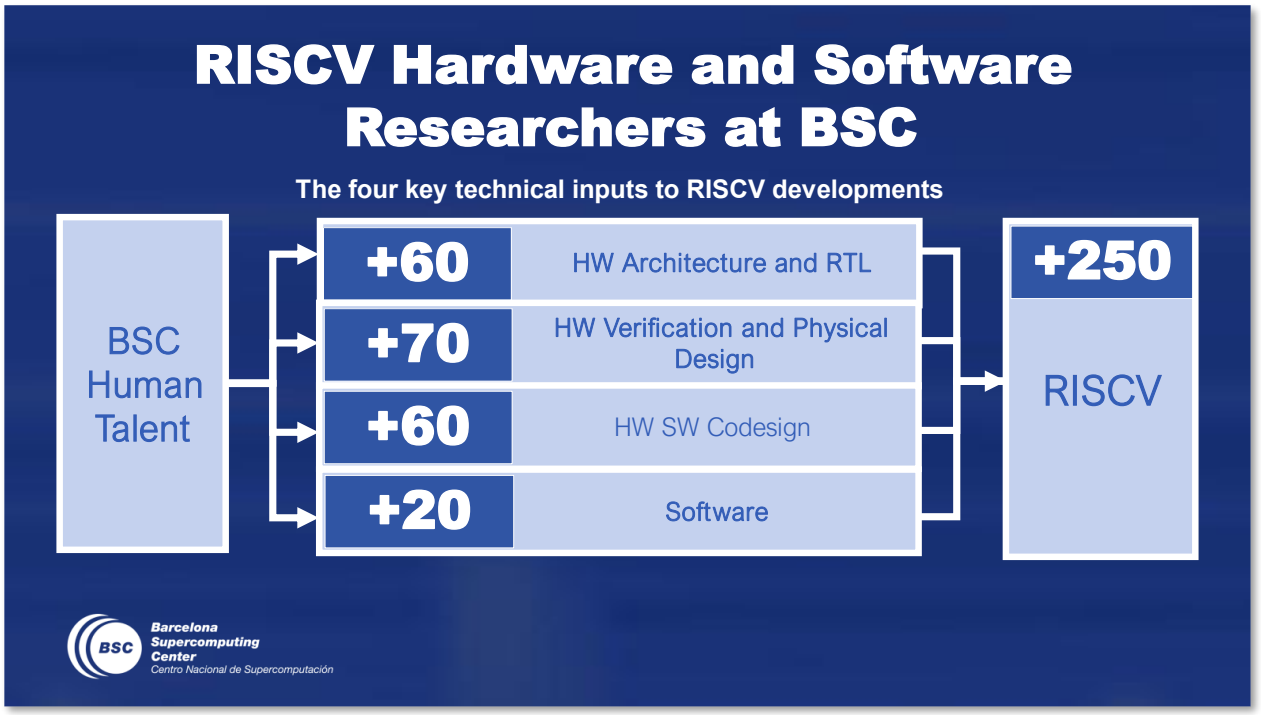
RISC-V at BSC

The BSC is making significant strides in its RISC-V efforts, particularly through the European Processor Initiative (EPI), which aims to establish semiconductor independence in Europe. BSC is making significant contributions to the RISC-V ecosystem, with over 60 researchers focused on hardware architecture and RTL development, more than 70 on hardware verification and physical design, and another 60 on hardware-software co-design. This collaborative effort aims to enhance the open-source hardware landscape, promoting innovation and flexibility in computing solutions, particularly for high-performance computing applications.

Figure 2 shows the work being done at BSC to support the development of RISC-V processors.

FIGURE 2

RISC-V Hardware and Software Teams at BSC



Source: Hyperion Research, 2024

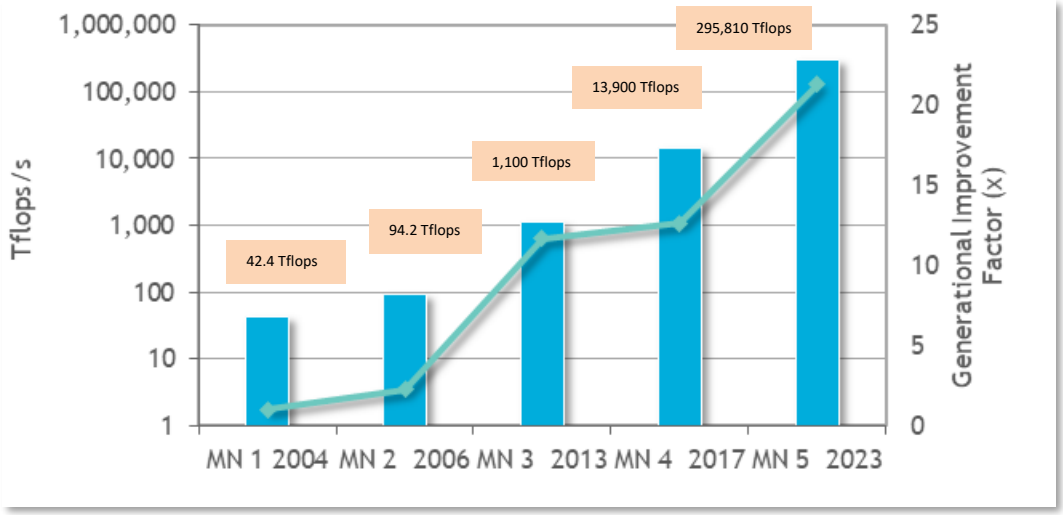
Historical Comparison

MareNostrum 5, the latest supercomputer at BSC, represents a substantial leap in computational power, achieving a performance of 295,810 Tflop/s in 2023, compared to MareNostrum 4's 13,900 Tflop/s in 2017. With a total peak performance of 315.2 Pflops, MareNostrum 5 includes a general-purpose partition delivering 46.4 Pflops and an accelerated partition reaching 260 Pflops. Additionally, BSC is working to add an additional 2.82 Pflops to general purpose partition performance and 6 Pflops to accelerated partition performance in the near future. This impressive performance positions MareNostrum 5 as the 3rd and 7th most powerful supercomputer in Europe in 2022, highlighting BSC's commitment to maintaining its leadership in the field of HPC while integrating cutting-edge RISC-V technologies.

The following figure provides performance comparisons of the 5 MareNostrum generations.

FIGURE 3

MareNostrum Performance Evolution



Note: MN = MareNostrum

Note: y-axis Performance metric is log scale

Note: projected peak performance and acceptance date

Source: Hyperion Research, 2024

Figure 4 shows an overview of the new MareNostrum 5 supercomputer performance statistics.

FIGURE 4

MareNostrum 5 at a Glance

Source: Hyperion Research, 2024

MareNostrum 5 Strategy[10]

MareNostrum 5 is designed to be highly energy efficient, fully powered with green energy, and will utilize heat reuse technology. MareNostrum 5 is also a part of the EuroHPC JU's commitment to developing European hardware, helping to achieve technological sovereignty for the EU's member states. BSC-CNS would also be well-served to highlight requirements to streamline HPC code development to operate reliably and performantly on the widest variety of computer platforms possible, regardless of where in the world they originate.

MareNostrum 5 aims to support two key areas of importance for the EU:

- Developing European hardware to be used in future generations of supercomputers and helping to achieve technological sovereignty for the EU's member states.
- Promote green and sustainable technologies.

The emphasis on sovereign EU-based HPC technology bodes well to create more technological independence and additional economic opportunities for European industry. By providing a showcase for successful implementation and deployment of indigenous technology alongside legacy HPC architectures should provide confidence for users of the stability and longevity of the technology. Care should be taken, however, to prevent developmental overhead or unintended performance constraints for codes that are required to support both legacy and indigenous technologies.

The MareNostrum 5 Architecture

MareNostrum 5 seeks to extend the legacy of MareNostrum 4 in providing a test bed for emerging technologies. Based on a combination of Eviden's' BullSequana XH3000 architectures and Lenovo's Think System architecture, four partitions are defined in the initial architecture, including 2 accelerated GPU-based partitions and 2 general purpose CPU-based partitions. These are described in the following table:

TABLE 2

MareNostrum 5 Partitions

Partition	Components and Targeted Performance
Accelerated	NVIDIA Hopper GPUs Sapphire Rapids GPUs 1120 nodes with 4 Hopper GPUs each one 230 PFlops peak
Accelerated - Next Generation	260 PFlops
General Purpose	Intel Sapphire Rapids CPUs 6408 nodes + 72 HBM nodes 45 PFlops peak
General Purpose - Next Generation	NVIDIA Grace superchips 2 Linpack Pflops

Source: Hyperion Research, 2024

Key to the architecture of MareNostrum 5 is its extensibility as new technological innovations come to fruition. New partitions can be integrated to provide researchers with access to new computing elements, including those funded as part of the European Processor Initiative (EPI), to prove and enable application functionality for the new platforms. One goal in this area is the desire to become one of Europe's major hubs for chip design based on RISC-V technology.

Also key is the ability to provide a wide-ranging array of platforms for researchers and application developers to optimize the development of their codes, enabling the broadest return on those software investments.

Funding[9]

MareNostrum 5 is co-funded with a total investment of over €151 million with 50% coming from the EuroHPC JU and 50% coming from a Spanish-led consortium consisting of three EuroHPC participating countries: Spain (with the participation of the Spanish Ministry of Science and Innovation,

the Government of Catalonia, and the Universitat Politècnica de Catalunya (UPC)), Portugal, and Turkey.

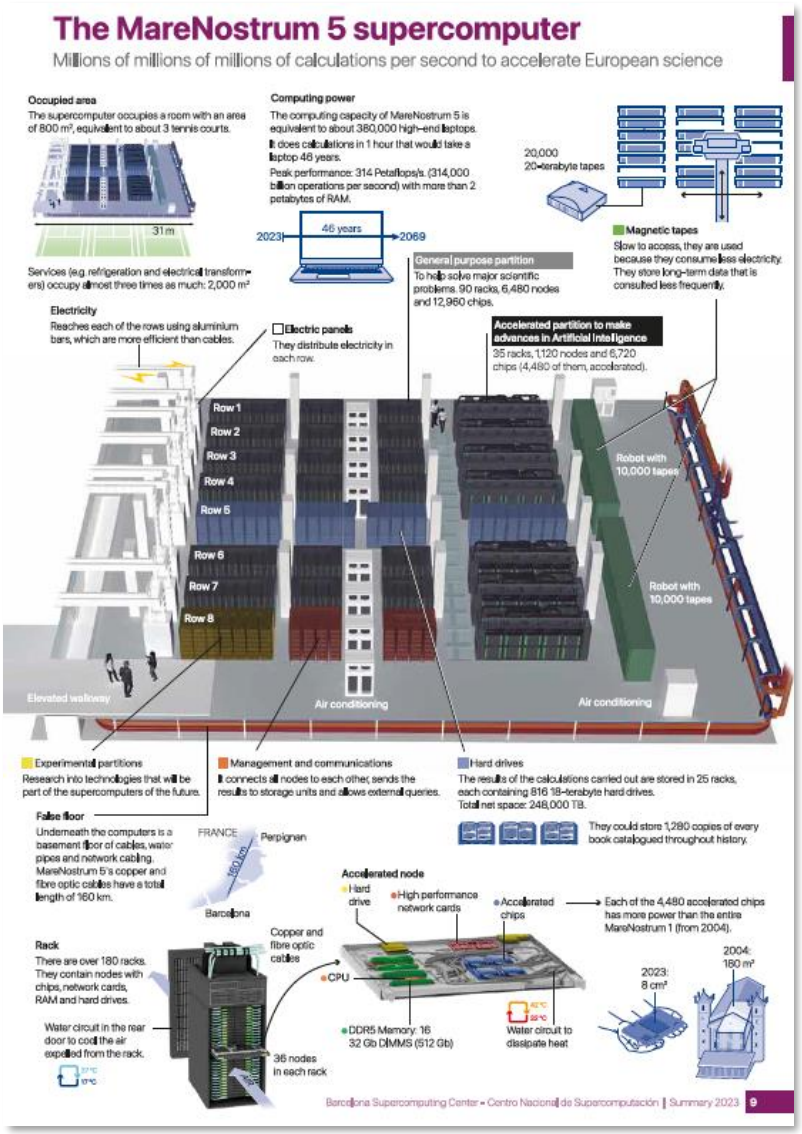
As half the funding for MareNostrum 5 is coming from the EuroHPC JU, half of its computing resources will be allocated to EuroHPC JU users, following open periodic and peer-reviewed calls to which all eligible European users may participate.

MareNostrum 5 Floorplan and Details

The following figure provides details of the MareNostrum 5 infrastructure.

FIGURE 5

MareNostrum 5 Infrastructure



Source: Hyperion Research, 2024; https://www.bsc.es/sites/default/files/public/annualReports/BSC-Summary-2023.pdf

FUTURE DIRECTIONS AT BSC

The future directions for BSC are firmly anchored in the development of MareNostrum 6, following the successful installation of MareNostrum 5. As articulated by Mateo Valero in the quote below (figure 6), this next-generation supercomputer will draw upon the unwavering support of the European Commission, the Spanish and Catalan governments, and the Universitat Politècnica de Catalunya (UPC), alongside a network of public and private European partners. A key feature of MareNostrum 6 will be the integration of European-designed and owned processors based on RISC-V architecture, reflecting BSC's commitment to fostering technological sovereignty in Europe. This initiative not only aims to enhance computational capabilities but also to promote innovation in open-source hardware. With the talent of its researchers and collaborators, BSC is poised to lead advancements in HPC, ensuring its continued influence in the global HPC landscape while contributing to the sustainable growth of the European digital ecosystem.

FIGURE 6

MareNostrum6 Path Forward

Source: Hyperion Research, 2024

Quantum Computing at BSC

Quantum computing at BSC is experiencing significant advancements with the introduction of a digital superconducting circuits quantum computer, procured through a collaborative effort involving Qilimanjaro Quantum Tech, GMV, and partners such as IQM, Quantware, and Leiden Cryogenics. This cutting-edge quantum computer will feature a series of quantum chips, initially deploying 5 qubits and ultimately scaling up to 30 qubits by the project's conclusion. This enhanced capability promises to

significantly boost computational power, enabling researchers to accelerate scientific discovery and innovation across Europe.

BSC's quantum computing initiative will also emphasize public and free access for research and development, fostering an open environment for scientists and engineers to experiment with quantum technologies. Once installed, the system will be operated exclusively by BSC-CNS personnel, ensuring a high level of expertise in its management. Furthermore, the integration of this quantum computer into the EuroHPC network will facilitate European research collaborations. As BSC continues to develop its quantum capabilities, it aims to position itself as a leader in this emerging field, driving forward collaborative projects that leverage quantum computing to address complex scientific challenges and contribute to advancements in various disciplines. The following two figures are slides shared by BSC team members at the recent HPC User Forum describing the quantum efforts at BSC:

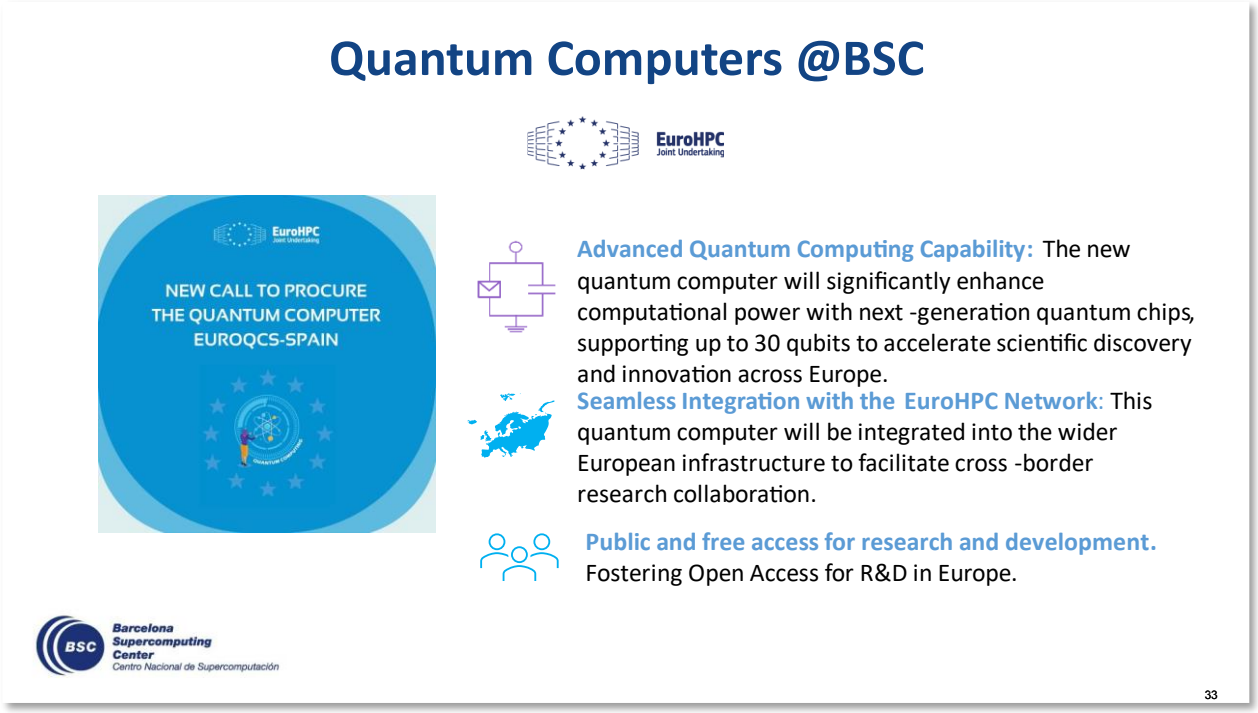
FIGURE 7

Quantum Computer at BSC

Source: Hyperion Research, 2024

FIGURE 7

Quantum Computers at BSC



Source: Hyperion Research, 2024

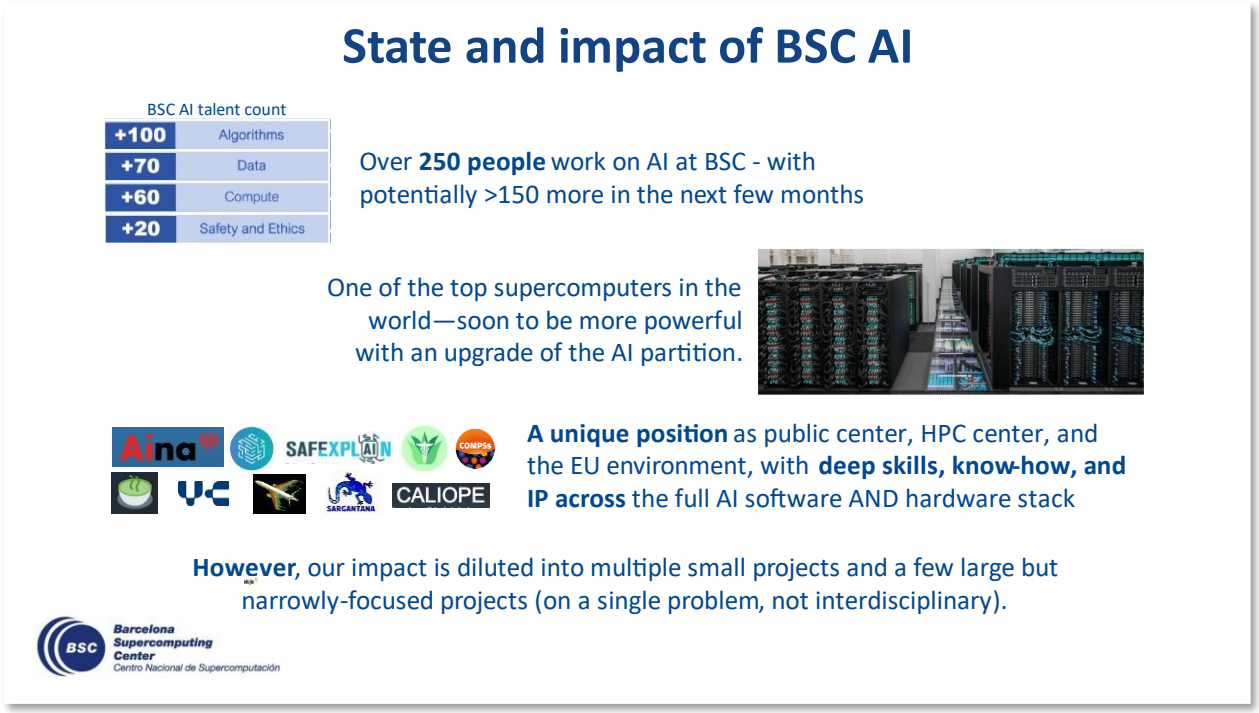
AI at BSC

BSC is rapidly advancing its capabilities in AI, with over 250 researchers actively engaged in this field. This workforce is expected to grow in the coming months as BSC prepares to upgrade the AI partition of its supercomputing infrastructure. This upgrade is crucial to reinforcing BSC's position among the world's top supercomputers, enabling the center to tackle increasingly complex AI challenges and maintain its competitive edge in HPC.

BSC is involved in a variety of AI projects that span multiple domains, including healthcare, climate modeling, and smart cities. However, while these initiatives demonstrate BSC's diverse capabilities, its impact is somewhat diluted by a tendency to pursue multiple smaller projects alongside a few larger, narrowly focused efforts. To maximize its potential in the AI landscape, BSC may benefit from consolidating these initiatives and fostering more interdisciplinary collaboration, allowing it to leverage its expertise more effectively across the AI spectrum. The figure below is an overview of the AI efforts at BSC.

FIGURE 8

AI at BSC



Source: Hyperion Research, 2024

OPPORTUNITIES

BSC-CNS continues to be the most qualified HPC center in Spain and one of the most capable in not only Europe but the world. Through its relationship with the various EU HPC entities, including the EuroHPC JU, PRACE, and ETP4HPC, the center can continue to play a major role in support the EU strategy of moving towards technology sovereignty and independence.

Striving for environmental stewardship and responsible, efficient power utilization for its HPC infrastructure is another area where BSC-CNS can assert regional and global leadership. This is especially true if the goals can be achieved in a major urban setting, as opposed to datacenters fortunate to have more temperate and environmentally friendly natural surroundings.

BSC-CNS provides a great opportunity to researchers across Europe, and more researchers should consider using their resources in the future to improve their research capabilities and results.

ESSENTIAL GUIDANCE FOR OTHER HPC SITES

HPC sites around the world in all sectors (industry, government, and academia) can benefit from the approach BSC-CNS has taken in developing its mission and infrastructure:

- Develop a strong roadmap with a sound economic cadence for HPC resource investment.
- Make measured investments in physical infrastructure between existing facilities for legacy equipment and new facilities to support the physical space, power, and cooling requirements for new and emerging solutions.
- Establish a strong industry relations, collaboration, and technology transfer program.
- Focus research on areas important to the country's and regional economic and societal needs.
- Balance investments across a diverse set of goals and requirements.
  - Legacy, global infrastructure vs. new, sovereign technology.
  - Compute-intensive vs. data-intensive workloads.

APPENDIX 1: THE HISTORY OF BSC-CNS[3]

Currently located in the former 19th century Chapel Torre Girona on the campus of the Polytechnic University of Catalonia is the Barcelona Supercomputer Center-Centro Nacional de Supercomputacion (BSC-CNS). BSC-CNS is the leading research site in Spain and was the former home of the MareNostrum 4 supercomputer. The site is currently being configured for the installation of EuroQCS-Spain, a new EuroHPC quantum computer to be integrated into the EuroHPC supercomputer MareNostrum5.

Before being officially established in 2005 as BSC-CNS, the facility evolved out of what was initially known as the European Center for Parallelism of Barcelona (CEPBA). CEPBA was a well-known research, development, and innovations center on efficient computing technologies for both academia and industry. While belonging the Universitat Politècnica de Catalunya (UPC), it was also sponsored by two R&D support agencies: the Spanish CICYT (Comisión Interministerial de Ciencia y Tecnología) and the Catalan CIRIT (Consell Interdepartamental de Recerca i Innovació Tecnològica).

Created in 1991, CEPBA started its activities, gathering the experience and needs of various UPC departments. The Computer Architecture Department (DAC) provided experience in the lower level of a computing system (numerical kernels, operating systems, tools and architecture) and joined five other departments of UPC with high computation demand [Signal Theory and Communications (TSC), Strength of Materials and Structural Engineering (RMEE), Computer Systems and Languages (LSI), Nuclear Physics and Engineering (FEN) and Applied Physics (FA)] to set up the CEPBA.

Several relationships and sponsoring entities evolved over the next decade before BSC-CNS was formally created:

- **1995 to 2000** CEPBA coordinated the service activities with CESCA (Supercomputing Center of Catalonia) through the C4 (Computing and Communications Center of Catalonia) founded by the CIRIT, Catalan Research Foundation and UPC.
- **2000** CEPBA signed an agreement with IBM to launch the CEPBA-IBM Research Institute. The objectives of this agreement were to join research on topics related with Deep Computing and Architecture, and to support local research in other areas of science and engineering. This Research and Development Partnership between UPC and IBM had an initial commitment of 4 years.
- **2004** The Ministry of Education (Spanish Government), Generalitat de Catalunya (local Catalan Government) and UPC took the initiative of creating a National Supercomputing Center in Barcelona.
- **2005** BSC-CNS was officially established in 2005 and the initial MareNostrum was deployed as the largest supercomputer in Europe at the time. MareNostrum 4 cracked the Top500 in June 2017, coming in ranked at #13 with an Rmax of 6.2 Pflops.
- **2021** A new BSC-CNS corporate headquarters, the BSC-REPSOL building, was completed in 2021. Connected by a walkway to the iconic Torre Girona temple, the new headquarters was built to include a new supercomputer room in the basement, capable of supporting larger and higher-capacity supercomputing infrastructures.
- **2023** Inaugurated in December 2023, MarenoNostrum5, a petascale-class machine, is the first supercomputer to be housed in the new headquarters. The Torre Girona Chapel datacenter, home to MareNostrum1 – MareNostrum4, welcomed one of Europe's first quantum computers to come on-line.

APPENDIX 2: MISSION, VALUE AND COMPETENCIES, AND GOVERNANCE

The BCS-CNS Mission[12]

The mission of the BSC-CNS is to research, implement, manage, and transfer technology and knowledge in the area of HPC with the aim of facilitating progress in a variety of scientific fields, and with a special emphasis on computer, life, earth and engineering sciences.

The main objectives of the centre are:

- Scientific and technical excellence
  - To be a centre of excellence at international level.
  - To promote cooperation between multidisciplinary groups.
  - To attract and retain national and international talent.
  - To be a leader in the innovative application of computation to non-conventional fields.
- Support for e-science in Spain
  - To provide competitive, Europe-wide HPC resources.
  - To be the Spanish leader in providing support for access to supercomputing infrastructure.
  - To participate actively on the supercomputing stage at international level.
- Wealth creation
  - To facilitate technological transfer.
  - To promote the development of the knowledge society.
  - To maintain effective resource management.

Values and Competencies

The BSC-CNS is committed to establishing and maintaining the conditions that will ensure continuing access to the knowledge that people need for professional growth. Within this framework, values have been defined that exemplify its corporate competencies:

- Ethics and honesty
  - To work with integrity and rigor, striving at all times to do what is correct and demanding utmost honesty of ourselves and the people around us.
  - To respect people, the community and the environment.
  - To offer the same opportunities in an environment in which diversity is a source of incalculable value.
- Responsibility and commitment
  - To apply logic and common sense to seeking, analyzing, and offering the best possible response to all that we undertake to achieve.
  - To strive to make a contribution through our mission, objectives, high performance and continuous learning.
  - To be motivated to be at our best and to uphold the values of the centre.
  - To aspire to and achieve personal and professional leadership in our relationships.
- Excellence and quality

        - To apply effective solutions for attaining optimum results to make us highly credible people and teams.
        - To be non-conformist and to seek the highest quality information and decision-making with the aim of achieving maximum effectiveness.
    - Enthusiasm and anticipation
        - To understand that challenges are opportunities and to imbue all that we do with passion and optimism.
        - To offer personal attention to the people with whom we interact.
    - Innovation
        - The defining characteristic of our culture is to maintain a creative attitude in all our activities in order to make the greatest impact possible and to support the development potential of our staff. To be positive and flexible in the face of change and to promote a dynamic environment so as to overcome all challenges.
    - Collective identity and teamwork
        - To cooperate to build solid, loyal relationships with each other so as to obtain synergies and alliances that produce multidisciplinary results.
        - To listen, discuss and share the curiosity needed to investigate and discover new challenges for the BSC-CNS.

Governance

The main governance boards of BSC-CNS are the Board of Trustees and the Executive Commission. Members come from the three shareholding institutions of the BSC:

- Spanish Ministry of Science and Innovation
- Catalan Ministry of Research and Universities
- Polytechnic University of Catalan

Additionally, there is a Scientific Advisory Board and an Access Committee. The **Scientific Advisory Board** is made up of distinguished senior scientists and science managers from around the world. It reports to the BSC-CNS Board of Trustees and meets periodically to analyze BSC-CNS's research programs, results, and plans. The Board issues a written report which evaluates the period in question and includes suggestions and advice for the future. The **Access Committee** is comprised of various functional experts, including external innovation management, supercomputing, and data services/management, and is advised by a panel of scientific research subject matter experts.

ENDNOTES

1. Barcelona Supercomputer Center, https://www.bsc.es/

2. "*BSC to team up with Japanese Centre for Computational Science RIKEN*", https://www.bsc.es/news/bsc-news/bsc-team-japanese-centre-computational-science-riken

3. BSC-CNS History, https://www.bsc.es/discover-bsc/the-centre/history

4. The European High Performance Computing Joint Undertaking (EuroHPC JU), https://eurohpc-ju.europa.eu/index_en

5. EuroHPC Our Supercomputers, https://eurohpc-ju.europa.eu/about/our-supercomputers_en

6. PRACE history: https://prace-ri.eu/about/introduction

7. ETP4HPC History, https://www.etp4hpc.eu/who-we-are.html

8. ETP4HPC Strategic Research Agenda (SRA), https://www.etp4hpc.eu/sra.html

9. BSC-CNS 2023 Annual Summary, https://www.bsc.es/sites/default/files/public/annualReports/BSC-Summary-2023.pdf

10. *MareNostrum5: a new EuroHPC world-class supercomputer in Spain*", https://eurohpc-ju.europa.eu/marenostrum5-new-eurohpc-world-class-supercomputer-spain-2022-06-16_en

11. BSC-CNS MareNostrum, https://www.bsc.es/marenostrum/marenostrum

12. Barcelona Supercomputer Center, https://www.bsc.es/

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Hyperion Research provides data-driven research, analysis and recommendations for technologies, applications, and markets in high performance computing and emerging technology areas to help organizations worldwide make effective decisions and seize growth opportunities. Research includes market sizing and forecasting, share tracking, segmentation, technology, and related trend analysis, and both user and vendor analysis for multi-user technical server technology used for HPC and HPDA (high performance data analysis). We provide thought leadership and practical guidance for users, vendors, and other members of the HPC community by focusing on key market and technology trends across government, industry, commerce, and academia.

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