Materials Innovation Strategy

April 27, 2021

Approved by the Council for Integrated Innovation Strategy

Table of Contents

Chapter 1: Preface

The word VUCA (Volatility, Uncertainty, Complexity, Ambiguity) was coined to describe the current state of our world. Today, perhaps more than ever before, Japan and the entire world are in a dramatic state of flux.

Thanks to the development of the global economy and the rapid progress made in digitalization, recent abnormal weather, the international competition for innovation hegemony, and many other phenomena propagate almost immediately throughout the world. On top of all of this, the global Covid-19 pandemic has raised questions about how we live our day-to-day lives, and indeed, how we organize society itself.

Confronted as we are by these dramatic changes and the increased opacity and uncertainty they present, it behooves states to formulate and develop dynamic, effective strategies for the areas that will determine their future viability and prosperity.

Materials are an area where Japan has industrial competitiveness supported by both attractive products and strong technology development. The country is home to a large number of domestic companies that produce everything from general-purpose to specialty function products, and in functional materials in particular, Japan enjoys a high share of the global market.

In academic and basic research, Japan has a history of developing innovative materials like blue light-emitting diodes and lithium ion batteries, both of which earned Nobel prizes for their developers, and through these innovations we have had social and economic impacts on the entire world.

Nonetheless, in recent years, Japan has lost production share for some materials and is facing increased threats due to active research and development in emerging economies etc., the commoditization of products themselves, and increasingly intense price competition.

In light of these circumstances, the Ministry of Education, Culture, Sports, Science and Technology and Ministry of Economy, Trade and Industry established the "Preparatory Meeting for the Formulation of a Strategy to Enhance Materials Innovation Capacity[1], and in June 2020 produced a document entitled "Formulation of a Government Strategy for the Enhancement of Materials Innovation Capacity.[2]

That document identified the following four initiatives for focus:

1) Creation and enhancement of a data-centric platform for materials research and development
2) Strategic promotion of key materials technologies and implementation areas
3) Creation of a materials innovation ecosystem
4) Training and recruitment of talent to support materials innovation capacity

---

[1]Jointly established in April 2020 by the Ministry of Education, Culture, Sports, Science and Technology and Ministry of Economy, Trade and Industry to identify and organize the priority issues in the formulation of a government strategy to enhance materials innovation capacity and investigate concrete policies and initiatives (Chair: Hideo Ono, President, Tohoku University)

[2]Published in June 2020 as a summary of basic concepts and directions for future initiatives in the formulation of an all-of-government strategy to enhance materials innovation capacity, incorporating the perspectives of the Integrated Innovation Strategy 2020 and 6th Science and Technology Basic Plan

The document outlines basic concepts for the formulation of a whole-of-government strategy and recommends directions for future initiatives.

This Materials Innovation Strategy was formulated on the basis of the recommendations of the preparatory meeting and a decision in Integrated Innovation Strategy 2020 Cabinet resolution of July 2020 to formulate a government strategy for the enhancement of materials innovation capacity.[3]

This strategy defines "materials innovation capacity" as "the ability to create materials innovation" and positions itself as a strategy to enhance that capacity.

More specifically, it aims to achieve the visions for society and industry in 2030 with a comprehensive policy package that includes social implementation, research and development, industrial/government/academic coordination, and human resources development to strengthen materials innovation capacity in light of the crucial role that materials will play in the achievement of Society 5.0, fulfillment of SDGs[4], overcoming of resource and environmental constraints, and building of a robust social and industrial structure.

The following four perspectives were of particular importance in the formulation of the strategy.

For technology development and enhancement:

1) Materials informatics
2) Manufacturing process technology

As external factors:

3) Circular economy (resource recycling)
4) Resources (metal resources etc.)

The key questions within this context where how to identify themes upon which Japan should focus and how to build and enhance Japan's strengths.

Second, the meeting highlighted the need for different approaches to basic (entry) and applied (goal) research.

In basic research, Japan must ceaselessly strive to be a "gold medalist," the best in the world. Efforts to create new value by better understanding the essential nature of things (fundamental research) translate directly into innovation.

---

[3]A government strategy to enhance "materials innovation capacity" (the potential to create materials innovation) under a common vision of interested parties in industry, academia and government as a priority strategy following up on strategies for AI, bio, quantum technology and environment"

[4]Sustainable Development Goals. International goals for a better, more sustainable world by 2030 incorporated in the "Sustainable Development Agenda 2030" adopted by the United Nations summit in September 2015

Conversely, in applied research, it is acceptable to win silver and bronze medals; the important point is early social implementation. Swift social implementation of the technologies and products developed has not necessarily been Japan's strong suit. Materials development usually takes years and in some cases decades, but once basic research has produced results, even if they are not final, it is necessary to have a new goal-oriented strategy, which includes coordination among industry, government and academia to produce a stream of social implementations.

Third, the meeting emphasized the importance of training people oriented towards the goal-oriented strategy, not just people who are skilled in basic research. It is essential in this not to focus purely on "developing people," but to incorporate the idea that "people develop on their own" and provide opportunities for people to do so.

Vision, when accompanied by action, can change the world.[5]

This strategy is the first strategy to take a comprehensive view of the materials area, where Japan is known for its strengths, since the "Field-Specific Promotion Strategy (Nanotechnology and Materials)" formulated by the Council for Science and Technology Policy in 2006, and it represents a first step in a new direction that will bring the country to 2030 and 2050.

Our goal is for interested parties in industry, academia and government to work together swiftly and in coordination so that Japan is able to provide strong leadership to the world in addressing social issues, strengthening industrial competitiveness, and creating innovation.

"Vision without action is merely a dream. Action without vision just passes the time. Vision with action can change the world," Joel Arthur Barker (USA)

Chapter 2: The environment for materials

1. Industry

Japan's materials industry has large numbers of products with high shares, particularly in the functional materials area, but their use is currently skewed towards electronic parts and devices, mostly for the automotive and electronic parts sectors.[6] It is important that Japan add more advanced functionality to materials and develop new uses and markets, particularly in the environment and energy areas where expansion is expected.

Meanwhile, in emerging economies, technology levels are rapidly rising, and inexpensive labor and utility costs create fierce technological and price competitiveness and the real potential for a decline in Japan's relative competitiveness as a result.

There are, in addition, changes taking place in the global industrial structure as digitalization makes progress and public interest in sustainable societies grow. While these trends result in high expectations for Japanese materials, they also produce competition for leadership in global markets.

On the one hand are more intense global development competition, shorter times for the spread of new technologies and shorter product lifecycles; and on the other, more demanding requirements for final products and parts. Together, they are resulting in more diverse and more complex markets. These trends require the development of materials based on new concepts, faster development times, more flexible manufacturing facilities, and the elimination of redundancy.

On the resource side, rare metals and rare earths are essential to the high functionality achieved by batteries, motors, semiconductors, catalysts and other advanced electronic parts and functional chemical products. Conversely, there are also supply risks due to the uneven geographical distribution of resources and the frailty of supply chains. Initiatives to develop stable supplies of rare metals, rare earths and other resources are urgent and have been highlighted in the "New International Resources Strategy."[7]

2. Academia

In recent years, emerging economies and other players have been active in materials research and development. This has resulted in a sharp drop in the international share of materials-related publications from Japan, both in terms of quantity and quality.

Universities and other research institutions are markedly behind in their research platforms and facilities, and there is a significant shortage of postdoctoral students and younger talent. It has been noted that this trend, together with the aging of current research talent, means that a part of Japanese research is now supported by non-Japanese researchers.

---

[6] Challenges and outlook for the Japanese manufacturing industry identified in the FY2019 Monozukuri White Paper (Chapter 2)

[7] Formulated by the Ministry of Economy, Trade and Industry in March 2020. Contains guidelines for low-cost energy supply and appropriate adaptation to the environment based on the primary goal of ensuring stable supplies of energy while maintaining the key prerequisite of safety

It has also been noted that in higher education, the attractions of materials areas have not been adequately communicated to students. As it becomes more and more urgent to attract and retain talent, professional societies involved with materials are experiencing steady declines in membership numbers, and the decline in student members is a cause of particular concern.

There is also a gap in the talent pool as demand rises for people with expertise in materials and information. Compared to other fields, materials has a high percentage of students accepting employment after completing their master's degrees, and this trend has only increased in recent years. As a result, a lower percentage of students are matriculating into doctoral programs upon completion of the master's course.

Conversely, there is high demand for doctorates; for example, the percentage of new hires at Japanese chemicals companies who have doctoral degrees is gradually increasing. Going forward, there are expectations that universities will increase the supply of talented professionals in this area by, for example, increasing the attractiveness of relevant fields of study and providing broader educational environments.

The expectation of companies for universities and research institutes is that they focus primarily on basic research and scientific theory. Obviously, academia and venture companies will continue to work on social implementation as well, but the hurdles to product development high and require long periods of time and large amounts of funding to bring concepts from research and development to commercialization.

What is important is that the novel, innovative technologies developed by academia and venture companies move reliably forward toward social implementation so that new markets are created and captured. This requires a more advanced innovation ecosystem that encourages venture-style thinking and contributes to the solution of the particular challenges encountered in materials.

3. External environment

As the disease spread around the globe, the World Health Organization declared Covid-19 a pandemic in March 2020. Countries all over the world have been forced to change their social structures and living patterns to prevent infection and maintain economic activity. The spread of Covid-19 has also exposed the risks and frailties of international supply chains due to the concentration on specific sources and markets for raw materials.

Alongside this are growing worldwide challenges for the sustainability of the global environment, including climate change, marine plastic waste, and biodiversity.

Japan declared that by 2050 Japan will aim to reduce greenhouse gas emissions to net-zero, that is, to realize a carbon-neutral decarbonized society,[8] and the country is marshaling policy to encourage innovation while also reforming regulation

A new world order will bring changes on the geopolitical front, and there is growing competition among states as the international community searches for this order. In the areas of science, technology and innovation in particular, there is increasingly intense competition among the United States, China and other leading countries for technological hegemony, and growing concerns about what this means for technology security.

[8] General policy speech by Prime Minister Suga to the 203rd session of the Diet (October 26, 2020)

In March 2020, the EU formulated the "Circular Economy Action Plan"[9] as part of the European Green Deal, under which it recommends additional measures for manufacturers, including new regulations that cover the entire flow of business, from the design stage to the manufacturing process and after-sales servicing

Europe made further progress toward strengthening and standardizing regulations concerning the circular economy with the publication in December of that year of a proposal from the European Commission for significant amendments to existing regulations on batteries.[10] This has created a growing risk of being shut out of supply chains within the EU.

To summarize, there are significant changes to the environment and circumstances associated with "monozukuri," and uncertainty is on the increase; examples go beyond falling birthrates and aging demographics and the consequent decline in the working-age population to include the Covid-19 pandemic, growing concern about environmental problems, and geopolitical challenges.

Maintaining and strengthening the front lines of monozukuri in Japan will require improvements in labor productivity and higher added value, including greater use of digital technologies to train talent and pass down skills.[11]

---

[9] Circular Economy Action Plan for a cleaner and more competitive Europe

[10] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020

[11] Recruitment and training of manufacturing talent as outlined in the FY2020 Monozukuri White Paper (Chapter 2)

Chapter 3: Significance of strategy

1. Unique aspects of materials development

Materials support the world; the history of humanity tracks the development of materials, from iron to metals, plastics, advanced ceramics and electronic materials.

Materials have changed the world at many points in history, but one of the things that sets them apart is the long period of time required from discovery and development to industrialization. One recent example is carbon fiber. Full-fledged research began in the 1960s, but it was not until the 2000s that it was used as a structural material for passenger aircraft, and today, it has a broad range of applications and contributes substantially to global sustainability.

To this point, Japan has been particularly skilled at cumulative-style development, the creation of innovative materials through the refinement of technology. However, the time required for development is extremely long, and shortening this period it is one of the major challenges confronting the materials area. Recent advances in AI and big data have significantly changed research and development approaches. Instead of the traditional pattern of formulating hypotheses on the basis of experience and expertise, and then moving on to validation, the current approach is to quantitatively capture phenomena in the form of large volumes of data that can be analyzed to move research and development forward. This "data-driven research and development" has garnered much attention and is helping to shorten development times and reduce costs. Japan has created numerous innovative materials, many of which have gone on to earn Nobel prizes for those involved. We must continue to develop these kinds of innovative materials, and to do this, it is necessary to create new value by building and enhancing the data-driven research and development platform so that researchers are able to delve into the essential nature of materials and phenomena. This is what will drive materials innovation in Japan.

Materials are a component of final products, but they are also the source of many of the functions of the final product, and one of the strengths of Japanese industry and economy. In actual practice, however, materials are not necessarily valued as they should be; the spotlight is on the performance of the final product, and there is little recognition of the role that materials play in making that performance possible. In advanced technologies like AI, bio, quantum technology and semiconductors, the materials area makes extremely large contributions, particularly in areas where Japan is strong like silicon and optical fiber manufacturing technology. On the other hand, materials-related product lifecycles are growing shorter, and products quickly become commoditized. Materials are on the one hand always required to have advanced functions, but on the other, constantly subject to cost pressures and excessive competition. Meanwhile, when all of the many different potential combinations are factored in, the potential types of materials are limitless and represent one of humanity's expanding frontiers. It is this that is the thrill and excitement of materials research and development. While it is often necessary to make the effort to develop new users ("goals") for the products developed, there is an extremely high degree of satisfaction when a material that one has developed makes real contributions to society.

2. Role in social implementation

Given the growing importance of sustainability around the world, Japan has decided to focus its efforts on "achieving the digital society" and "achieving the green society." Materials and the innovations they spur are essential to simultaneously creating virtuous cycles for the economy and environment and achieving the green society.

In a document entitled "Green Growth Strategy for Carbon Neutrality in 2050,"[12] Japan has formulated action plans for 14 key areas of the green society. In most of these areas, materials innovations are required. Below are some examples.

- Automotive and storage battery industries: Focus on research, development and validation for performance improvements in all-solid lithium-ion batteries and advanced batteries, performance improvements in storage battery materials, speed improvements, quality improvements and low-carbon production processes for storage batteries and materials, reuse and recycling, and use of stationary storage batteries to regulate electric power supply and demand etc.

- Aircraft industry: Progress is being seen in the introduction of new aircraft and engine materials that reduce the weight and improve heat performance. In aircraft structures (body and main wings etc.), progress is being made on the shift from aluminum alloys to carbon fiber composites. For aircraft engines, lightweight, strong carbon fiber composites are being applied to fan parts, and ceramic-based composites, a material with high potential heat resistance, has begun to be applied to turbine parts. The demand for materials that reduce weight and improve efficiency is expected to continue as a result of more rigorous requirements for carbon reductions. Japanese companies currently have technology advantages in the materials area, but it will be crucial to make further performance improvements and cost reductions going forward.

Japan advocates "Society 5.0," which it defines as "a human-centric society that provides for economic development while also addressing social problems by using systems that provide advanced levels of integration between cyberspace (virtual space) and physical space (real space)." This concept corresponds to the vision for the future known as digital transformation ("DX" for the remainder of this document)[13] in which the ubiquity of ICT changes all aspects of human life for the better, but Society 5.0 requires materials technologies to achieve optimal DXs, not just the digital technology to support cyberspace.

Japan has maintained an excellent academic and research base backed by numerous research results that have had measurable social and economic impacts, for example, the blue light-emitting diode and lithium ion battery.

However, there are also many examples of materials with excellent functions but have nonetheless never been commercialized or reached social implementation. Achieving this new form of discontinuous society will require significantly different systems that enable the swift social implementation of innovative materials.

For example, the Clean Ocean Materials Alliance (CLOMA)[14] was established in 2019 as a platform to accelerate innovation by coordinating the efforts of a broad range of players in different industrial sectors towards solutions to the problem of marine plastic waste. Similarly, that same year, the "Carbon Recycling Fund" was created to provide private-sector research subsidies and publicity activities to support carbon recycling innovation that will simultaneously address global warming while improving global energy access.

These are just two examples of initiatives to go beyond industry boundaries to reduce environmental load and achieve sustainability. Going forward, it will be important for a wide range of players involved with materials to learn from these examples, develop shared values, and collaborate for swift social implementation.

---

[12]Formulated by the Ministry of Economy, Trade and Industry in December 2020. Formulated in collaboration with relevant ministries and agencies as industrial policy that will lead to a "virtuous economic and environmental cycle," addressing the challenges articulated by the Suga Government in "Carbon Neutrality 2050"

[13]Concept articulated in 2004 by Professor Erik Stolterman of Umea University (Sweden)

[14]More than 400 corporate and institutional members as at April 2021

3. Strategy formulation

The Covid-19 pandemic has brought significant changes to the economic and social environment, and for companies has increased the need to emphasize not only the pursuit of profit, but also the creation of common values, including efforts to address environmental problems. This is evidenced by the new attention being given to ESG investment and other non-traditional approaches to valuation; ESG, for example, also considers such non-financial information as environment, society and governance. The growing awareness of ESG and SDGs increases the position of materials, because it is materials that translate directly into the achievement of carbon neutrality and a circular economy.

Advances in materials are essential not just for the green society, but also for the achievement of AI strategy, bio strategy, quantum technology innovation strategy, the Progressive Environment Innovation Strategy and other programs, and there are strong expectations for their swift social implementation. As it becomes easier to collect and analyze large volumes and wide ranges of data using approaches like big data, computer-generated simulations and AI-driven research are gaining greater impact. Particularly with the Covid-19 pandemic, there has been a global trend towards the DX of research activities. Forums for exchanging research findings, for example, have moved to a remote setting, equipment and machinery in research facilities can be accessed remotely, and there is a growing use of data-driven research and development.

At the international level, we are seeing an increasingly intense competition for technical hegemony between the United States, China and other leading countries, but we have also seen an increase in uncertainty through the exposure of the risks and frailties in international supply chains, and new environmental policies like the regulations in the EU. These trends reconfirm the importance of the materials industry in securing vital rare resources and maintaining a circular economy.

To this point, Japan has continued to play a leading role internationally in the development of innovative technology and maintains its competitive advantages in this area. The materials industry, in particular, has grown as an industry that collaborates with and supports other manufacturing. The major changes that are taking place in the external environment and the increasing intensity of international competition make it more essential than ever that Japan pursue a differentiation strategy rooted in its core strengths.

Chapter 4: Basic guidelines

1. Targets

Contribute to the world by taking leadership in the conversion to a sustainable society through the enhancement of materials innovation capacity in ways that provide for both economic development and solutions to social issues

"Materials innovation capacity" supports the very foundations of society, and a coordinated, timely effort by interested parties in industry, academia and government to strengthen it will enable materials to drive social transformation (materials innovation). Japan is an essential player in providing strong forward impetus to the solution of global social issues and in the development of a sustainable world, and it is necessary to strengthen and enhance the country's industrial competitiveness.

1) Achieve Society 5.0

Combine new technologies like AI, quantum technology and biotechnology with high-function materials and other materials technologies in a coordinated effort among industry, academia and government and also within industry (horizontal, vertical) to address problems and create new industries

2) Create social systems with the world's lowest environmental load

Achieve both advanced resource recycling and low-carbon manufacturing. Develop markets that focus on reduced environmental load as a value

3) Use world-class research environments and swift social implementation to strengthen international competitiveness

Enhance the research platforms that are Japan's strength,[15] and move forward with DX. In addition to facilities and equipment, position data as common social capital, and promote the accumulation and use of the data generated. Build an innovation ecosystem that enables swift social implementation as a collaboration among industry, academia and government

2. Basic guidelines for the enhancement of materials innovation capacity

Working from the spirit of "win-win-win"[16] in the value chain, build disciplined, open, coordinated relationships that go beyond the differing positions of industry, academia and government to work together to address domestic and international social issues and develop the economy and society

---

[15]The National Institute for Materials Science (NIMS), National Institute of Advanced Industrial Science and Technology (AIST), research institutes of national universities, Nanotechnology Platform Japan, "Fugaku" supercomputer, and synchrotron radiation facilities etc.

[16]The motto of Omi merchants seeking three "goods," "good for the buyer," "good for the seller" and "good for the public," i.e. "trade should not merely be for one's own profit, but for the good of the buyer as one's customer, and also for the good of the world at large"

Basic Guideline 1	**Collaboration among industry, academia and government for swift social implementation**
Basic Guideline 2	**Enhancements to data-driven research and development platforms**
Basic Guideline 3	**Assurance of sustainable development**

(1) Basic Guideline 1 Collaboration among industry, academia and government for swift social implementation

ESG-focused materials innovation

In June 2020, the "Science and Technology Basic Act" was amended to create the "Science, Technology and Innovation Basic Act," which adds "promotion of humanities and social sciences" and "creation of innovation" to the areas of emphasis. This significantly changes the implications found in the concept of "innovation," amending science and technology innovation policy to include policies to create social value, not just research and development.

In the past, the concept of innovation tended to be thought of entirely in terms of corporate product development and actions with direct impact on production activities, but today it is viewed more broadly as a range of activities performed by actors to create significant changes in economies and societies. In short, innovation itself is evolving into a concept that focuses on the creation of new value and the transformation of society itself.

The Covid-19 pandemic has spurred major changes in the economic and social environments. There is a growing need for companies to emphasize not only the pursuit of profit, but also the creation of common, universal values, including efforts to address environmental problems. Companies around the world are stepping up their efforts to simultaneously address environmental constraints and economic growth.

In the materials area, this translates into greater need for responsible supply chain management that reduces the environmental load throughout the lifecycle, from manufacturing to disposal. Japan has also pursued research and development initiatives that address this agenda and has achieved a certain level of global recognition in this area, but it is crucial for the country to accelerate coordinated initiatives by industry, academia and government.

Materials have the ability to significantly change society and are directly related to goals like carbon neutrality and circular economy, and from this perspective, there are growing expectations for materials to contribute to the simultaneous creation of virtuous cycles for both economy and environment.

To this point, Japan has focused primarily on closed, linear innovation within the framework of existing companies. Large, established companies have a strong orientation towards "insourcing," which has been pointed to as a factor in creating large stockpiles of idle patents and hoarded materials.

From the perspective of innovation, it is not only the novelty of the technology itself that is important, but how it can be combined with existing technologies and creatively applied to produce novel changes.

The swift social implementation of materials requires "spiral" innovation, an open, multi-linear cycle of entries and goals based on collaboration with universities, venture companies and other players.

There is particular need for the articulation of a grand design for the circular economy that focuses on innovation in materials to develop goal-oriented strategies for design and implementation based on the ideas expressed in Circular Economy Vision 2020.[17] These initiatives must be comprehensive in their approach, providing a clearly defined image for social transformation, forming platforms to promote ESG-oriented open innovation, delivering products swiftly to society even if technologies are not necessarily mature, and studying and establishing new ESG-oriented investment approaches that seek to effectively utilize recycled materials.

[17]Formulated by the Ministry of Economy, Trade and Industry in May 2020. Articulates basic directions for Japanese circular economy policy that will enable Japanese companies to draw on the strengths they have built in 3 Rs initiatives as they compete on global markets and enhance the country's medium and long-term industrial competitiveness

(2) Basic Guideline 2 Enhancements to data-driven research and development platforms

Differentiate on strengths

Japan's materials industry grew during the latter half of the 20th century as an industry that collaborated and coordinated with other domestic manufacturing. Today, the industry boasts numerous products with majority shares in global markets and is one of Japan's key export centers.

In functional materials, efforts have been made to differentiate products, and while the individual product markets are small in size, the products themselves enjoy high shares. Japan currently has 70 materials with global shares of 60% or higher, and 19 with global shares of 100% (top of the niche).

A strong collaborative materials industry (i.e., advanced manufacturing process technology and the advanced technologies held by the companies producing the measurement and analysis equipment, processing equipment and devices that support it) is a lifeline for Japan in maintaining its presence on the global stage and bolstering its position in international negotiations.

Even today, the industry is distinguished by large numbers of domestic companies and researchers, players all along the value chain (upstream, midstream, downstream), and close relationships with academia.

The collaborative development approach and industrial/academic diversity that Japan has fostered are strengths compared to other countries on par with top class research and development platforms.

Advances in digital technology are producing a rapid shift towards data-driven models in research and development, as they are in other areas. Materials informatics (MI) is an inductive approach to identifying the interrelationships and laws governing materials performance and structure from systematically accumulated data. It represents a fusion of materials science and computational science to provide directions for new materials design and will become the platform for materials research and development going forward. As this happens, the high-quality materials data accumulated by industry, academia and government as the results of development by a wide range of domestic academic and industrial researchers are likely to be a significant factor in Japan's favor, but the country does not yet make adequate use of this strength.

Overseas, there is an intense competition for control of materials data and increasingly active efforts to accumulate it. Companies with strengths in AI actively collect data, and data-related companies under the control of major publishers and professional societies collect research papers and patent information.

The value of Japan's materials database will be increased with the formation of a virtuous cycle in which large numbers of users use large volumes of data to create new data and extend existing data. Efforts are underway to launch industrial/academic and inter-industry initiatives for the collection of materials data, for instance, the development of patent databases geared specifically to MI. As these efforts progress, they will translate directly into international competitiveness for Japan.

Japan's manufacturing process technology is one of the country's strengths and represents the accumulation of the experience and expertise of engineers based on close collaboration and coordination throughout the value chain. However, there are growing trends towards more diverse product needs and shorter lifecycles that must be met with more advanced manufacturing processes and shorter development periods. Greater fusion of empirical science, theoretical science, computational science and data science, which aim to produce insights and observations from data, with the experience and expertise that underlie manufacturing process technology can bring new and potentially more robust strengths to Japanese materials. For this to happen, it is urgent that a scientific approach be established for basic technology required for the use of data science in the analysis of manufacturing process data (process informatics: PI). There are large expectations that active use of PI will facilitate the optimization of synthesis and manufacturing processes and enable faster, more efficient scaling up. It is particularly urgent to build structures for the efficient collection and use of manufacturing process data.

The shift to data-driven research and development has the potential to dramatically increase the speed, quality and quantity of research and development, but achieving data-driven research and development in the materials area will require not only the integration of materials science and data science, but the digitalization of the research and development styles practiced by researchers themselves. By using IoT and robotics, the process by which researchers do hands-on experimentation and analysis in the laboratory will shift to more automated, remote operations, reducing both the labor required of researchers for experiments and the potential for mistakes, and creating more reliable data at vastly higher speeds. Meanwhile, researchers will be released from the physical labor of experimentation and able to spend more time on more intellectually productive work.

The key to all of this is to marshal the talented individuals, quality data, and advanced research facilities and equipment in industry, academia and government to maximize their performance in a mature, collaborative industry/academia/government relationship. As other countries emerge in this field, Japan's strengths will become its "lifeline" and "path to victory."

As industry, academia and government work together to accelerate DX in materials research and development, they will lead the world in the establishment of new models for data-oriented research and development and increase the country's materials innovation capacity.

(3) Basic Guideline 3 Assurance of sustainable development

Industry/academia/government collaboration to develop talent, create a circular economy, and produce more robust supply chains

Most of the researchers and engineers in the materials area are in industry. Meanwhile, there is a lack of postdocs, doctoral students and other younger researchers in academia, particularly Japanese researchers.

The materials area has many industry-academia partnerships to train talent, and is making progress in developing individuals able to appropriately handle materials data. These initiatives will need to continue to spread and expand.

Environment and resource sustainability are vital topics for the entire world.

For example, the EU has formulated a wide-ranging circular economy policy that extends beyond care for the environment and effective use of resources and includes industrial policies for the improvement of international competitiveness within the region, sustainable growth, and the creation of jobs.

Japan should likewise formulate and establish policies in which relevant ministries and agencies and relevant institutions collaborate with the front lines of industry and academia in an integrated industrial economy and research and development strategy, particularly for key areas like next-generation storage batteries and new materials like cellulose nanofibers that have low environmental loads and excellent properties.

Rare metals and rare earths will continue to be strategic rare resources.

As we move to a decarbonized society, demand is expected to increase in many areas, not just electronic equipment and functional materials. For example, they are the key to the spread of renewable energy equipment and electric vehicles (xEV).

Japan relies on imports for most of its rare resources, and in many cases, is extremely dependent on imports from specific countries. As the competition for resources grows more intense among Europe, North America, China and emerging economies, securing stable supplies of rare resources will be a major challenge for Japan's materials and advanced industries.

There are growing concerns about the risks of international supply chains being cut off and technology flowing out as a result of more intense competition for technological hegemony, and it is essential that Japan maintain and secure its advantages on both the technology and institutional sides as it works to establish more stable and more robust economic activities.

3. Directions for initiatives from the perspective of product lifecycle

This strategy organizes concepts for actions at different stages of the materials development lifecycle (introduction stage, growth stage, mature stage) as outlined below.

1) Introduction stage

- ✓ Prepare and enhance the research environment to further strengthen basic, foundational research
- ✓ Actively incorporate domestic and international "knowledge and insights"
- ✓ Integrate different areas and fields of expertise to marshal knowledge and insights (encourage open innovation)

2) Growth stage

- ✓ Establish data-driven materials development technology (MI x PI) (building from a foundation of data, work in an integrated fashion to use materials informatics (MI) to forecast and prototype materials, and process informatics (PI) to prototype and manufacture materials)
- ✓ Develop smart laboratories (use AI, IoT and robotics technologies etc. to develop and implement self-sustaining research and development approaches)
- ✓ Shift emphasis to mass customization
- ✓ Expand global share in functional materials
- ✓ Establish competitive advantages with a rigorous strategy of being first to market with data-driven materials development technologies (develop sets that extend from materials to manufacturing equipment, develop advanced measurement devices under industry-academia partnerships, strategically prepare and enhance common facilities, make reverse engineering impossible etc.)

3) Mature stage

- ✓ Develop robust value chains by maintaining key domestic locations etc.
- ✓ Coordinate among all value chain players to maximize value from reductions in environmental load
- ✓ Develop and implement total solutions
- ✓ From ESG perspectives, use collaboration with other countries to move to knowledge-intensive industries
- ✓ Get out of the power game (capital-intensive industries)

Chapter 5: Action plan

This chapter builds on the basic guidelines articulated in Chapter 4 to organize the shared targets of Japanese industry, government and academia, policies (tactics) for their achievement, and actions to be taken. Note that this represents a summary of findings as at FY2021, and conclusions must undergo a process of continued improvement as discussions and collaborations among industry, academia and government deepen.

1. Development and swift social implementation of innovative materials

[Target]	Move forward on the social implementation of the "innovative materials" that are the source of Japanese competitiveness

Key numerical indicators to be achieved through the Materials Innovation Strategy (KPIs):

1) By 2030, double the number of products with global shares of 60% or higher

2) By 2030, create at least 10 examples of social implementation of materials technology that is crucial from ESG perspectives

(1) Policies to achieve targets

One of the distinctive features of Japan's materials industry is that it is comprised of a wide variety of players representing both researchers and companies (upstream, midstream, downstream), but the coordination among these players is still limited. Greater mutual coordination will be required for the swift social implementation of technologies going forward. In more concrete terms, it will be crucial to collaborate on the basis of ESG and other "common language" so that there is a shared awareness of increasingly complex social issues and a common approach to costs and other issues encountered in the social implementation of innovative materials technologies.

(2) Concrete initiatives

1) Support for social implementation initiatives for materials that are innovative from the perspective of ESG etc.

✓ Develop platforms to address social issues

In the social implementation of materials with cost or other challenges, it will be effective to use platforms that encompass upstream and downstream, are cross-disciplinary, and involve industry, academia and government because these platforms will enable collaboration to address the challenges in developing businesses and visually represent the initiatives to do so. For example, in the area of plastics recycling, support the initiatives that have been undertaken by CLOMA and expand the similar approach to other areas.

[METI] [MoE]

✓ Collaborate to develop new values through industry/academia/government partnerships

In materials areas where there are expectations for social implementation under industry/academia/government partnerships (e.g. next-generation storage batteries and multi-materials), develop and enhance open innovation centers for collaboration and co-creation by multiple stakeholders, and provide momentum for coordination among universities, national research and development institutions, research institutes and companies.

[MEXT] [METI]

2) Use the Green Innovation Fund and other vehicles to implement materials technologies that contribute to the achievement of carbon neutrality

✓ Achieve carbon neutrality in the chemicals industry

Move forward with the establishment and social implementation of artificial photosynthesis and other technologies to take the place of naphtha chemistry. More specifically, in addition to the development of photocatalytic hydrogen technology, move forward on the establishment and social implementation of separation and collection technologies to provide for more effective utilization of CO2, as well as allied areas like alcohol chemistry, waste plastic and rubber use, bio-naphtha and recycled naphtha technologies, and carbon-free crack technologies.

[METI]

✓ Achieve zero-carbon steel

Develop hydrogen-reduction steelmaking technology that uses hydrogen in place of coke to reduce iron ore, and also build the social systems to provide for stable, high-volume supplies of hydrogen that is sufficiently price-competitive compared to fossil fuels, and appropriately allocate the environmental costs.

[METI]

✓ Use electronic materials to achieve carbon neutrality

Identify strategically essential innovative materials and develop and socially implement materials used in the pre-processing of advanced semiconductor devices (nanosheets and other semiconductor materials, wiring materials, insulation materials etc.), parts and materials used in the post-processing of advanced semiconductor devices (encapsulants, bump material, three-dimensional package substrates etc.), and technologies for next-generation innovative memory devices that make use of carbon nanotubes through the collaboration between device and materials manufacturers.

[METI]

3) Develop and enhance platforms for the effective social implementation of innovative materials technologies held by startups and other players

✓ Encourage the use of unused and buried technologies

It is important to appropriately match novel technologies able to contribute to the solution of social issues to the needs of the market so that these technologies are not buried and lost. Support to coordinate matching sites specifically for advanced materials with databases administered by national research institutes and public agencies like the Organization for Small and Medium Enterprises and Regional Innovation to ensure effectiveness of these sites.

[METI]

✓ Recruit talent as social implementation partners

The social implementation of new technologies at startups and similar entities requires the use of senior talent, particularly engineers and managers etc. with business experience. Provide support for the creation of platforms for the recruitment of talent able to serve as social implementation partners.

[METI]

✓ Build a matching ecosystem for outsourced production of chemical products

Support the creation of platforms for matching startups with manufacturing outsourcing companies because their collaboration is needed for process investigations and provisions of plant equipment and facilities in pilot-scale, which are among the challenges faced in the social implementation of new materials.

[METI]

- ✓ Encourage the use of tools to support innovation

Encourage the use of regulatory reform tools like the "regulation sandbox system" that lead to the review of regulations that are barriers to the social implementation of new materials and technologies.

[METI]

[Target]	Promote strategic research and development in key materials technology and implementation areas
KPIs:	1) Increase international position in the materials area as measured by total number of papers published, the number of adjusted top 10% and top 1% papers. Note: The adjusted top 10% (top 1%) papers represent papers whose citation counts are in the top 10% (1%) of each field and of each year. 2) Provide for ongoing increases in research and development funding in the materials area

(1) Policies to achieve targets

There are two different forms of research that aims to develop the innovations required to address social issues: strategic research based on backcasting to identify key technology fields, and wide-ranging, ambitious, creative research based on the creative ideas of researchers themselves. Both should be enhanced. When doing so, encourage initiatives that maximize the use of materials data, manufacturing process technologies and advanced shared facilities to create and provide for the swift social implementation of dramatic results ahead of the rest of the world.

(2) Concrete initiatives

- ✓ In key technology fields in which materials will contribute to the solution of social issues and enhancement of industrial competitiveness, implement projects to collect the knowledge and insights of industry, academia and government in Japan and other countries under the administration of the New Energy and Industrial Technology Development Organization (NEDO) and Japan Science and Technology Agency (JST)

  [CO] [MEXT] [METI] [MoE]

- ✓ From medium and long-term perspectives, support strategic research in basic, foundational research and implementation areas. Enhance both strategic and creative research by reforming competitive research funds and appropriately coordinating among funding agencies

  [CO] [MEXT] [METI]

- ✓ Within the Strategic Innovation Promotion Program, develop a materials integration system able to forecast consistently from processing to structure, properties and performance

  [CO]

- ✓ Use results like next-generation semiconductors (gallium nitride (GaN) semiconductors etc.) to develop, demonstrate, implement and refine technologies that can be applied to specific uses at the current point in time

  [MoE]

- ✓ Through the leading-edge research conducted under NEDO's "Research and Development of Enhanced infrastructures for the Post-5G Information Communication Systems" etc., move forward on the research, development and social implementation of innovative materials, parts and manufacturing processes required for the pre- and post-processing technologies in advanced semiconductor manufacturing

  [METI]

- ✓ Accelerate research and development to create the seeds of innovative technologies that will result in decarbonization (e.g., develop new approaches and technology seeds that result in science-based break-throughs on bottleneck issues, achieve dramatic improvements in performance by combining innovative materials with existing technologies, and create innovative technologies based on new principles and ideas like next-generation spintronics technology)

[MEXT]

- ✓ By FY2021, identify and articulate the priority technology challenges in the materials area through a process of discussion and debate within the research community from the perspectives of the high social demand for the achievement of carbon neutrality and Society 5.0, the difficulty and feasibility of specific technologies, and affinity to data-driven research. From FY2022 onwards, implement full-fledged projects to solve problems

[MEXT]

2) Examples of technology fields requiring backcast-driven research

- ✓ Materials able to express advanced functions expected to contribute to Society 5.0 (e.g., power electronics devices, IoT sensors, actuators, and MEMS[18]) and materials that use quantum and electronic control to express innovative functions (e.g., quantum sensors, spintronics devices, quantum cryptography communications, and nanoelectronics devices)
- ✓ "Materials that enable innovative energy conversion" that will contribute to low-environmental load societies (e.g., high-output, large-volume storage batteries, energy conversion materials, high-performance motors, thermoelectric elements etc.), and "basic technologies for advanced materials cycles" that will achieve both recycling and carbon neutrality (materials and product design technologies oriented towards reuse and recycling, technologies to replace scarce elements, technologies that reduce the volume of resources used, technologies for the separation, collection and use of CO2, materials separation technologies, and biodegradable materials technologies)
- ✓ "Next-generation bio and polymer materials" that will enable everyone to enjoy healthy, safe lives (e.g., health-adaptive materials, antiviral materials, self-repairing the materials, bio sensors and wearable devices)
- ✓ "Materials with extreme functions" that will build the world's safest, most secure and most resilient state (e.g., ultra heat resistant and fire resistant materials, strong, lightweight materials, and structural materials for extreme environments)

3) Examples of technology fields requiring forecast-driven research

- ✓ "Next generation nanoscale materials" (e.g., nanofibers, nanocarbon) and "multi-materials technologies" (e.g., dissimilar material adhesion and connection technology, welding technology, 3D lamination technology, composite materials)
- ✓ "Material and function design and control technologies" that will produce innovative approaches to research and development (e.g., surface, interface and grain-boundary controls, reaction controls, atomic and molecular-level autonomous controls) and "common basic technologies for materials" (e.g., materials data structures, high throughput technologies, advanced measurement, analysis, processing and precision processing technologies, smart laboratories, safety, reliability and risk assessment)

[18]Micro Electro Mechanical Systems: Devices that use fine processing technology to integrate mechanical elements, sensors, actuators and electronic circuits on a single silicon substrate, glass substrate or organic material

- ✓ Development of new functional materials using innovative technologies in measurement, calculation, processing and data-driven research for areas largely unexplored in current materials development (e.g., multi-element materials, composite materials and metastable phase materials)

2. Use materials data and manufacturing technology to promote data-driven research and development

[Target]	Promote the creation and enhancement of data-driven research and development platforms (material DX platform) and the use of materials data	
KPIs:	1)	By FY2025, develop and enhance nationwide systems to provide advanced shared facilities, focusing on six data hubs in different locations throughout Japan, and achieve approximately 1 million data creations per year
	2)	At least 3,000 uses per year by industry, academia and government of the nationwide system to provide advanced shared facilities

(1) Policies to achieve targets

In addition to excellent advanced shared facilities and the actual data and expertise accumulated within the country, both of which are Japanese strengths compared to other countries that are moving forward on the collection and use of academic papers and other open data, the target is to also collect and use quality materials data, including unused data. When doing so, engage in discussions with industry/academia/government experts about data structuring and handling, and formulate and implement concrete policies for the use of industry/academia/government materials data in ways that are truly effective in quickly producing results and improving the quality of outputs.

(2) Concrete initiatives

1) Prepare and enhance the environment for data collection and accumulation and encourage its use

- ✓ Prepare and enhance soft infrastructure

  Collect and accumulate suitable data in industry/academia/government collaborations (data on government-sponsored research (experimental/computational), public data) by identifying excellent data areas requiring strategic collection and accumulation (areas within materials, parts and analysis requiring the creation of excellent, strategic databases) from the perspective of securing and strengthening Japan's future competitiveness in materials, and discussing with industry, government and academia experts the basic guidelines for the collection and accumulation of data (common metadata and formats, sustainable database administration etc.)

  - ◇ Experimental data government-sponsored research: By FY2022, NIMS and AIST which take the lead and work in consultation with experts in relevant professional societies[19] and industry organizations[20] identify excellent targets for the collection and accumulation of data from

[19]E.g., The Chemical Society of Japan and The Iron and Steel Institute of Japan

[20]E.g., Japan Association for Chemical Innovation (JACI), The Japan Iron and Steel Federation, Japan Mining Industry Association

government-sponsored research and formulate concepts for storage and preservation formats (data storage formats etc.).

[MEXT] [METI]

◇ Computational data (government-sponsored research): Beginning FY2021, work within the Computational Materials Science Forum, which has membership from industry, government and academia, to formulate repository rules for computational data created by Fugaku and supercomputers at research institutes etc., investigate approaches to linking experimental and computational data, and develop mechanisms for the use of materials data

[MEXT]

◇ Public data (academic papers, patents): Industry and academia experts to take the lead in formulating methodologies for the extraction and structuring of required data from academic papers, patents and other publicly-available information, and developing automated data extraction (initial target area: polymer materials etc.)

[MEXT] [METI]

◇ Analysis and measurement data: Strategically investigate frameworks to enable measurement and analysis data, which differs from manufacturer to manufacturer and device to device, to be used by industry, academia and government as a public good, and promote initiatives to make them international standards using international frameworks and other methods

[MEXT] [METI]

✓ Prepare and enhance hard infrastructure

Build facilities and environments able to collect and accumulate government-sponsored research data (experimental data)

◇ Beginning FY2021, launch a continuous process of strengthening and enhancing facilities to provide a nationwide advanced, shared resource encompassing Nanotechnology Platform Japan, and Advanced Research Infrastructure for Materials and Nanotechnology in Japan, move forward on DX, and prepare and enhance data use hubs (create structures for the accumulation and use of data in conjunction with the use of advanced shared facilities)

[MEXT]

◇ By FY2023, begin trial operations on a system for the centralized collection, accumulation and use of data created by the nationwide advanced shared facility, and begin full operation by FY2025

[MEXT]

◇ Strategically enhance public facilities with the development and government procurement etc. of advanced measurement equipment by industry-academia partnerships[21]

[MEXT] [METI]

2) Encourage data sharing and use

[21] One example is the collaboration between University of Tokyo and JEOL for joint research and joint use of advanced electron microscope facilities, and the establishment of social collaboration courses

- ✓ Implement data-centered industry/academia and industry/industry partnerships

  Encourage industry/academia and industry/industry partnerships by creating opportunities to share confidential data and encounter potential development partners

  - ◇ By FY2022, articulate and organize concepts for the handling of industry/academia/government materials data in closed information sharing areas, based on discussions with industry/academia/government experts in light of the status of current initiatives for the sharing and use of company and national research institution data and the circumstances in individual materials fields

    [MEXT] [METI]

  - ◇ Continue to move forward on the creation of platforms for on-demand materials development support for companies, focusing on computational science related to polymer compounds etc., and beginning FY2022, target the creation and operation of a platform able to achieve use of the acquired data across companies

    [METI]

  - ◇ By FY2022, prepare, enhance and begin operations of a structure for data sharing and use as a cooperative effort by companies and national research institutes in areas of corporate collaboration (e.g., new materials development and assessment)

    [CO] [MEXT] [METI]

3) Provide education and the skills required for data-driven materials development

- ✓ Training of required talent

  - ◇ Use the material DX platform to train talent using data and talent structuring data in nationwide advanced shared facilities and NIMS etc.

    [MEXT] [METI]

  - ◇ Provide training courses on data use by industry organizations, universities and professional societies etc.[22]

    [MEXT] [METI]

  - ◇ Introduce assessment standards for talent structuring and curating data in outsourced research projects (hiring, evaluation) in the materials area

    [MEXT] [METI]

[22]E.g., Japan Association for Chemical Innovation (JACI), The Institute for Solid-State Physics at The University of Tokyo, The Iron and Steel Institute of Japan

[Target]	Establish basic technology for process informatics (PI) and build a process innovation platform	
KPIs:	1)	By FY2021, build on the core services of the regional centers of the National Institute of Advanced Industrial Science and Technology to create at least three process innovation platforms around Japan
	2)	By FY2024, achieve at least 40 uses by industry and academia of the process innovation platform

(1) Policies to achieve targets

Improve the speed, efficiency and level of technology development by accumulating expertise, experience and technology to integrate manufacturing process development and data science. The target in this is to develop and implement innovative, next-generation manufacturing processes able to address the needs for mass customization etc. while also building a common technology foundation for manufacturing processes. In specific terms, this requires the use of advanced measurement technologies etc. to collect process data, the development and use of analytical technologies, and the creation and social implementation of wide-ranging basic technologies to achieve manufacturing processes able to address market needs.

(2) Concrete initiatives

1) Build a process innovation platform and establish basic technology for PI

✓ Build a process innovation platform

By approximately FY2021, identify priority areas (materials in which Japan has high levels of international competitiveness) and build and begin operations of facilities and environments (process innovation platform) at the regional centers (Tsukuba, Chubu, Chugoku) of the National Institute of Advanced Industrial Science and Technology. The process innovation platform is able to consistently collect manufacturing process data with high throughput in the area of high-function materials (e.g., catalysts, ceramics, and cellulose nanofibers)

[METI]

✓ Build basic technology for PI

By approximately FY2026, use and refine advanced measurement and analysis technologies and link them to integrated manufacturing process facilities to create manufacturing process data and build basic technologies for process informatics that use both AI modeling and process simulations to develop advanced and universal processes

[METI]

✓ Encourage the social implementation of developed technologies

Encourage the swift social implementation of developed technologies by providing industry, primarily small, medium-sized and venture companies, with support and talent for data-driven research and development using the process innovation platform

[METI]

✓ Strengthen industry/academia/government partnerships

Swiftly respond to the diversification of social needs by building a multidisciplinary industry/academia/government structure for the design and development of materials and processes based on the idea of total performance by coordinating a wide range of stakeholders to provide support for swift social implementation of important and new materials and technologies (multi-materials etc.)

[METI]

2) Development of the innovative manufacturing process technology

- ✓ Develop process technology for the joining and interface structure control of nano-materials

  Conduct research and development of process technologies for the joining and interface structure control of nano-materials to build a scholarly, scientific foundation for processes that contribute to the design and development of innovative materials

  [MEXT]

- ✓ Develop manufacturing process technologies for fast, efficient, on-demand production

  Develop technologies for optimum production pathway design for target chemical products using PI and computational science etc. and innovative manufacturing processes (e.g., flow synthesis technology) that will enable low environmental load (low energy, low waste) and fast, efficient, and on-demand production of chemical products

  [METI]

- ✓ Conduct research and development of manufacturing processes for advanced ceramics

  Elucidate sintering and other mechanisms using advanced measurement technologies together with process simulation technologies and develop innovative manufacturing process technologies with PI for reliable advanced ceramics required for the electronic devices etc. in 5G/6G

  [METI]

- ✓ Develop innovative combinatorial methods for alloys

  Develop innovative combinatorial methods able to quickly and automatically synthesize high volumes of prototype samples and continuously, quickly and automatically analyze them to accelerate the development of new alloys combining multiple metals

  [METI]

3. More sustainable international competitiveness

[Target]	Industry/academia/government coordination for human resources development	
KPIs:	1)	Alleviation of the supply and demand gaps for talent in materials area companies
	2)	Ongoing increases in the percentage of PhDs among new corporate hires

(1) Policies to achieve targets

Increase the attractiveness of the materials area by working as closely as possible with distinctive industrial/academic partners in the materials area in a coordinated industry/academia/government program to emphasize the satisfaction (thrill) of research and Japan's track record in contributing to global sustainability. Particularly for PhD talent, for which strong demand is emerging, attract talented individuals and implement initiatives ahead of other areas by developing attractive, practice-oriented environments in collaboration with industry organizations and relevant professional societies.

(2) Concrete initiatives

1) Utilize industry/academia strengths in the materials area to create environments in which students are able to experience attractive career paths

✓ Beginning FY2021, implement programs to recruit PhD students to work in academia and industry by providing support to universities that improve compensation and secure career paths for PhD students under university-wide strategies, and by using competitive research funds to enhance support for PhD students

[MEXT]

✓ Implement initiatives by universities, companies and industry organizations to use human resources development programs under industry-academia partnerships to communicate the attractions of the materials area, focusing particularly on the use of the Doctoral Program for World-leading Innovative & Smart Education (WISE Program), JST and Japan Society for the Promotion of Science (JSPS)

[MEXT] [METI]

✓ Provide visual representations of career options and their benefits by clearly articulating the positioning of career paths for PhDs within companies

[MEXT] [METI]

✓ Broaden the talent base by using industry-academia partnerships and professional society activities etc. to enhance monozukuri activities at the elementary and secondary education

[MEXT] [METI]

✓ Provide an environment in which younger researchers are able to make use of advanced facilities and equipment by strategically installing equipment and enhancing common-use platforms

[MEXT]

2) Recruit professional technicians to support research [MEXT]

- ✓ Recruit professional technical talent to provide advanced expertise on the use of the advanced facilities and equipment of universities etc.

- ✓ Establish and provide visual representations of the career paths open to professional technicians at universities etc.

3) Use OJT for target-oriented human resources development to provide opportunities to gain entrepreneurial experience

- ✓ Encourage human resources exchanges among major companies, venture companies and universities, and encourage the use of interns

  [MEXT] [METI]

- ✓ Implement university, corporate and industry organization initiatives to train the talent required by companies under industry-academia partnerships, making use of JST, JSPS and other programs

  [MEXT] [METI]

4) Provide skills training required for data-driven materials development (repeat)

- ✓ Use the material DX platform to train talent using data and talent structuring data in nationwide advanced shared facilities and NIMS etc.

  [MEXT] [METI]

- ✓ Provide training courses at the industry organization, university and professional society levels for personnel using data

  [MEXT] [METI]

- ✓ Introduce assessment standards for talent structuring and curating data in outsourced research projects (hiring, evaluation) in the materials area

  [MEXT] [METI]

[Target]	Achieving the circular economy	
KPIs:	1)	By 2035, efficiently utilize used plastics with 100% reuse and recycling etc.
	2)	By 2030, introduce approximately 2 million tons of biomass plastic

(1) Policies to achieve targets

Both institutions and technologies are important to the achievement of a circular economy that will maintain sustainable development for the world. In addition to responding to institutional circumstances in different countries, it is particularly important to seek international harmonization. More specifically, build and enhance institutions that will achieve circular economies, focusing on the areas of carbon neutrality and plastics in light of the growing importance of plastic waste problems. Along with this, move forward with the social implementation of technologies required by the circular economy.

(2) Concrete initiatives

1) Formulate the rules and develop and enhance the social infrastructure environment required to achieve milestones set in the "Resource Circulation Strategy for Plastics"

[CO] [MEXT] [METI] [MoE]

- ✓ Design recyclable materials and products

  Develop materials and product design technologies (mono-materials) for reuse and recycling, and formulate product design guidelines

- ✓ Introduce low-environmental load materials

  Develop and use alternative materials (e.g., reusable materials, biomass materials, biodegradable materials) technologies and evaluation methods and stimulate demand by means of government-led procurement and other measures

- ✓ Streamline social infrastructure environments

  Develop and enhance recycling and transportation systems for plastic waste from households and companies and recycling platforms by, for example, formulating nationwide rules required for the efficient and voluntary collection of plastic resources from the households by manufacturers and vendors, and formulating the rules required for initiatives for efficient and advanced recycling of plastic resources voluntarily segregated and emitted by emitting businesses in partnership with recyclers

2) Encourage the development of technologies and social implementation to achieve the circular economy

[CO] [MEXT] [METI] [MLIT] [MoE]

- ✓ Develop and implement plastics recycling technologies

  Develop efficient and advanced recycling technologies of materials and chemicals, which will also contribute to achieving carbon neutrality

- ✓ Materials and product design technologies (e.g., multi-materials, adhesion, separation of content, printing, prevention of decay) and tracing technologies (e.g., identification, approval and tracking) for reuse and recycling

- ✓ Promote the development and implementation (e.g., quality evaluation, design execution manuals) of technologies for materials that reduce environmental load in the manufacturing process and materials for the effective utilization of unused resources (e.g., construction byproducts)
- ✓ Support the development and installation of technologies for the effective use of scrap electrical wires and other low-quality scrap
- ✓ Expand the use of carbon fibers especially for mobility and develop and implement recycling technology

[Target]	Overcome resource constraints
KPI:	Spread heavy rare earth-free magnets to xEVs (heavy rare earth-free magnets used on 50% of xEVs sold in 2030)

(1) Policies to achieve targets

Based on the "New International Resource Strategy," we identify resources that are essential to industry and for which there is a high degree of dependency on imports from specific countries, high risks of supplies being cut off, and potential for tighter supply and demand balances in the future. In addition, from medium and long-term perspectives in consideration of the specific properties of individual ores, we plan to increase robustness throughout strategic supply chains using a comprehensive approach that leverages Japan's strengths to, for example, obtain upstream and midstream interests, effectively utilize low-quality ore (advanced separation and refining technology), build stockpiles, recycle, develop alternatives and reduce resource requirements, and develop domestic resources.

(2) Concrete initiatives

1) Build more robust supply chains

- ✓ Quantitatively identify and categorize risks in light of the distribution of resources, country risks, demand forecasts and other perspectives as well as the specific properties of different kinds of ore. Simultaneously, develop and organize countermeasures such as priority policy tools, and implement policies to secure strategic resources by, for example, diversifying supply sources.

[METI]

- ✓ Support the enhancement of the social infrastructure environment (standardization strategies and, studies of deregulation and the use of special zone system as needed) by, for example, providing support for the development and installation of technologies that will lead to more robust supply chains, focusing on rare metals and other resources that are essential to carbon neutrality

[MEXT] [METI]

- ✓ Diversify supply sources by developing technology for the effective use of low-quality ore and unused resources

[METI]

- ✓ For rare-earth rich mud, establish and demonstrate technology for deep-sea resource surveys and collections at depths of 2,000 m or deeper

[CO]

- ✓ For seafloor hydrothermal deposits, cobalt-rich crust and manganese nodules, implement initiatives for commercialization by, for example, establishing technologies to estimate the amount of resources and produce resources

[METI]

2) Develop technologies for alternative materials, reducing use of resources, and recycling

- ✓ Develop and implement recycling technologies and streamline social infrastructure environments to maximize domestic recycling of common and rare metals

[METI] [MoE]

- ✓ By the end of FY2021, identify and organize the challenges to maximize the effective and efficient utilization of the materials in lithium ion batteries (LIB), and by the latter half of the 2020s, achieve social implementation of LIB recycling by developing recycling technologies and streamlining environments etc.

[METI] [MoE]

- ✓ Implement research and development for the use of widely available elements to substitute for the unique functions of scarce elements

[MEXT]

- ✓ Develop and implement technologies and enhance the social infrastructure environment for recycling that will provide for stable supplies of nitrogen, helium, fluorine, phosphorus and other resources

[METI]

[Target]	Strategic international cooperation
KPI:	Secure and maintain the global shares of major advanced materials produced by Japanese companies in materials fields

(1) Policies to achieve targets

A strong, constant awareness of international cooperation and competition is necessary to the enhancement of materials innovation capacity. For example, innovation is created in the context of collaboration and competition among a wide range of actors, and the strengthening of the international brain circulation is an essential condition for active, vital research and development. On the other hand, there are also causes for concern from the competition among states for hegemony in technology and the international outflow of technologies. Japan will seek to promote the global exchange of "knowledge" as it strengthens research and innovation capacity.

(2) Concrete initiatives

1) Build strategic international networks

- ✓ Strategically promote initiatives to support international joint research by coordinating with overseas research funding institutions and build attractive research centers and encourage international exchange among students and researchers etc.

[CO] [MEXT] [METI]

- ✓ Encourage greater coordination and exchange with the international community in academic congresses by, for example, actively providing information and strengthening collaboration in international conferences on materials,[23] and improving international presence in materials-related professional societies[24]

[MEXT]

2) Strengthen functions for the collection and analysis of domestic and international information

- ✓ Strengthen the functions and coordination of the JST Center for Research and Development Strategy and NEDO Technology Strategy Center to improve strategic investment and science and technology intelligence in the area of materials

[MEXT] [METI]

3) Rigorously manage advanced technology

- ✓ Implement and strengthen management systems, including compliance with the Foreign Exchange and Foreign Trade Act and appropriate protection and use of intellectual properties, in universities and research institutes that handle research on innovative materials and other advanced technologies

[CO] [MEXT] [METI]

---

[23]E.g., the long-term collaboration between The Japan Society of Applied Physics and the US Materials Research Society (MRS)

[24]For example, the Japan MRS (The Materials Research Society of Japan) established the MRM (Materials Research Meeting) 2019 as a cross-disciplinary international conference

4) Strategic standardization

- ✓ Strengthen initiatives under the leadership of AIST and other organizations and in close coordination with a wide range of stakeholders to better address the needs for standardization in new industries that span multiple sectors (recycling of functional materials, marine biodegradable plastics etc.)

[METI]

Chapter 6: Strategy implementation structure

Ensuring the effectiveness and implementation of initiatives under this strategy will require investigations under the leadership of the "Council for Integrated Innovation Strategy" and with the collaboration and cooperation of relevant government agencies of all aspects, including research and development, taxation, fiscal policy, institutions and regulation. A structure is required to fully move this forward. The "Materials Strategy Experts Meeting" and "Materials Strategy Task Force" will continue to monitor domestic and international trends in a timely and appropriate manner and provide steady follow-up for this strategy.

Given the rapid changes taking place in materials, a member of priority themes will be set, and a forum established under the Experts Meeting where experts from government and industry and academia can engage in thoroughgoing discussions of tactics. The outcomes of those discussions will be reflected in the measures of relevant government agencies and in updates of this strategy and the action plan.

In light of the medium and long-term nature of this strategy, appropriate divisions of labor between government and the private sector and the voluntary participation of the private sector will be encouraged in follow-ups.

[Attachment 1]

Convention of the Experts Meeting to Promote Stronger Innovation Policy on "Materials Strategy"

October 20, 2020 Decision of the Chair of the Council for Integrated Innovation Strategy February 16, 2021 Partially amended

1. We will convene an Experts Meeting to Promote Stronger Innovation Policy on "Materials Strategy" (hereinafter "Meeting") pursuant to Paragraph 2 on the establishment of the "Experts Meeting to Promote Stronger Innovation Policy" (Council for Integrated Innovation Strategy decision of July 27, 2018).

2. Pursuant to Paragraph 2 and Paragraph 3, the chair and members of the meeting are as set forth in the Annex.

3. The meeting will be administered pursuant to Paragraph 4 through Paragraph 7.

(Annex)

Experts Meeting to Promote Stronger Innovation Policy: "Materials Strategy"

<Chair and members>

	Shuhei Onoyama	Vice President, Nippon Steel Corp.; Director, Technology Development Division
Chair	Michitaka Sawada	Chair, Kao Corp.
	Shizuo Sugawara	Managing Executive Officer, JX Nippon Mining & Metals Corp.
	Tsuyoshi Sekitani	Assistant President, Osaka University; professor, Institute of Scientific and Industrial Research (Sanken)
	Shoichi Nakagawa	General Manager, Devices Research and Development and Director of the Advanced Materials and Devices Research Center, Kyocera Corp.
	Kazuhito Hashimoto	President, National Institute for Materials Science
		Special Councilor to the President and professor, University of Tokyo
		Member, Council for Science, Technology and Innovation, Cabinet Office
		Director, Okinawa Institute of Science and Technology Graduate University
	Taro Hitosugi	Professor of applied chemistry, School of Materials and Chemical Technology and Vice President for Educational Activities, Tokyo Tech Academy for Convergence of Materials and Informatics, Tokyo Institute of Technology
	Norimitsu Murayama	Director and Chair of the Materials and Chemicals Division, National Institute of Advanced Industrial Science and Technology
	Hideyuki Yamagishi	Managing Executive Officer, Asahi Kasei Corp.; Director, Specialty Solutions Division

(Attachment 2)

Outline of investigations to prepare for the formulation of the Materials Innovation Strategy

2020	October 21	1st experts meeting
		・ Summary of key discussion points in materials strategy
		・ Major perspectives in strategy formulation
		(1) Materials informatics
		(2) Manufacturing process technology
	November 24	2nd experts meeting
		・ Major perspectives in strategy formulation
		(1) Circular economy
		(2) Resources
	December 18	3rd experts meeting
		・ Major perspectives in strategy formulation
		(1) Social implementation
		(2) Human resources development
		・ Preparations for finalization of materials strategy
2021	January 19	8th Council for Integrated Innovation Strategy
		・ Materials Innovation Strategy (interim report on main points of discussion)
	January 25	4th experts meeting
		・ Major perspectives in strategy formulation
		(1) International trends
		・ Preparations for finalization of materials strategy
	February 22	5th experts meeting
		・ Preparations for finalization of materials strategy
	March 19	Summation of Experts Meeting on "Draft Materials Innovation Strategy"