COCN 10 Emerging Technologies 2025

Contents

Introduction

Emerging technologies —areas where global competition in both research and commercialization is fierce—are seeing the gap between science and market close at unprecedented speed. Unless we identify these technologies ahead of other countries and respond with strategic foresight, the decline in Japan's relative position in the world, as multiple indicators already show[1,2], will likely continue. Alarmed by this prospect, COCN established the "Emerging Technologies Subcommittee" and has been discussing emerging technologies that should be addressed immediately from the perspective of recovering Japan's industrial competitiveness and finding strategic stories over the past 6 months. COCN leverages its diverse member companies, whose agility enables concrete, rapid debate, and has undertaken various project activities to date. In keeping with COCN's principle of making bold, forward-looking proposals without fear of criticism, we have selected 10 priority emerging technologies Japan should pursue, with the following expectations:

- By deliberately naming specific technologies, we aim to challenge the tendency to speak only in generalities about technology. Each member of the COCN Executive Committee selects items based on their own experience and intuition, so we acknowledge the possibility of bias or omissions. However, this does not imply that we consider unlisted technologies to be unimportant.
- When selecting R&D themes, fear of failure has steered choices toward low-risk targets with guaranteed results, easily assessable by evaluators and often verified by foreign precedents. Through these 10 selections, we hope to spur challenges aimed at high-risk, high-return breakthroughs.
- We anticipate that themes chosen from an industry-driven perspective will generate momentum distinct from similar announcements by academia or government.

To enable Japan to once again lead the world as a science-and-technology nation and revive its industrial competitiveness, we hope these 10 selections will act as a catalyst for collaborative identification and cultivation of emerging technologies across industry, academia, and government.

The cover page and each emerging-technology section feature images that represent either the technology itself or the society and phenomena it enables. All images in this report were generated with Microsoft Copilot Visual Creator.

[1] National Institute of Science and Technology Policy, Ministry of Education, Culture, Sports, Science and Technology, Science and Technology Indicators August 2024
[2] IMD World Competitiveness Booklet June 2024

SELECTION CRITERIA

In selecting the COCN 10 Emerging Technologies for 2025, we focused on the following criteria:

1. **Strategic indispensability for Japan's economic security**

   We have selected technologies that are likely to make Japan indispensable to global supply chains by ensuring the stable provision of critical goods, protecting essential infrastructure, securing technological superiority, and reinforcing economic autonomy[3].

2. **Areas where Japan can achieve global leadership**

   We have prioritized fields in which Japan's technological capability and R&D depth, built on its accumulated expertise, foundational strengths, and favorable geopolitical position, give it a plausible path to outcompete other nations.

3. **Technologies not yet widely industrialized**

   Technologies that are already broadly commercialized—however important to economic security—were ranked lower, as they fall outside the scope of this emerging-technologies initiative.

4. **Demonstrated technical feasibility**

   Early-stage concepts without proof-of-principle were excluded; each selected technology must have credible experimental validation.

[3] Ministry of Economy, Trade and Industry, Expert Meeting on Strengthening Industrial and Technological Foundations for Economic Security, February 2025

1 Living Material and Bio-Device

⇒Cell Robots, Cell Machines

■ Overview

Living materials and bio-devices are artificially designed and created synthetic life forms that autonomously proliferate and produce biomolecules, through synthetic biology technology. These engineered entities are expected to act as cellular robots or machines, and the same technological platform can be leveraged to build entirely new classes of such systems.

■ Reasons of Interest

Living materials and bio-devices are expected to have applications across medicine, biofuels and environmental protection. Researchers can now design cells from scratch to perform specific tasks—for example, to break down refractory compounds, to serve as biosensors, to eliminate tumor cells, to synthesize target products such as hydrogen, electricity, alcohol or pharmaceuticals, or to degrade persistent pollutants such as per- and polyfluoroalkyl substances (PFAS).

Synthetic biology, the enabling technology behind living materials and bio-devices, is gaining momentum worldwide. Initiatives such as Build-A-Cell (USA), SynCell EU, SynCell Asia and SynCell Africa have emerged, and the first SynCell Global Summit was held in China[4].

At present, fully de-novo-designed cells survive only a limited number of divisions. Although there are still few reports of synthetic cells with robust specialized functions, the breadth of potential applications is vast, and the impact once practical viability is achieved will be significant. Consequently, major breakthroughs are anticipated within the next two to three years.

■ Impact on Industrial Competitiveness

Living materials and bio-devices could revolutionize healthcare. Their ability to selectively target pathological cells (e.g. cancer cells or virus-infected cells) may enable curative therapies for diseases once considered intractable, thereby improving patient quality of life. In addition, bio-devices used for continuous biological monitoring could help prevent disease onset.

Engineering cells that degrade refractory compounds—such as flame-retardant plastics—may help resolve persistent environmental challenges, while cells engineered to generate hydrogen, or electricity could address energy security concerns.

[4] The International Alliance of Synthetic Cells was established_Synthetic Biology November 2024

2 Genome Editing Technology for Therapy

⇒CAR-T, DDS-in vivo gene therapy, ex vivo gene therapy

■ Overview

Genome-editing technologies can be applied across multiple fields, including medicine, agriculture, and environmental protection. Particularly in medicine, genome-editing, which precisely modifies defined DNA sequences, can be deployed in gene therapy and CAR-T-cell (chimeric antigen receptor T-cell) therapy and is expected to be effective for treating numerous intractable and rare diseases.

■ Reasons of Interest

Gene therapy using genome-editing technologies is expected to deliver curative treatments for cancer, infectious diseases, and other intractable conditions. Many pre-clinical and clinical results are being reported, and empirical research is progressing for disorders such as HIV infection, muscular dystrophy, and hemophilia. Furthermore, applying genome-editing to CAR-T-cell therapy for hematological malignancies is expected to improve editing efficiency, shorten manufacturing timelines, lower costs, and potentially broaden indications to blood tumors.

In these approaches, the edited genetic material must be delivered efficiently into target cells to maximize therapeutic precision. Moreover, combining genome-editing with Drug Delivery System (DDS) technologies that mitigate off-target editing events are expected to achieve significant effects for a wider range of diseases. Research on DDS is also active in Japan, and we anticipate an expansion of applicable cases within 2–3 years.

■ Impact on Industrial Competitiveness

The number of patients with rare diseases is estimated at approximately 263–446 million worldwide[5], and Japan alone has over 1 million patients designated with intractable diseases[6]. In cancer alone, patient numbers are estimated at about 19 million worldwide and 1 million in Japan[7, 8]. With patient populations rising, the global pharmaceutical market is expected to expand substantially. It is projected that around 20 % of this market will be captured by emerging therapeutic modalities (in vivo/ex vivo gene therapy, mRNA vaccines, and cell therapies) [9], many of which stand to benefit markedly from genome-editing technologies.

Nevertheless, ethical considerations surrounding genome-editing-based therapies remain paramount and must be addressed carefully.

5 Estimating cumulative point prevalence of rare diseases: analysis of the Orphanet database September 2019
6 JPMA Number of Holders of Certificates for Specified Medical Care (Designated Intractable Diseases) March 2024
7 National Cancer Center Japan Announcement of Latest Global Cancer Incidence December 2023
8 Cancer Research Promotion Fund, Cancer Statistics 2024 April 2024
9 CRDS Research Report Trends and Prospects of Drug Modalities February 2025

3 Local Natural Energy

⇒Natural Hydrogen, Geothermal Power Generation

■ Overview

Natural energy refers to energy sources derived directly from nature. CO_2-free energy sources in this category include natural hydrogen (serpentinization) and geothermal power generation. The concept of locally harvested natural energy, which taps these resources at their point of origin, is expected to gain growing importance.

■ Reasons of Interest

Japan offers favorable geological and hydrological conditions for exploiting natural energy. Serpentinization[10], one of the processes that generates natural hydrogen, occurs through the reaction of olivine and water. Areas such as Mt. Apoi in Hokkaido and the Shimane Peninsula are among the few places where olivine outcrops at the surface, while Japan's island geography ensures abundant water.

Although Japan ranks third globally in geothermal potential, it is only tenth in installed capacity—just 2 % of its theoretical potential (versus 12 % in the United States) [11, 12].

Geothermal power is CO_2-free and delivers baseload electricity around the clock.

Demand for on-site energy production and consumption is rising; for example, many U.S. hyperscale data centers are now co-located with nuclear plants. Local energy production and consumption not only cuts CO_2 and transmission losses but also spurs regional revitalization and enhances disaster resilience.

■ Impact on Industrial Competitiveness

Japan's energy self-sufficiency rate is only 15.2 % (FY 2023) [13], far below that of other major economies. Promoting locally sourced natural energy is crucial for improving this figure.

Moreover, reversing the over-concentration of population and industry in megacities remains a pressing national challenge[14]. Deeper product decarbonization will increase demand for low-carbon inputs, positioning local natural energy to catalyze new industries across Japan's regions.

[10] Mineralogical Consideraion on the Landslides in Serpentinite Belt 1998
[11] ThinkGeoEnergy's Top 10 Geothermal Countries 2024 January 2025
[12] Geothermal power generation in the world 2010–2014 update reportt March 2016
[13] FY2023 Energy Demand and Supply Results November 2024
[14] Cabinet Secretariat Overview of "Basic Concept" of Regional Revitalization 2.0 December 2024

4 Metal Organic Framework/ Porous Coordination Polymers

⇒Advanced Water Treatment, PFAS Separation, CO2 Separation

■ Overview

Metal–organic frameworks (MOFs) and their closely related porous coordination polymers (PCPs) are crystalline, highly porous materials assembled from metal ions or clusters bridged by organic linkers. Their angstrom- to nanometer-scale pores enable exceptional capacity for gas storage and separation, catalysis, and other advanced functions. The following discussion therefore focuses on MOFs.

■ Reasons of Interest

Nearly three decades have passed since MOFs were first reported, yet commercial roll-out remains limited and large-scale businesses have not emerged. Meanwhile, interest is surging in their use for CO_2 capture, solar-driven seawater desalination, gas purification, and other climate-critical applications.

For example, the copper-based MOF HKUST-1 adsorbs ≈ 4.2 mmol CO_2 g^{-1} (≈ 5.4 kg of sorbent per ton of CO_2). Another system, PSP-MIL-53, produces ≈ 140 L fresh water kg^{-1} day^{-1} under sunlight and can be fully regenerated in < 4 min, enabling repeated use.

These laboratory results underscore the disruptive potential of MOFs; rapid scale-up and industrial adoption are therefore eagerly anticipated.

■ Impact on Industrial Competitiveness

Japan aims to cut greenhouse-gas emissions 46 % by FY 2030 relative to FY 2013, with an aspirational 50 % target[15]. FY 2022 emissions were 1.09 Gt CO_2-eq—22.9 % below FY 2013[16]. Deploying high-performance MOF sorbents, coupled with Japan's strong CO_2-separation technologies, could materially accelerate progress toward carbon neutrality.

The global seawater-desalination equipment market is forecast to reach ≈ USD 73.6 billion by 2030, growing at ~10 % CAGR (2024-30) [17]. If solar-regenerated MOF desalination achieves large-scale deployment, it could disrupt conventional plant technology and open new export avenues for Japanese industry.

[15] Plan for Global Warming Countermeasures (Cabinet Decision) February 2025
[16] Ministry of the Environment, On Japan's Greenhouse Gas Emissions and Absorption in FY2022 April 2024
[17] Grand View Research Global Seawater Desalination Plant Equipment Market (2024-2030) September 2024

5 Vibronics

⇒Electron-phonon interaction, Nonequilibrium heat transport at semiconductor-insulator interfaces, Surface acoustic wave-spin wave interaction

- Overview

Vibronics is a new academic field that comprehensively addresses the propagation of vibrations and energy transport.

Its objective is to seamlessly connect microscopic heat transport with macroscopic thermal management.

It covers topics such as electron–phonon interactions, nonequilibrium heat transport at semiconductor–insulator interfaces, and surface acoustic-wave–spin-wave coupling.

- Reasons of Interest

Vibronics, a new academic field for understanding atomic and molecular dynamics in the energy-transport domain, has advanced the elucidation of microscopic heat-transport mechanisms through the framework of phononic engineering, thereby laying the groundwork for precise thermal control across diverse applications.

Leveraging atomic- and molecular-level phenomena makes it possible to surpass performance thresholds once thought fundamental. For example, controlling bubble dynamics in liquids could dramatically improve the efficiency of hydrogen production via electrolysis. Additional opportunities include high-efficiency boilers, cooling ponds for power plants, and medical devices that prevent thrombosis. These advances could underpin low-power technologies that complement renewable-energy-based stable power supplies.

Vibronics remains an emerging discipline[18]; most findings are still confined to conference proceedings, but we expect major technical breakthroughs within the next two to three years.

- Impact on Industrial Competitiveness

If vibronics achieves near-zero interfacial thermal resistance, enabling heat-exchanger areas to be halved, a wide range of applications become conceivable, including higher air-conditioning efficiency, improved automotive and marine engines, and better power-plant performance. Moreover, mastering boiling-bubble dynamics could raise hydrogen recovery yields from electrolysis.

Widespread deployment of vibronics could thus deliver profound benefits—particularly across the energy sector.

[18] 85th Autumn Meeting of The Japan Society of Applied Physics, Vibronics Energy transport science of vibration in solid September 2024

6 Spin Science

⇒Multiferroic materials, High-efficiency memory devices

- Overview

  Spin science is an academic field that studies the properties and behavior of materials through the quantum-mechanical property of the electron's spin. Electron spin is the intrinsic angular momentum of an electron which gives rise to a magnetic moment. This property underpins the development of advanced technologies, including multiferroic materials.

- Reasons of Interest

  Spin science enables information processing and transmission by manipulating electron spin. Compared with conventional charge-based electronics, it promises low-power, high-speed devices. For example, magnetic tunnel junctions (MTJs) comprise alternating ferromagnetic and insulating layers and exploit spin-dependent tunnelling. They underpin magnetic random-access memory (MRAM), a fast, non-volatile memory technology. Multiferroic materials exhibit more than one primary "ferroic" order (e.g., ferromagnetism and ferroelectricity), enabling electric-field control of magnetism and vice versa. They therefore hold promise for next-generation electronic devices, memory elements, and ultra-sensitive sensors. Japanese research groups—frequently cited in recent review papers—are well positioned to lead practical demonstrations.

- Impact on Industrial Competitiveness

  The market for high-efficiency memory devices was valued at USD 125 billion in 2021 and is expected to reach USD 360 billion by 2029, implying a compound annual growth rate (CAGR) of about 14.9 %[19]. Spin-science-enabled ultra-efficient memory devices could secure a substantial share of this expanding market. Likewise, spin-based ultra-sensitive sensors have cross-sector applications in metrology, medicine, energy, and environmental monitoring, with the greatest competitive advantage anticipated in scientific instrumentation.

[19] FORTUNE BUSINESS INSIGHTS Memory Device Market Size, Share, Growth | Forecast 2025 February 2025

7 Topological Material

⇒Anomalous Nernst effect, Photonic crystal laser

- Overview

Topological materials are substances with unconventional electronic structures and were cited in the award of the 2016 Nobel Prize in Physics. These materials are studied as a new category that does not fit into the traditional classifications of insulators, conductors (metals), or semiconductors.

- Reasons of Interest

Due to their unique electronic structure, topological materials exhibit a range of remarkable phenomena, foremost among them the anomalous Nernst effect. The physical properties of topological materials have no analogue in conventional solids and are expected to unlock new devices and electronic components. The anomalous Nernst effect is the generation of a transverse voltage when a heat current passes through a magnetized topological material. Utilizing this effect could enable the mass production of thermoelectric materials that are fast-responding, highly sensitive, low-cost, and offer broad design flexibility. Potential applications include heat-flux sensors—such as biological sensors that detect thermal comfort—anomaly detection in batteries and semiconductors, fault prediction and monitoring in manufacturing equipment, detection of heat leakage and insulation defects, and thermoelectric power-generation devices.

Another promising application, beyond devices based on the anomalous Nernst effect, is the photonic crystal surface-emitting laser (PCSEL). PCSELs generate laser light through two-dimensional resonance within topological materials. They offer high output power, high beam quality, and a narrow divergence angle, and their practical application is expected in areas such as high-power light sources for materials processing and LiDAR.

- Impact on Industrial Competitiveness

The market for anomaly detection is predicted to expand considerably by 2030, rising from USD 5.3 billion in 2022 to USD 15 billion, a CAGR of 16.1 % over 2023–2030[20]. Furthermore, the global market for laser processing—where PCSELs are expected to be key—was valued at USD 22.4 billion in 2022 and is projected to grow to USD 48.2 billion by 2030 (from USD 24.1 billion in 2023) [21]. Topological materials, as an enabling technology for these markets, are expected to have a significant impact on industrial competitiveness.

[20] Panorama Data Insights Anomaly Detection Market Outlook November 2024
[21] FORTUNE BUSINESS INSIGHTS Laser Processing Equipment Market Size/Share February 2025

8 Physical AI

⇒AI × Robotics, Service Robots, Autonomous Driving

■ Overview

Physical AI refers to AI that understands the physical laws of the real world and operates by directly interacting with its environment and physical objects. To realize Physical AI, Sim2Real (Simulation to Reality), which transfers knowledge and skills learned in a simulation environment into the real world, is crucial. By repeatedly testing movements that are impractical in the physical world using a simulator faithfully representing physical laws, and then having generative AI learn from the results and automatically generate control code for deployment on real hardware, significant improvements in performance and reduced development time in manufacturing, for example, become possible.

■ Reasons of Interest

While Japan lagged in the field of generative AI, which succeeded in learning from web data, in the next stage—extending AI to physical phenomena with multimodal models and connecting it to the real world as Physical AI—there is a potential competitive strategy for Japan, which is strong in hardware and manufacturing. For example, by federating and training on the vast amount of physical data held by Japanese companies, universities, and other organizations, it becomes possible to develop service robots capable of ultra-precise manipulation that competitors would struggle to replicate. Furthermore, high-fidelity simulators, underpinned by Japan's deep understanding of physical phenomena honed through decades of manufacturing, can generate high-performance Physical AI by running hundreds of millions of trials. The resulting AI can automatically generate optimal control code, and implementing this in automobiles, construction machinery, or drones can enable safe and efficient autonomous driving with just a handful of real-world tests conducted over a very short period. These characteristics present a great opportunity for Japan, which has continuously refined its manufacturing capabilities.

■ Impact on Industrial Competitiveness

The global robot market is growing rapidly. It is projected to grow to USD 56 billion for industrial robots by 2032[22] and USD 108 billion for service robots over the same period. [23]Additionally, the global drone market is predicted to reach USD 74 billion by 2030[24].

Combined with cross-industry data platforms being discussed in Japan, such as the Ouranos Ecosystem, if Japan can leverage the data held by its companies and universities to scale up and demonstrate superiority in Physical AI, the impact on entire industries within these massive markets will be immeasurable.

[22] FORTUNE BUSINESS INSIGHTS Industrial Robot Market Size, Share, Growth 2025 February 2025

[23] Grand View Research Global Service Robot Market (2024-2030) September 2024

[24] Mordor Intelligence Drone Market Size and Share Analysis - Industry Research Report 2025

9 Quantum Network and Quantum Sensing

⇒Quantum Clustering, Quantum Interference, Diamond Quantum Sensors

- Overview

A quantum network distributes entangled states across distant sites and operates fundamentally differently from today's classical internet. Quantum sensing, by contrast, exploits quantum-mechanical effects to measure physical quantities with extreme sensitivity. When multiple quantum computers and sensors are interconnected through such a network, each device's performance can be boosted dramatically. Moreover, quantum networks also pave the way for practical quantum teleportation.

- Reasons of Interest

Japan is competitively positioned not only in quantum-computer development but also in optical communications. Because quantum networks carry entanglement via photons, they sit at the intersection of these two strengths. Likewise, quantum sensing—which leverages interference arising from the wave nature of particles—is an area where Japan already excels, thanks to decades of advanced photonic and electron-based instrumentation. Consequently, Japan's research standing in quantum networking and sensing is high, and major breakthroughs are expected within the next 5 years.

- Impact on Industrial Competitiveness

While nations worldwide are already investing heavily in quantum computing, early commitment to quantum networks and quantum sensing—areas still underfunded—could accelerate the emergence of a fully quantum society. Adding the value unlocked by these technologies to the USD 850 billion market projected for quantum computers by 2040[25] would further enlarge the industrial impact, and Japan is well placed to take a leading role.

[25] Boston Consulting Group The Long-Term Forecast for Quantum Computing Still Looks Bright July 2024

10 Brain Technology

⇒Brain-Machine Interface, Neurofeedback, Neuromarketing

■ Overview

Brain technology integrates neuroscience and engineering to decipher the brain's structure and function and to translate that knowledge into practical applications. It already finds use in medicine, education, marketing, and beyond.

■ Reasons of Interest

Advances in brain technology are enabling direct collaboration between human brains and machines, promising breakthroughs across medicine, communication, education, and entertainment. For instance, wireless brain–machine interfaces (BMI) have experimentally shown that quadriplegic patients can control robot arms or computer cursors purely through thought[26].

■ Impact on Industrial Competitiveness

The global brain-technology market is valued at USD 2.44 billion in 2024 and is projected to reach USD 6.52 billion by 2030, a CAGR of 18.1 %[27]. The Japanese market alone is expected to exceed USD 400 million by 2030. In the non-invasive segment—where Japan enjoys a comparative advantage—the market should grow to USD 2.37 billion by 2030 at a CAGR of 9.3 %[28]. Capturing a share of this fast-growing sector would significantly strengthen Japan's industrial competitiveness. However, rapid deployment must be balanced with robust safeguards for privacy and ethics.

[26] Neuralink November 2024
[27] GRAND VIEW RESEARCH Brain Computer Interface Market Size & Outlook, 2030 February 2025
[28] GII. Brainwave Measurement Equipment Market | Market Size Analysis Forecast 2025-2030 October 2024

Acknowledgments

We extend our sincere gratitude to the Center for Research and Development Strategy (CRDS) of the Japan Science and Technology Agency (JST) and the Technology and Innovation Strategy Center (TSC) of the New Energy and Industrial Technology Development Organization (NEDO) for their invaluable advice and cooperation during these selection processes.