HANAMI Roadmap for Future Collaboration

First iteration – Key Themes for Future Collaboration

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Introduction – Roadmap for EU-Japan HPC collaboration

Research and innovation (R&I) and digital technologies are critical enablers of competitiveness, productivity and prosperity in today's global economy. In the race towards a leading technological position, various regions in the world have made huge investments in the development of critical technologies and infrastructures, such as high-performance computing (HPC), artificial intelligence (AI) and Quantum Computing (QC), as well as developing related competences.

EU and Japan are like-minded partners and two world-leading HPC superpowers. Their long-standing strategic relationship is grounded in shared values, including democracy, human rights, multilateralism, free and fair trade, and the green transition. In recent years, cooperation in digital technologies has deepened through the EU–Japan Digital Partnership[1], launched in 2022, which promotes collaboration in critical areas such as HPC, quantum technologies, AI, digital connectivity and cross-border data flows.

As the global landscape becomes more divided due to geopolitical tensions, working together with partners who share the same values and goals is exceedingly important. By joining forces and connecting the best tools with the best experts across borders, it is possible to magnify the impact of technological investments and significantly boost scientific innovation. Support for deeper EU-Japan collaboration is not merely an R&I investment – it is a policy instrument to advance green and digital transitions. With Japan's association to the Pillar II of the EU's Horizon Europe Framework Programme[2], with formal signature and entry into force expected in 2026 and transitional arrangements enabling Japanese entities to apply from January 2026, there is now also a clear procedural bridge to move from strategy to implementation that enables long-term institutional integration rather than ad-hoc cooperation.

The HANAMI project[3], funded by the EuroHPC Joint Undertaking under the Digital Partnership, was established to strengthen this strategic cooperation. This roadmap sets out a vision and framework for expanding EU–Japan collaboration in HPC and related critical technologies. It consolidates insights from the scientific community, policymakers and industry to identify the major scientific and infrastructural challenges to be addressed through the collaboration and articulates the mutual benefits of coordinated action. Its purpose is to outline concrete thematic areas and mechanisms for collaboration over the coming decades, enabling the EU and Japan to align priorities, combine strengths and promote scientific development, thus supporting a stable, long-term partnership capable of advancing technological excellence, scientific innovation and societal resilience in both regions.

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[1] https://digital-strategy.ec.europa.eu/en/policies/partnerships

[2] https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/europe-world/international-cooperation/bilateral-cooperation-science-and-technology-agreements-non-eu-countries/japan_en

[3] https://hanami-project.com/

Benefits of global collaboration on high-performance computing

Despite the global trend of increasingly protectionist attitudes towards the development and sharing of critical technologies, international collaboration can provide vital benefits that promote the resilience, sustainability and competitiveness of digital ecosystems.

Joint development of software libraries, services, and shared best practices allows communities to pool knowledge and ensure that complex scientific code remains scalable, interoperable, and sustainable. In addition, it reduces duplication of portability and validation work across national silos, which increases economic efficiency and deployment-grade outcomes. When scientists gain access to a diverse set of high-performance computing architectures, they can run workloads on the systems best suited to their objectives, improving efficiency and enabling fairer access to cutting-edge capabilities.

Cross-border cooperation also enhances the quality and reliability of scientific software. Common approaches to acceptance testing, performance metrics, benchmarking, and software readiness help ensure reproducible results across systems operating in different countries. Collaborative optimisation enables applications to be tuned more broadly and ported more easily, resulting in faster performance and greater portability across international infrastructures.

Closer coordination between the EU and Japan offers significant benefits but, currently, remains underexploited. While both partners have world-class supercomputing infrastructures, advanced research communities and strong industrial actors, collaboration is still largely ad hoc, project-based, and limited in scale. Without a shared long-term vision, opportunities for joint development, interoperability, and coordinated scientific workflows may be missed. Collaborative action can improve the collective capacity to address global challenges that require computing power and expertise beyond the reach of any single region.

HANAMI vision for EU-Japan collaboration

HANAMI envisions a future in which EU–Japan cooperation is an essential part of the development of advanced computing ecosystems and compute-intensive science in both regions. It is not based on individual projects addressing singular issues, but a long-term strategic partnership around joint grand challenges that produces operational impact for fundamental research, society, policy and industry.

This collaboration fosters new generations of scientists who grow into their careers with a collaborative mindset and enduring professional ties across Europe and Japan. These long-standing connections form a stable basis for continued joint work, allowing the partnership to evolve organically as scientific needs and technological opportunities develop.

The collaboration brings together political priorities and the needs of the scientific community, ensuring that the topics it promotes are both strategically relevant and scientifically meaningful. As a result, it enables research with tangible impact on fundamental research and societal development in Europe and Japan. Over time, the partnership will have matured into a trusted relationship in usage and development of critical technologies covering the entire computing ecosystem, including high-performance computing, artificial intelligence, and quantum technologies, where experts from both regions face technological challenges together to improve efficiency, sustainability, and innovation through combined expertise.

European and Japanese researchers in strategic scientific fields benefit from a wide selection of high-quality computing tools and applications for research. Facilitated access to world-class infrastructures, combined with the joint development, optimisation and benchmarking of code strengthens scientific excellence while supporting reproducibility and performance across different architectures. The collaboration also leverages synergies with other international initiatives and networks, allowing it to amplify its impact and further enhance the benefits for both regions.

Supercomputing landscape in Europe and Japan

Europe has built one of the world's most advanced and diverse high-performance computing (HPC) ecosystems to support scientific excellence, industrial competitiveness, and digital sovereignty. The expansion of computing capacity is tightly linked to broader European goals of technological leadership and resilience: managing data-intensive digital technologies at scale, supporting open scientific collaboration, and reducing reliance on non-European infrastructures[4][5][6].

The European High-Performance Computing Joint Undertaking (EuroHPC JU)[7] coordinates much of this effort. Between 2021–2027, approximately 1.9 billion euros of its budget is dedicated to acquiring, upgrading, and operating Europe's supercomputing systems, alongside matching national investments.

As of early 2026, the EuroHPC portfolio[8] includes 12 petascale, pre-exascale, and exascale systems deployed or under procurement across Europe. Europe entered the exascale era with JUPITER in Germany, which began operation in September 2025 and supports large-scale climate, weather, and AI workloads. A second exascale system, Alice Recoque in France, is under procurement and will combine high-performance simulation capabilities with advanced AI processing and early quantum integration. The EuroHPC Federation Platform, currently under deployment, is planned to connect all these systems into a federated environment, ensuring that the distinctive advantages of each infrastructure are fully leveraged.

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[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2025:497:REV1

[5] https://digital-strategy.ec.europa.eu/en/library/ai-continent-action-plan

[6] https://digital-strategy.ec.europa.eu/en/library/joint-communication-international-digital-strategy-eu

[7] https://www.eurohpc-ju.europa.eu/index_en

[8] https://www.eurohpc-ju.europa.eu/supercomputers/our-supercomputers_en

European systems occupy five of the world's top ten supercomputing positions according to late-2025 rankings[9], including the EuroHPC systems JUPITER, LUMI, and Leonardo, in addition to other top-tier systems like the pre-exascale supercomputer MareNostrum5. This makes Europe one of the strongest global HPC regions, alongside the United States and Japan. National and private investments complement the EuroHPC deployments, notably Alps in Switzerland and Italy's HPC6 operated by Eni, which both rank among the world's fastest. Significant investments are made also to implement multiple new AI-optimized systems in European AI Factories and Gigafactories, showcasing a shift towards more AI-HPC integration.

Japan hosts a similarly vibrant national HPC ecosystem. The strategy driving the development follows Japan's 7th Science and Technology Basic Plan, published in March 2026[10]. The plan places science and technology, especially disruptive technologies such as AI and quantum, at the core of national security and growth, doubling previous total investment target for government R&D up to 60 trillion yen (appr. 321 billion euros) and combined public-private investment target to 180 trillion yen (appr. 936 billion euros) between 2026-2030.

Japan's technical HPC ecosystem is centered around strong flagship systems. Their current flagship system, Fugaku, is a CPU-based exascale system that was procured in 2021 and remains the world's 7th fastest supercomputer according to the top500 ranking in November 2025[11]. In addition to Fugaku, Japan's national HPCI network[12] includes 14 smaller systems hosted at national universities and research institutions that form the core computing resources available for public research.

Japan is currently preparing for the procurement of Fugaku's successor supercomputer, FugakuNEXT[13], which will exceed exascale and support AI development as well as high-level research in fields including healthcare and drug discovery, materials and manufacturing, energy, and climate sciences.

Key themes for future collaboration

HANAMI is centered on human collaboration and the development of scientific talents. Building a strong and interconnected research community between Europe and Japan is essential to ensuring long-term innovation and knowledge exchange. In this context, HANAMI aims to address an important gap within research and innovation by fostering skills development, strengthening interdisciplinary expertise, and creating sustainable networks of researchers capable of driving future scientific and technological advances together. This is why also the proposed collaboration activities in this roadmap focus on co-development and joint research, rather than investments in hardware, where HANAMI already benefits from access to high-end supercomputers and quantum facilities through key partners in its consortium.

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[9] https://www.top500.org/lists/top500/2025/11/

[10] https://www8.cao.go.jp/cstp/kihonkeikaku/index7.html

[11] https://www.top500.org/lists/top500/2025/11/

[12] https://www.hpci-office.jp/en

[13] https://www.r-ccs.riken.jp/en/fugaku-next/

Future trajectories of HPC development

The next stage of computing will enable tackling completely new scientific and social challenges through more accurate models, faster processing, and massive simulations. HPC increasingly forms the computational backbone for not only scientific workloads but also AI development and, in the future, quantum-accelerated applications. While quantum systems are expected to accelerate specific computations, they will rely on classical HPC for orchestration, error mitigation, and post-processing.

Foundations of (Post)Exascale Computing - Exascale computing is the immediate frontier of HPC, with both Europe and Japan planning additional exascale-class systems beyond 2026. Realising their full value requires applications adapted to massively parallel and GPU-centric architectures. In late 2025, Japan launched a 2.48 billion yen (approx. 13.6 million euro) programme to support next-generation GPU-based HPC and AI applications, with corresponding initiatives underway in Europe. To avoid the creation of fragmented national workarounds, joint work on GPU porting is recommended. The GPU market (hardware and partially software) is, at the time of writing this document, led by American companies. It is therefore critical to maintain the performance of European and Japanese scientific applications regardless of what the future hardware will be. To this end, HANAMI supports the development of software and applications with components that remain hardware-agnostic to maintain sovereignty of research.

Proposed collaboration activities:

- GPU porting with a priority on efforts to develop hardware-agnostic frameworks, optimizing and tuning strategic applications of both regions on massively parallel GPU supercomputers.
- Inclusion of low-precision arithmetics and accuracy emulation within the scientific applications in Europe and Japan, alongside with applied mathematics research to ensure the correctness of the models.
- Shared performance-portability infrastructure, including kernel libraries, solver refactoring patterns, and Continuous Integration (CI) benchmarking across EU and Japanese machines.

AI-Augmented Science – Artificial Intelligence (AI) is a priority of global digital development all around the world, expected to enhance productivity and competitiveness, and a key determinant of demand for HPC resources. Many of Europe’s existing systems are optimized for AI workloads, and EuroHPC is significantly expanding this capacity. At least nine new AI-optimised supercomputers are being procured for the AI Factories network, expected to triple the current EuroHPC AI capacity. In parallel, the planned InvestAI Facility will mobilise a twenty-billion-euro fund to support up to five AI Gigafactories, further integrating HPC capability with Europe’s long-term AI ambitions. In Japan, the new flagship system FugakuNEXT is explicitly stated to be developed as a HPC-AI platform. AI for Science is a shared priority in Europe and Japan, supported in the EU by the RAISE platform and in Japan by an AI for Science strategy and a dedicated supercomputer operational in 2026. The proposed activities here contribute to research community development: Building expertise at the intersection of AI, HPC, applied mathematics, and domain science is essential to bridge the current skills gap and create a sustainable long-term research community.

Proposed collaboration activities:

- *AI for Science:* Leveraging artificial intelligence and machine learning to accelerate scientific discovery in key areas. Europe and Japan can jointly develop AI models and AI-enhanced simulation workflows that combine HPC, data analytics, and large-scale scientific datasets to reduce time-to-solution and enable new research capabilities. This activity can also focus on joint development of responsible "agentic AI", i.e. AI systems that can orchestrate simulation pipelines, propose mesh/refinement strategies, use AI/ML to produce reduced-order models from HPC simulations, manage parameter studies, or flag non-physical solutions, while maintaining traceability and human oversight.
- *Science for AI:* advancing the scientific and mathematical foundations required to build trustworthy, efficient, and explainable AI systems. This includes numerical methods, uncertainty quantification, low-precision arithmetic, optimization algorithms, and physics-informed AI approaches that improve robustness, reproducibility, and energy efficiency of AI models.
- *HPC–AI convergence on heterogeneous infrastructures:* fostering co-design between AI researchers, computational scientists, and hardware specialists to optimize AI and scientific applications on emerging CPU/GPU and accelerator-based architectures. The software developed within this activity should remain hardware agnostic. The work will focus on performance portability, scalable software ecosystems, and interoperable frameworks across European and Japanese supercomputing infrastructures.
- *Trusted, sustainable, and human-centric AI ecosystems:* promoting ethical, transparent AI technologies aligned with European and Japanese values. Collaboration can focus on trustworthy AI methodologies, secure data-sharing environments, and governance frameworks that ensure societal benefit and scientific integrity.

Enhance science through Large Data Analysis - As computational capacity grows, the ability to process increasingly large amounts of data becomes increasingly important, and thus access to sources of high-quality data is at the core of the development of the HPC ecosystems as a whole. These data can be utilised for more accurate models and predictions, including complex model ensembles such as the digital twin of the Earth developed by the Destination Earth initiative, or for instance in AI training. Within Europe, sectorial data spaces are planned to address this need by providing frameworks for secure, domain-specific data sharing, but global solutions will be necessary to prevent geographical biases and ensure scientific integrity.

Proposed collaboration activities:

- *Trusted and interoperable data ecosystems:* enabling secure data sharing between Europe and Japan through common standards and interoperable infrastructures.
- *FAIR and open science practices:* promoting reproducible and reusable scientific data aligned with FAIR principles to strengthen collaborative research.
- *Data infrastructures for AI:* developing shared platforms and curated datasets supporting AI for Science and simulation workflows.
- *Secure and privacy-preserving collaboration:* advancing federated learning, confidential computing, and secure data exchange technologies for international research cooperation.
- *Large-scale data management for HPC and AI:* addressing exascale data challenges through efficient storage, analytics, and energy-aware data processing workflows.

- *Training and community development:* building expertise in data science, AI-driven analytics, and scientific data management through joint EU–Japan training and mobility programs.
- In situ analysis, processing and data management to ensure an efficient data output and storage management

Interoperability, standardisation and sustainability - are important for breaking down silos between specialised hardware, software stacks, and data environments. Globally recognised open standards are necessary to avoid vendor lock-in and support efficient cross-border collaboration. Interoperability between different computing models, such as traditional HPC, cloud computing and distributed computing environments allows the different systems to work together efficiently, securely and reliably. It is also the key need for co-design of hardware, software and AI workflows. Standardised data formats and API frameworks support integration across storage systems, while container technologies improve software portability across infrastructures.

Proposed collaboration activities:

- Joint development of open-source software components, with a priority on hardware agnostic frameworks, and developing a critical mass of researchers and engineers within key international software, such as Kokkos, spack, modules, etc.
- Strengthening EU and Japanese representation within key foundations, such as High Performance Software Foundation (HPSF) or Software Heritage, to ensure the sustainability of key software in both regions.
- Exchange of best practices on cross-platform collaboration between both regions.
- Sharing of best practices for software engineering, reproducibility, and FAIR data principles in scientific computing workflows.

Training, outreach and workforce development - The complexity of modern architectures requires specialists capable of developing, optimising and maintaining scalable code, managing heterogeneous systems, and designing hybrid workflows that combine HPC, AI, and quantum resources. Demand is also increasing for experts in data engineering, scientific software development, energy-efficient computing, and security. Sustained investment in education, long-term career pathways, and cross-disciplinary training will be essential to ensure that advanced HPC infrastructures can be fully utilised, and that scientific and industrial users can adopt new computing paradigms effectively.

Proposed collaboration activities:

- Joint PhD and training programmes, such as a program to hire PhD and Postdoc researchers within the European and Japanese research organizations in the long term. The hired researchers would work in collaboration with both EU and Japanese research organisms.
- Enabling access to high-end supercomputers to young researchers through the joint PhD and Postdoc program: EU and Japan would agree on cross-access to their supercomputers, dedicating computing resources to EU-Japan collaboration.
- Expanded opportunities for short- and long-term researcher and engineer exchange with a priority on young researchers.

Quantum computing is advancing rapidly and is expected to far surpass the efficiency of traditional computing for specific workloads in the future. Europe and Japan are deploying early quantum systems across multiple technology platforms, including superconducting qubits, trapped ions and neutral atoms, and integrating them with classic supercomputers. This early access enables developing hybrid HPC-quantum applications and methodologies, as well as testing quantum applications and algorithms on multiple different architectures, preparing the ground for the quantum advantage once quantum computing becomes viable to use at scale. An existing collaboration, the Q-NEKO project, works to advance EU-Japan collaboration in the quantum field. Q-NEKO will produce a roadmap focused on potential future EU-Japan quantum activities, and thus, they will not be covered in this document.

Collaboration in scientific fields

The existing HANAMI collaboration focuses on three scientific paradigms : climate sciences, biomedical science, and materials science. In addition to future collaboration in these three fields, this roadmap will propose potential new additional fields where EU-Japan collaboration might bring concrete mutual benefits.

Climate sciences

Climate simulations are a cornerstone of climate science, providing a systematic way to understand how and why Earth's climate is changing and to disentangle the role of natural variability from the impacts of human activities. By integrating observations with physical laws, these simulations allow scientists to understand the behaviour of the climate system, explore the consequences of greenhouse gas emissions, land-use change, and other drivers, and to assess the effectiveness of possible mitigation and adaptation strategies.

Looking ahead, a major question in climate simulation is the future role of AI-based models. To what extent will traditional physics-based models remain central, and how can artificial intelligence complement them by accelerating calculations, improving resolution, and extracting new insights?

A parallel challenge is strengthening the interoperability between climate software, workflows and HPC infrastructures, with the core objective of enabling coordinated large-scale scientific campaigns that can be executed across leading European and Japanese supercomputers, while maintaining reproducibility, transparency, and comparable evaluation frameworks. By aligning how simulations are set up, executed, and evaluated, scientists could more easily compare results, verify findings, and build a clearer, more reliable picture of how the climate system behaves.

Together, these advances promise more accurate, actionable information to support informed decision-making on issues such as climate adaptation, disaster preparedness, and long-term sustainability.

Proposed collaboration activities

Development of shared experiment workflows and reproducibility frameworks for global climate models

- Integration of workflow management systems to support experiment orchestration for climate simulation models, enabling coordinated execution of simulation campaigns across different infrastructures, improving experiment traceability, and enabling consistent monitoring of performance and scientific outputs across platforms.
- Collaborative studies performing comparisons between European and Japanese climate models at a high spatial resolution, using harmonised experiment definitions and evaluation methodologies. This aims to improve the flexibility of applications and algorithms in view of future paradigm changes in HPC, such as new chip architectures or computing paradigms as for example emerging from quantum computing.
- Collaborative porting of climate applications to GPU architectures and their evaluation to enable exploitation of future HPC systems.
- Extending existing replicability testing methodologies to create a common framework combining workflow management, performance monitoring and reproducibility verification, ensuring that experiments conducted with different models or model versions (eg GPU vs CPU) remain comparable and scientifically robust.

Explore emerging approaches combining HPC and artificial intelligence, particularly through the development of surrogate models that complement traditional numerical simulations

- Investigate the use of AI-based surrogate models to accelerate parameter exploration, model evaluation and sensitivity analysis within large climate experiment workflows. These could be integrated into existing modelling pipelines, enabling hybrid modelling strategies that combine physics-based simulations with data-driven components.
- Investigate full replacement of selected applications through data-driven techniques, for example using suitable modelling frameworks to build localised data-driven forecasting models.

Biomedical science

Europe and Japan are facing a profound transformation in healthcare driven by demographic trends, chronic diseases, and the need for personalized medicine. In both regions, cardiovascular diseases, respiratory disorders, and neurological conditions remain the leading causes of mortality and healthcare costs.

At the same time, advances in computational fluid dynamics (CFD) and HPC are opening a new paradigm: the ability to simulate physiological flows, e.g., air in the lungs, blood in arteries, or cerebrospinal fluid in the brain, with patient-specific accuracy. In parallel, similar HPC-driven approaches are enabling the simulation of molecular and cellular processes, such as intracellular signalling, gene regulation, and cell population dynamics, providing complementary insights across biological scales.

Through joint EU–Japan efforts, the computational investment in HPC can be transformed into clinical impact, linking infrastructure, science, and societal outcomes. The state-of-the-art in biomedical simulations already include patient-specific modelling, multi-physics coupling, and data-driven approaches integrating medical imaging and clinical data.

One of the future directions includes moving towards multi-scale modelling that bridges molecular, cellular, tissue, and organ levels, combining simulations with omics data and longitudinal clinical records (EHR) to create mechanistic and data-grounded representations of disease processes. At the same time, the frontier is shifting towards AI-HPC integrated platforms, GPU acceleration, and AI technologies embedded within simulation pipelines. Future gains depend on portability and AI-assisted workflows. This requires coordinated investment not only in domain research, but also software ecosystems, validation frameworks, and interoperable infrastructures across regions. In this context, there is a strong need to:

- align scientific and clinical capabilities across the HPC and biomedical domains,
- develop shared, portable, and verifiable simulation workflows for clinical use, and
- investigate and accelerate the development and deployment of data-driven, multi-scale biomedical digital twin technologies.

This would allow the development of HPC-enabled, AI-augmented biomedical simulations as decision-support tools across the clinical pathway. This includes diagnosis, treatment planning and prevention, and agentic AI for diagnosis support and hypothesis generation. The proposed actions would also strengthen long-term healthcare innovation and system resilience, which are key to building improved healthcare systems

Proposed collaboration activities
Patient-specific and multi-scale biomedical simulations supported by high-fidelity Computational Fluid Dynamics computations, cellular modelling, and physics-based surgical support systems • Joint development of simulation workflows that couple organ-level CFD models with molecular and cellular-scale simulations, enabling multi-scale representations of disease processes. This includes integrating intracellular signalling, cell population dynamics, and tissue behaviour with physiological flow simulations for patient-specific diagnosis and treatment planning.
GPU portability and HPC scalability, supporting biomedical simulations in heterogeneous AI-HPC systems • Development of portable code that first, on heterogeneous HPC systems, is capable of generating data at scale using real patient data, training AI on dedicated (GPU) hardware, and generating models that can be deployed for yielding efficient and sufficiently accurate predictions in practice. The effort must take into account the whole code and model production pipeline, including feedback mechanisms to re-simulate and re-train the models on HPC systems.
AI-enhanced and agentic workflows for automated orchestration of simulation pipelines • Development of autonomous, self-organizing, energy- and efficiency-aware workflow orchestration to accelerate and automate components in HPC workflows, such as AI training and inference, pre- and post-processing of data, and interaction with users. In addition, agentic systems can assist in interpreting simulation outputs and integrated biomedical data by leveraging embedded biomedical knowledge. This supports contextualization of results, knowledge extraction, and the generation of new testable hypotheses from simulation and patient data.

Validated digital twins that integrate simulations with patient data

- Joint development towards digital twins of patients, specific pathologies, or treatment methodologies. Since in-vivo data is limited, its integration into such digital twins need careful steering and complementation by simulation data. In this context, validation is key to arrive at reliable models that support medical treatment, hypothesis generation, and research focus selection.

Materials sciences

Materials science research is a central driver of advances in energy production and storage, information technology, quantum devices, and sustainable manufacturing. It enables the rational design of materials with tailored electronic, optical, and mechanical properties that are essential for next-generation technologies. Addressing modern challenges, such as the need for more efficient solar cells and batteries, the development of topological and quantum materials for next-generation computing, the discovery of high-temperature superconductors, requires approaches that go beyond traditional disciplinary boundaries. This fosters integrated theoretical, computational, and experimental strategies in which parameter-free calculations play a central role in achieving a predictive understanding of complex materials systems.

A central challenge in modern materials science is the transition from static, ground-state descriptions to the fully predictive modeling of non-equilibrium states of matter. This is made increasingly demanding by next-generation experimental facilities achieving ever higher temporal and spectral resolutions, which require theoretical models capable of capturing excited-state dynamics with greater accuracy. Time-resolved spectroscopy techniques are at the forefront of this effort, directly probing materials under non-equilibrium conditions and ultrafast timescales. To match this experimental precision, many-body perturbation theory provides the natural theoretical framework, enabling the accurate description of excited states and spectral properties beyond the reach of standard approximations. Complementing this, Quantum Monte Carlo (QMC) methods offer a systematically improvable, parameter-free treatment of ground-state many-body quantum effects, proving especially powerful in the study of phase transitions involving energy materials, such as hydrogen storage or superconductivity, the latter relevant for quantum computing and other technological applications, or the study of correlated systems, such as iron-based clusters responsible for photosynthesis and other catalytic processes.

Quantum transport modeling represents another frontier, linking the microscopic motion of electrons in quantum systems to macroscopic phenomena of direct technological relevance, including photovoltaics, nanoelectronics, and superconducting materials. Advances in this field could open pathways to energy transport without dissipation and highly efficient energy conversion, with a direct impact on the green energy transition.

Combining these experimental and theoretical advances enables the modeling of complex materials phenomena, with direct applications in optoelectronics, photovoltaics, and photocatalysis, as well as in energy storage, superconducting materials, and bio-inspired systems, underpinning technologies ranging from solar cells and advanced batteries to CO_2 conversion, quantum computing, and the broader green energy transition

The development of artificial intelligence and AI agents shows promising avenues in materials science. For example, building an execution environment (using industry standard approaches like the model context protocol, agent skills, etc) suitable for materials research would allow AI agents to be used as “co-scientists” and make it possible to study materials science at a scale and scope beyond the cognitive limitations of today’s researchers. At the same time, AI workflows are driving modern hardware to emphasize the use of low-precision arithmetic units. This is a major challenge in materials science, where extreme numerical fidelity of simulations is required. This makes the development of high-precision emulation strategies an essential and urgent priority. In recent years, a substantial research effort has been invested in the design of mixed-precision algorithms along with high-precision emulation from low-precision engines. In addition to extracting excellent performance from the upcoming modern machines, such schemes allow the user to better control the trade-off between performance and accuracy.

Proposed collaboration activities :

Accuracy emulation in numerical methods for Materials

- Integrate emulation techniques, such as the Japanese Ozaki-scheme, to existing numerical libraries, permitting them to exploit the next exascale systems. This would ensure the sustainability of the simulation codes on upcoming HPC platforms and allow the libraries to gain maturity from real-world applications.

Implementation of time-dependent techniques for experimental spectroscopy to materials science codes

- Extend relevant codes toward coupled electron–ion dynamics in the non-adiabatic regime, enabling the accurate simulation of real-time phenomena, such as coherent phonon generation and the complex interplay between electrons, excitons, and the crystal lattice.
- Implementation of advanced self-consistent schemes and self-energy functionals to relevant codes. This will improve the description of systems where standard mean-field or many-body perturbation theory approximations fall short.

Developing a comprehensive suite of AI tools for driving simulation software

- Define a broad knowledge base enabling AI agents to select the correct simulation protocol (software, method, system model, simulation parameters) for achieving high fidelity results. HPC expertise would contribute to building tools in a way that ensures proper management of computer time budgets, safe deployment, and operational independence from specific commercial model providers.
- Integrate materials science codes with AI agents and large language models, allowing real-time interpretation of simulation results and decision-making during execution. Such an integration would support the development of autonomous workflows capable of steering complex simulation campaigns, optimizing computational resources, and reducing human intervention.

DFT and quantum transport for energy materials

- Develop code interface that will enable quantum transport simulations in large systems with DFT accuracy and a controlled basis set for convergence. This new tool would enhance the investigative capabilities of quantum transport simulations with applications to nanoelectronic and optoelectronic materials, including energy materials for photovoltaics and thermoelectricity.
Closer integration of Quantum Monte Carlo (QMC) methods with machine learning - Train machine learning models on limited QMC datasets to enable the prediction of new configurations at a fraction of the computational cost while preserving QMC-level accuracy. - Apply machine learning techniques to the QMC wave function ansatz through neural network quantum states. The robustness of this optimisation can be improved through stochastic methods and linear algebra schemes, providing a natural opportunity for a cross-disciplinary approach to address one of the most computationally demanding problems in modern quantum simulation.

Other strategic fields of interest

Engineering

Engineering simulations, have become a cornerstone of technological competitiveness in sectors, such as automotive, aerospace, energy, and heavy industry. These sectors are central to addressing global societal challenges, including climate neutrality, energy security, sustainable mobility, and resilient manufacturing systems. However, the complexity of emerging engineering challenges, such as decarbonized propulsion systems, hydrogen combustion, sustainable aviation, and electrified industrial heat, increasingly exceeds the capabilities of any single nation. Through collaborative development, Europe and Japan can jointly lead the global transformation toward sustainable engineering and resilient industrial systems by aligning scientific capabilities, addressing shared societal challenges, strengthening long-term industrial competitiveness, and accelerating the development of next-generation digital engineering tools.

Currently, turbulence modelling and numerical simulations, multi-physics coupling, adjoint optimisation, and production-grade workflows are in place across research institutions, universities, public entities, and industry. What is changing now is the underlying architecture and the way computational workflows are organized. The next decade of engineering simulation is shaped by *(i)* heterogeneous AI-HPC platforms and accelerators, *(ii)* the need for shared verification/validation across jurisdictions and industries, *(iii)* supply-chain and research-security constraints, and *(iv)* the scale of industrial decarbonisation challenges spanning aviation, road transport, and energy-intensive process industries[14] [15].

With the plurality of the software ecosystem, the EU and Japan need shared, portable, verifiable simulation capabilities across multiple code bases. Otherwise, each new architecture or regulation cycle will force costly reinvention, and the cross-border industrial collaboration will lose pace and become less trustworthy. Engineering collaboration can contribute to safer, cleaner aviation, cleaner mobility, and a decarbonised industry through

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[14] https://digital-strategy.ec.europa.eu/en/policies/partnerships

[15] https://digital-strategy.ec.europa.eu/en/news/eu-and-japan-reinforce-tech-and-digital-partnership

three mutually reinforcing streams: 1) GPU portability and performance engineering, 2) agentic AI as the missing layer between simulation capability and societal deployment, and 3) industrial-grade verification, validation, and digital twin demonstrators.

Proposed collaboration activities:
Clean aviation combustion and propulsion chain • Reduce uncertainty in predictive simulation for low-carbon propulsion concepts and combustors (hydrogen and sustainable fuels), aligned with Clean Aviation's quantified objectives and its 2035 entry-into-service ambition. The activity would produce scientific papers, shared benchmark cases, uncertainty quantification protocols, and GPU-portable solver pathways spanning compressible reacting flows and coupled heat transfer.
Road transport thermal-aero multi-physics digital validation • Thermal management for electrified drivetrains, external aerodynamics, and hydrogen/fuel-cell balance-of-plant flows, with agentic AI accelerating design-space exploration while keeping auditability. Aligned with the 2ZERO partnership's direction toward zero-emission road transport, this action focuses on comparability and speed.
Heavy industry processes digital twins • Aligned with Processes4Planet's climate-neutral process industry transformation goal, this action targets high-impact unit operations, e.g., industrial furnaces, heat exchangers, or reactors, where CFD-informed retrofits can reduce energy use and emissions. From a policy perspective, maintaining regional competitiveness while decarbonising industry requires credible transition pathways. Digital twins of heavy industrial processes can support this by providing reliable evidence for technology choices and retrofit strategies.
Shared GPU porting and benchmarking in the engineering commons • This is a cross-cutting collaboration that spans multiple CFD stacks used in research and industry. The governance principle is: port once, validate twice, reuse everywhere. GPU portability is justified by the direction of both EuroHPC (AI-HPC infrastructure) and FugakuNEXT (a GPU-accelerated flagship AI-HPC platform).
Institutional cooperation mechanism or EU-Japan Engineering Community of Practice (CoP) • Rather than a one-off project committee, establish a durable mechanism connecting research institutions, universities, HPC centres, and industry.

Numerical Linear Algebra

The introduction of new exascale systems highlights the existing deficiency in distributed dense Numerical Linear Algebra libraries (NLA) that can effectively harness their enormous computational power. As leading supercomputing centers prepare to integrate these new supercomputers, there is a critical need for software solutions that can manage and optimize computations at this scale. The lack of a clear candidate for such NLA library amounts to an entry-point barrier to fully utilizing exascale capabilities for scientific research and industrial applications, where distributed numerical linear algebra is essential for solving complex problems.

The conjunction of the absence of a suitable distributed NLA library, and the installation of supercomputing architectures capable of executing an exaflop, presents a unique opportunity for the EU-Japan ecosystem. Moreover, this is an historically favorable moment when the US-based traditional leadership is lacking momentum and resources. This situation provides a perfect moment to coordinate the development of advanced numerical algebra software that can bridge the gap between hardware and application efficiency and ensure that EU and Japan remain at the forefront of supercomputing capabilities, not only in terms of hardware but also in enabling groundbreaking research and innovation through effective software solutions. The strategic development of a novel distributed NLA library will empower our supercomputing centers to fully exploit their new hardware, fostering advancements across various scientific and engineering disciplines that rely on high-performance computing.

A comprehensive strategy involving key scientists and developers in numerical algebra as well as in the application codes that would benefit from such new library is required to address the need for advance NLA software that can fully exploit the capabilities of future exascale supercomputers in EU and Japan while ensuring robust fault tolerance and checkpointing. This could be realised building on existing work towards an ExaNLA library, in collaboration with application communities.

Emergency / urgent computing

Emergency and urgent computing represents a natural and high-impact domain for deepened EU–Japan collaboration, as both regions face increasingly frequent and complex crises that require rapid, compute-intensive responses. Japan’s long-standing expertise in real-time earthquake, tsunami, and typhoon monitoring complements Europe’s growing need for high-resolution flood, storm, infrastructure-failure, and epidemic simulations. HPC is essential to move from long-term risk assessment toward near-real-time, actionable decision support, where simulation outputs directly inform public authorities and critical infrastructure operators. Joint EU–Japan efforts can advance shared methodologies for immediate access to supercomputing resources, hybrid HPC–AI workflows, secure priority scheduling, and trusted communication of results to non-expert stakeholders, strengthening societal resilience while avoiding duplication of national solutions.

Astronomy

Astronomy is intrinsically global and data-intensive, making it well suited for structured EU–Japan cooperation in HPC. Both regions operate or contribute to world-leading observatories and space missions that generate massive, continuous data streams requiring advanced simulation, data reduction, and AI-assisted analysis. HPC is central not only to processing observational data, but also to running large-scale cosmological, astrophysical, and plasma simulations that connect theory with observation. Collaboration enables shared development of scalable, performance-portable software pipelines, cross-validation of simulation results on heterogeneous architectures, and coordinated use of flagship systems. By aligning Europe’s strong ecosystem in software frameworks and distributed workflows with Japan’s experience in tightly integrated, high-performance systems, EU–Japan collaboration can accelerate scientific discovery while setting common standards for reproducibility and long-term data stewardship.

Digital humanities & socio-technical fields

Digital humanities and broader socio-technical disciplines offer a distinctive yet increasingly critical collaboration axis, as HPC results are no longer confined to expert communities but directly shape public understanding, trust, and policy choices. Collaboration between Europe and Japan in this area could build on emerging work that applies high-performance simulation, visualization, and digital twin concepts to domains such as literature, cultural heritage, political science, sociology, and human–machine interaction. These fields contribute essential expertise in how reality is constructed, simplified, and communicated, which is vital for interpreting complex HPC outputs such as climate forecasts, disaster warnings, or autonomous-system simulations. Joint EU–Japan activities can integrate HPC with humanities and social sciences to improve explainability, scenario design, and human-centered validation of models, ensuring that advanced computing supports informed decision-making, public trust, and responsible technological deployment.

Summary of potential future collaboration activities

Field	Area	Challenge addressed	How to address (EU–Japan joint approach)
Digital infrastructures	High-performance computing	Exploitation of next-generation infrastructures, energy efficiency and sustainability of HPC itself	GPU porting for strategic applications and efforts to develop hardware-agnostic frameworks to exploit future infrastructures and support sovereignty of research. Low-precision arithmetic inclusion within the scientific applications in Europe and Japan and supporting shared performance-portability infrastructure. Joint development of open-source software components and interoperable programming environments to facilitate long-term sustainability and cross-platform collaboration.
	Artificial intelligence	Securing leadership position in AI technologies and its implementation in scientific research	Joint development in AI for Science and Science for AI, such as AI-enhanced simulation workflows, agentic AI, and advancing the scientific foundation required to build trustworthy and efficient AI, to accelerate scientific discovery and development of AI systems. Fostering co-design between AI researchers, computational scientists, and hardware specialists to optimize AI and scientific applications on emerging HPC infrastructures. Promoting ethical, transparent AI technologies aligned with European and Japanese values.

	Data sharing	Access to high-quality data for scientific and AI development	Enabling secure data sharing between Europe and Japan through common standards and interoperable infrastructures and developing shared platforms and curated datasets supporting AI for Science and simulation workflows. Promoting FAIR and open science practices to strengthen collaborative research and advancing privacy-preserving methods and data sharing for international research cooperation. Building expertise in data science, AI-driven analytics, and scientific data management through joint EU-Japan training mobility programs.
	Interoperability and standardisation	Cross-platform collaboration and sustainability	Joint development of open-source software components with a priority on hardware-agnostic frameworks, exchange of best practices on interoperability, and strengthening EU and Japanese representation within key international foundations on software and standardisation.
Climate sciences	Climate simulation workflows	Transparency and reproducibility of climate information	Strengthening the interoperability between climate software, workflows and HPC infrastructures through co-development of shared experiment workflows and reproducibility frameworks for global climate models. Collaborative studies performing comparisons between European and Japanese climate models to prepare and improve the flexibility of applications for future HPC infrastructures.
	AI in climate sciences	Efficient provision of climate information	Exploring emerging approaches combining HPC and artificial intelligence through the development of AI-based surrogate models that complement traditional numerical simulations to accelerate the provision of accurate, actionable climate information.
Biomedical science	Patient-specific modelling	Patient-specific diagnosis and treatment planning	Joint development of simulation workflows that couple organ-level CFD models with molecular and cellular-scale simulations, enabling multi-scale representations of disease processes.
	GPU portability and HPC scalability	Exploitation of next-generation infrastructures	Development of portable code capable of generating data at scale using real patient data, training AI on dedicated hardware, and generating models that yield efficient and sufficienty accurate predictions.
	AI in biomedical sciences	Increased efficiency of biomedical simulation and diagnosis pipelines	Development of AI-enhanced and agentic workflows for automated orchestration of simulation pipelines, accelerating and automating components such as AI training, pre- and post-processing of data, contextualisation of results, and interaction with users in HPC-based workflows.

	Digital twins	Patient-specific diagnosis and treatment planning	Joint development of digital twins of patients, specific pathologies, or treatment methodologies, which integrate in-vivo data with complementary simulation data and validation methods.
Materials science	Mixed-precision algorithms	Exploitation of next-generation infrastructures and sustainability of materials science applications	Integration of emulation techniques, such as the Japanese Ozaki-scheme, to existing numerical libraries in materials science to retain the numerical fidelity of materials simulations, permiting the applications to exploit the next exascale systems.
	Time-Resolved Spectroscopy	Characterization of excited-state dynamics and non-equilibrium phenomena in complex materials	Developement and applications of first principle time-dependenttechniques for experimental spectroscopy to materials science codes to enabling the accurate description of excited-state, non equlibrium properties and spectral characteristics of complex materials systems.
	AI in materials science	Implementation of AI methods in materials research	Developing a comprehensive suite of AI tools for driving simulation software, including integration of materials science codes with AI agents and LLMs for orchestrating autonomous workflows in materials science research. Closer integration of machine learning with Quantum Monte Carlo methods to reduce computational cost of high-accuracy models.
	Energy materials	Investigation of new materials	Interfacing Quantum Transport codes with accurate Density Functional Theory simulations in order to enhance the investigation of innovative nanoelectronic and optoelectronic materials.
Engineering	Aerospace / Aviation	Climate-neutral aviation and clean aviation demonstrators	Joint HPC/CFD campaigns for high-fidelity aerodynamics-propulsion-combustion integration aligned with Clean Aviation Joint Undertaking objectives (disruptive aircraft innovations, >30% net greenhouse gas (GHG) reduction; entry-into-service ambition around 2035).
	Automotive / Road Transport	Zero-emission road transport (battery, fuel cell, thermal management, aerodynamics)	Joint multi-physics vehicle simulation and digital validation aligned to the 2ZERO partnership's aim to support the transition to zero-emission road transport and renewable energy carriers.
	Heavy Industry / Process Industry	Decarbonisation of energy-intensive and process industries (e.g., cement	Digital twins and validated CFD for process intensification, heat transfer, and reactive flows aligned to Processes4Planet goals of transforming process industries toward climate neutrality by 2050.

		industry, steel, and glass manufacturers)	
	Energy Systems / Hydrogen Economy / Clean Fuels	Hydrogen and alternative fuels in industry and mobility	Combustion and reacting-flow modelling, safety-relevant simulation campaigns, and shared benchmarks aligned with the Clean Hydrogen Partnership mission to accelerate the deployment of clean hydrogen technologies.
Education / Workforce development	International Cooperation	Skills, inclusion, and long-term institutional ties	Joint long-term PhD and training programmes, also enabling access to high-end supercomputers to young researchers through the programme. Expanded opportunities for short- and long-term researcher and engineer exchange with a priority on young researchers.