TECHNOLOGIES TO WATCH IN 2023

Mitsui & Co. Global Strategic Studies Institute
Technology Foresight Center, Technology & Innovation Studies Div.

INTRODUCTION

Each year, MGSSI's Technology Foresight Center identifies technologies that deserve particular attention, and provides a forward-looking overview of those technologies and insights. This year, we will look at (1) mycelium, (2) upcycling technology, (3) metamaterials, and (4) quantum communication.

(1) Mycelium is a root-like structure of fungi (e.g., mushrooms), and is expected to be used in various applications as an organic material that can be obtained inexpensively from the natural world. Mycoprotein, a type of mycelium obtained through fermentation of fungi, is already being commercialized in Europe and elsewhere as a meat alternative. Other areas of development include leather substitutes, packaging materials, and building materials.

(2) Upcycling refers to technologies that go beyond simple recycling to create higher value-added recycled products and materials from waste and unused resources. Research and development on such technology is underway in various areas as an effective driver of the circular economy and decarbonization, such as producing graphene material from waste plastic, protein from waste methane, and aviation fuel from waste wood.

(3) Metamaterials are artificial materials that have been given new physical properties that do not exist in the natural world by forming microstructures on the surface of the material. As discussed once in Technologies to Watch in 2016, advances in electromagnetic- and sound-wave-related simulation technology have led to the development of applications as solutions to increasingly important social issues such as decarbonization.

(4) Quantum communication is a technology that utilizes a quantum property to conduct communication, similar to a quantum computer that can derive complex computational solutions in a short period of time. Three researchers who demonstrated the theory of this intriguing quantum property, known as 'quantum entanglement,' were awarded the Nobel Prize in Physics for 2022. Although the current focus of attention is on the high level of security, the possibility of accelerating computation by connecting quantum computers via quantum communication is also expected, and competition over development is gathering pace in many countries.

In addition, this report analyzes international trends in intellectual property related to each of the four themes discussed.

TECHNOLOGIES TO WATCH IN 2023

(1) MYCELIUM — A WIDE VARIETY OF APPLICATIONS —

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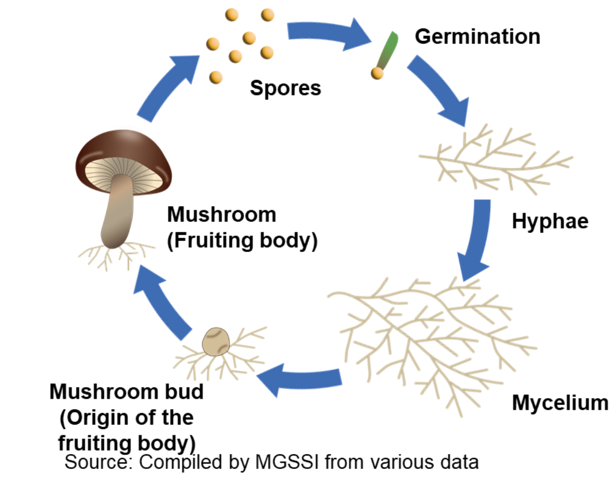
ABOUT MYCELIUM

Spores released from mushrooms germinate and become hyphae under the right conditions. Hyphae grow by taking in organic matter and other nutrients from their surroundings. Bundles of hyphae are called mycelium (Figure 1).

In recent years, mycelium has been considered for industrial mass cultivation and use in a wide variety of applications, including food, apparel, and packaging materials. With startups raising funds, companies are becoming more active in mycelium-based markets. The global market for mycelium is projected to grow at an average annual growth rate of 7.7%, from $2.48 billion in 2020 to $3.84 billion in 2026[1].

Figure 1: Life cycle of mushrooms



Source: Compiled by MGSSI from various data

The reason for the attention is that mycelium is biodegradable and fermentation technology is utilized in their cultivation. Being biodegradable means they can contribute to the circular economy, which has also been attracting attention in recent years, by being used as a plastic substitute. Fermentation is the transformation of a substance into something beneficial to humans through the activity of microorganisms (molds, yeasts, and bacteria), and has been used in the production of foods such as wine and sake. Another appealing aspect is that scaling up the industrially established fermentation technology in the new cases discussed in this report is considered relatively easy due to the accumulated technical knowledge.

PROMISING FIELDS OF APPLICATION

(1) MYCOPROTEIN

Mycoprotein is edible mycelium produced by fermentation using fungi. In recent years, plant protein foods have attracted attention from the perspectives of environmental impact of food, animal welfare, and other aspects of ethical consumption. On the other hand, many additives are required to make them taste more like real meat. Mycoprotein is attracting attention for the development of products that can meet the need for natural foods with as few additives as possible.

Mycelium is chewier than soybeans and other common plant protein materials because of their intertwined fibers, making them more meat-like in texture. Furthermore, the *umami* components of mushrooms are expected to contribute to improving the flavor of plant protein foods.

[1] Mycelium Market - A Global and Regional Analysis（https://bisresearch.com/industry-report/mycelium-market.html）

The best known food product that uses mycoprotein is that of Quorn Foods (UK), which began marketing it in 1985 and now has an annual production capacity of approximately 40,000 tons. The company's product shown in Figure 2 has a texture similar to fish sausage, and consumers say they can taste the *umami* flavor. The company has published the carbon footprint of its product, and its mycoprotein produces 0.79 kg CO_2e/kg compared to 32 kg CO_2e/kg[2] for beef and 11 kg CO_2e/kg for pork[3], making it an environmentally friendly protein as well.

Figure 2: Meatless Roast by Quorn Foods (left: exterior, right: contents)

Source: Photograph by MGSSI

Figure 3: MyBacon by MyForest Foods (left: exterior, right: contents)

Source: Photograph by MGSSI

The company's basic patent expired in 2010, and other companies are entering the market. One promising startup is MyForest Foods (US). The company has developed bacon made with mycoprotein (Figure 3), which it promotes as having few additives. For example, six ingredients are listed: mycelium, salt, coconut oil, sugar, natural flavors, and beet concentrate, suggesting that the company is targeting health-conscious consumers. In 2021, Mycorena (Sweden) succeeded in developing a fat that resembles animal fat using fungi[4], and there is a high possibility that it can be developed into materials other than protein. The Fungi Protein Association was established in November 2022 centered on startups such as Quorn Foods and Mycorena, as well as ProVeg International and the Good Food Institute—NPOs that promote alternative proteins. It is conducting consumer surveys, etc. on mycoprotein. In this way, companies are becoming more active overseas, and future trends will garner attention. In Japan, Associate Professor Daisuke Hagiwara of Tsukuba University is conducting research and development of mycoprotein using koji mold, a fungus native to Japan[5]. Koji mold is used in Japan to brew miso and soy sauce, and hopefully new foods made with traditional koji mold will be produced in Japan.

(2) LEATHER SUBSTITUTES

Issues surrounding leather production include the generation of greenhouse gases from livestock rearing, the use of chemicals that can negatively impact the environment during the tanning and finishing processes, and worker safety. One means of solving these issues is the use of leather substitutes created using mycelium.

Mycelium is cultivated under controlled conditions of temperature and nutrients necessary for growth, then compressed into mats, which are then processed like actual leather. Bolt Threads (US) has developed a leather substitute called Mylo from mycelium. The mycelium used for Mylo is produced in a vertical farming facility that runs on renewable energy and is harvested in just two weeks[6]. In order to scale production, the company has formed a partnership with Mycelium Materials Europe (Netherlands). The final product is used by companies such as Adidas, Lululemon, and Tsuchiya Kaban (Figure 4).

Figure 4: Tsuchiya Kaban products that use the leather substitute Mylo

Source: Tsuchiya Kaban (https://tsuchiya-kaban.jp/products/mylo-l-zip-purse) (accessed December 19, 2022)

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[2] Kg CO_2e/kg is a unit of measurement indicating the amount of greenhouse gases emitted to produce 1 kg of final product. Since there are several types of greenhouse gases, carbon dioxide is used as the standard value.
[3] Quorn Footprint Comparison Report 2022（https://www.quorn.co.uk/assets/files/content/Carbon-Trust-Comparison-Report-2022.pdf）
[4] https://mycorena.com/mycotalks/mycorena-cracking-the-code-of-the-worlds-first-fungi-based-fat-ingredient
[5] https://www.life.tsukuba.ac.jp/laboratory/lab_hagiwara_20220215/
[6] https://www.mylo-unleather.com/

Mycelium can also be made into materials with a variety of textures by changing growth conditions. MycoWorks (US) is developing a material called Reishi, which uses corn husks and other agricultural waste to culture mycelium. The Fine Mycelium technology used by the company in the development of the material makes it possible to control the direction of hyphae growth according to the growing conditions, achieving strength and durability comparable to cowhide[7]. MycoWorks announced partnerships with luxury brand Hermès in 2021 and with GM Ventures in October 2022. The company's materials are expected to be considered for a wide range of products from bags to automobile interiors.

(3) OTHER (PACKAGING/CONSTRUCTION MATERIALS)

Mycelium is composed of intertwined fibers, and a porous structure can be created by controlling the degree of entanglement of the fibers. Mycelium contains a large amount of air, making them lightweight and giving them excellent impact resistance, sound absorption, and heat insulation properties. They are expected to play a role as packaging and construction materials.

Ecovative Design (US) offers a packaging material made of mycelium as an alternative to expanded polystyrene and other materials (Figure 5, left). The company has developed a technology called AirMycelium, which uses a fermentation method called solid-state fermentation to cultivate mycelium in trays (Figure 5, right) and produce the product in vertical stacks. Production capacity is estimated to be 40,000 tons per year. Ecovative Design promotes mycelial packaging materials through licensing to other companies. Furthermore, it is interesting to note that the company's technology has a wide range of applications. Ecovative Design is also using the same technology to develop a leather substitute called Forager, as well as in the development of mycoprotein. The above-mentioned MyForest Foods is a spin-out of the company.

Figure 5: Mycelium-based package developed by Ecovative Design (left) and mycelium cultured by AirMycelium technology (right)

Source: Ecovative Design (https://www.ecovative.com/pages/packaging, https://www.ecovative.com/pages/airmycelium) (accessed December 20, 2022)

Mogu (Italy) sells sound-absorbing acoustic panels made of mycelium cultured from agricultural waste that no longer has any other use (Figure 6). Due to its excellent sound absorption in the mid-range (250 Hz to 1,000 Hz), which overlaps the range of the human voice, it is intended for use in places such as restaurants and large offices. Mycelium is slow to combust, making it flame retardant[8], which is also an advantage for such an application.

Figure 7 presents the fields in which mycelium is utilized, including those mentioned above, their overviews, and examples of companies that have entered these fields.

Figure 6: Sound absorbing acoustic panels sold by Mogu

Source: Mogu (https://mogu.bio/acoustic-collection/acoustic-palette/) (accessed December 19, 2022)

[7] https://www.madewithreishi.com/stories/performance-results-q120
[8] https://mogu.bio/acoustic-catalogue-2022/

Figure 7: Overview of fields where mycelia are utilized and examples of companies entering the market

Field	Overview	Companies
Mycoproteins	● Edible protein derived from mycelia. ● High in protein and similar texture to real meat due to the intertwining of mycelial fibers.	MyForest Foods (US), Quorn Foods (UK), MycoTechnology (US), Mushlabs (Germany), ENOUGH (UK), Nature's Fynd (US), The Better Meat Co. (US), Meati Foods (US), The Protein Brewery (Netherlands), Mycorena (Sweden), Prime Roots (US), Kinoko-Tech (Israel), Innomy (Spain), Sincarne (US), Eternal (Mexico)
Leather substitutes	● Obtained by pressing grown mycelia and processing them into mats. ● Texture can be adjusted by controlling growing conditions.	Bolt Threads (US), MycoWorks (US), Mogu (Italy), Ecovative Design (US)
Other (packaging/construction materials)	● Used as biodegradable packaging material as a substitute for plastic. ● Since the fibers are intertwined and contain a lot of air, it is used as sound-absorbing and heat-insulating materials.	Ecovative Design (US), Biohm (UK), Mogu (Italy), Embelium (France), Magical Mushroom Company (UK), Mycrobez (Switzerland)

Source: Compiled by MGSSI from various data

FUTURE PROSPECTS

Future prospects include the following. Mycoprotein could be used to improve the flavor of plant protein foods by taking advantage of the *umami* and texture of the material itself. In addition, with the rapid progress in gene editing and other technologies in recent years, the development of fungi themselves using such technologies is expected to advance. The challenge is to establish a supply chain that can collect agricultural waste used as raw materials in a stable and inexpensive manner.

(1) IMPROVEMENT OF PLANT PROTEIN FOOD FLAVOR

In the food sector, the market for mycoprotein may grow significantly as the plant protein food market expands. Plant protein foods are considered to require further improvements in flavor and texture in the future. While additives are used for this purpose, health-conscious consumers want to reduce their consumption of such. The use of mycelium would be a promising means to achieve this.

(2) DEVELOPMENT OF NEW FUNGI

Currently, the focus is on the use of mycelium, which have a proven track record, but in the future, new technologies such as gene editing will be used to develop fungi with the required functions. This is expected to shorten the growth period of mycelium and significantly improve their nutritional composition and flavor, which will lead to more active introduction into applications such as those described in this report. Mycelium-derived leather, which has currently been introduced in high-end products, will be rolled out to more general products, and further development in the area of mycoprotein will see the creation of products that are cheaper and more acceptable to consumers in terms of flavor and other factors.

(3) THE TASK OF SUPPLY CHAIN ESTABLISHMENT

The ability to use agricultural waste and other forms of biomass to cultivate mycelium and the fact that the material is biodegradable are attractive from a circular economy perspective. However, as social implementation progresses and the scale of production expands, there will be a need to collect agricultural waste in a stable and low-cost manner. The establishment of such a supply chain is expected to be a future task.

See here for the IP Report

TECHNOLOGIES TO WATCH IN 2023

(2) UPCYCLING TECHNOLOGY — ADDING VALUE TO WASTE TO REALIZE A RECYCLING-ORIENTED SOCIETY —

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ABOUT UPCYCLING TECHNOLOGY

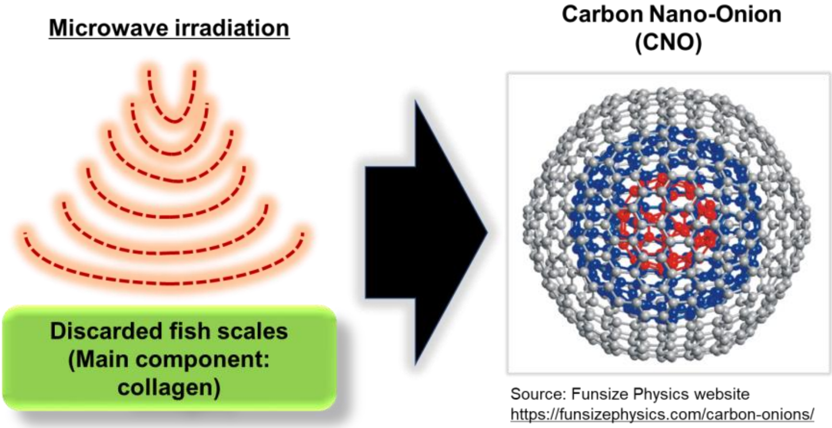
Upcycling technology creates high value-added recycled products and materials from waste or unused resources. Traditionally, efforts to achieve a recycling-oriented society have involved the 3Rs: (1) recycle, (2) reuse, and (3) reduce. (1) Recycle means to extract usable materials from waste for use elsewhere, (2) reuse means to use products repeatedly instead of disposing of them as waste, and (3) reduce means to avoid producing waste in the first place. Various 3R initiatives have been rolled out by companies and local communities, and related technologies have also been developed. Upcycling is also a technology that considers waste as something to be reused and aims to incorporate it into new and different areas for material circulation. This report presents simple upcycling technologies that do not require complex reprocessing.

PROMISING FIELDS OF APPLICATION

(1) UPCYCLING FISH SCALES (COLLAGEN) INTO NANOCARBON MATERIALS

The first technology is the case of upcycling from discarded fish scales to carbon nano-onions (CNOs), a type of carbon nanomaterial (CNM). CNM is an extremely fine material composed of carbon atoms. A rapid temperature rise and pyrolytic reaction (microwave pyrolysis) caused by microwave irradiation of the main component collagen is used to convert scales into CNOs. Although the principle has not been elucidated in detail at this time, it is possible to convert the scales simply by irradiating with microwaves in the same way as cooking in a microwave oven[9] (Figure 1). Existing production methods require long reaction times in high-temperature vacuum environments and the use of chemical solvents for post-treatment, which pose the issue of a high environmental impact. The ability to convert into CNOs by microwave irradiation alone is expected to promote its use in industry in the future.

Figure 1: Upcycling fish scales into nanocarbon materials



Source: Compiled by MGSSI

Source: Funsize Physics website
https://funsizephysics.com/carbon-onions/

[9] The Nagoya Institute of Technology research paper on the synthesis of carbon nano-onions and elucidation of the formation mechanism https://pubs.rsc.org/en/content/articlelanding/2022/gc/d1gc04785j has been selected for the back cover and cover profile of the Royal Society of Chemistry's Green Chemistry journal (Impact Factor: 10.182).

CNMs are classified into four categories according to their form. Graphene is a sheet-like material, carbon nanotubes are cylindrical, fullerenes are spherical, and CNOs are concentric multi-layered fullerenes (Figure 2). CNOs are expected to be used as blue light-emitting thin films for LEDs and next-generation solid-state light sources[10], as well as additives for lubricants (engine oil, machining oil, etc.), grease, and resin materials due to their form characteristics.

Figure 2: Types of carbon nanomaterials

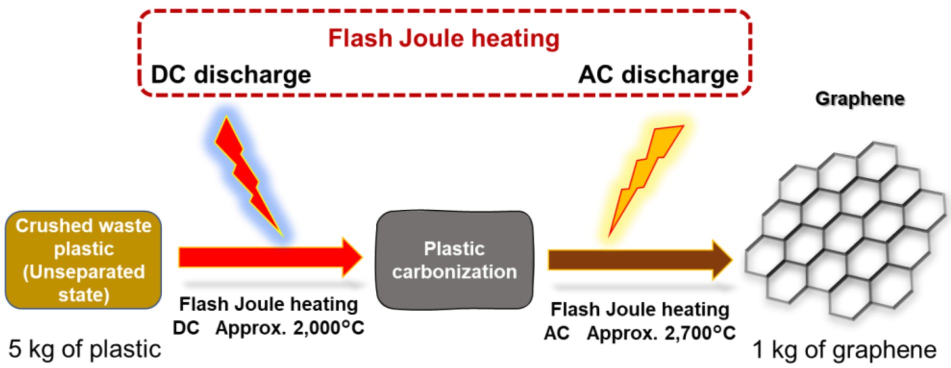
Type	Characteristics
Graphene	Hexagonal carbon atoms bonded in sheets
Carbon Nanotube	Cylindrical form. Cylinders can be single-layered or multi-layered.
Fullerene	Hexagonal carbon atoms joined into a sphere (soccer ball shape)
Carbon Nano-Onion	Fullerenes nested in multiple layers

Source: Compiled by MGSSI from various information

(2) UPCYCLING WASTE PLASTIC INTO GRAPHENE

The second technology is an example of upcycling waste plastic into graphene by direct discharge[11]. The conversion of waste plastic into graphene is carried out by a method called flash Joule heating (FJH). As shown in Figure 3, waste plastic lumps can be converted into highly pure graphene by heating and carbonizing them by electrical discharges (DC and AC discharges). In fact, experiments have been conducted in which plastic materials (vinyl chloride, polyurethane, etc.) such as pickup truck bumpers, carpets, and mats are washed and crushed in a mixed state without any particular separation, and converted directly into graphene by FJH, with good results.

Figure 3: Upcycling waste plastic into graphene



Source: Compiled by MGSSI based on various data

Graphene produced by FJH is highly pure, and since this method does not require an environmentally-damaging purification process (the only process required is the FJH discharge process), the life cycle cost is about one-tenth that of existing production methods. From 5 kg of waste plastic, 1 kg of graphene is obtained. Applications include battery materials, antibacterial materials, and filtration materials.

(3) CONVERSION OF WASTE METHANE INTO PROTEIN

The third technology is the upcycling of waste methane from wastewater treatment facilities, refuse landfills, and oil and gas facilities into protein with the help of microorganisms. Calysta (US), String Bio (India), and JGC Holdings (Japan) are already working toward commercialization. Methane-utilizing bacteria are used as the

[10] The absolute photoluminescence quantum yield (a measure of how efficiently absorbed (light) energy can be emitted as light), considered important in the evaluation of luminescent materials, is 40%, 10 times higher than that of CNOs produced by conventional methods and the highest performance in the world.

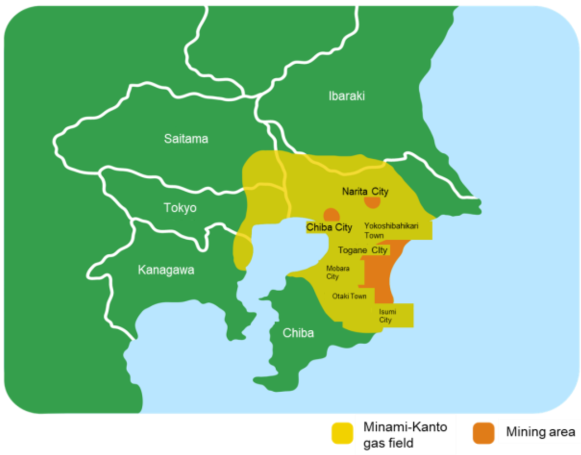
[11] Kevin M. Wyss et al., "Upcycling end-of-life vehicle waste plastic into flash graphene", communications engineering, Nature, May 26, 2022 https://www.nature.com/articles/s44172-022-00006-7

microorganisms in the production of protein from this waste methane. Proteins produced by methane-utilizing bacteria contain essential amino acids such as methionine, which has detoxification and antitumor effects, and are therefore expected to be used in livestock feed, especially aquaculture feed[12], which faces challenges in securing fishmeal for feed.

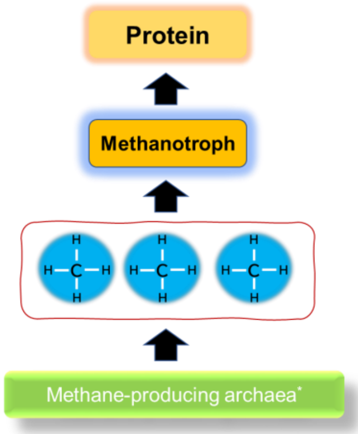
According to the scientific journal Nature Sustainability, there are approximately 9,700 sources of industrial methane emissions (power plants, wastewater treatment plants, landfills, oil and gas facilities, etc.) in the US, with a daily waste methane volume of approximately 67,400 tons[13]. For each emission source, the costs of producing protein from this discarded methane were estimated to be (1) power plants: $1,783/ton, (2) wastewater treatment plants: $1,645/ton, (3) landfills: $1,546/ton, (4) oil and gas facilities: $1,531/ton. This analysis shows that protein produced from waste methane originating from oil and gas facilities is cheaper than the price of fishmeal, and could be an alternative to fishmeal and other animal proteins that make up a large portion of aquaculture feed ingredients.

Since Japan has the Minami-Kanto gas field[14], which produces methane dissolved in water (Figure 4), the country is expected to make efforts with a view to utilizing this domestic resource.

Figure 4: Methane resources in the Minami-Kanto gas field



Map source: Godo Shigen
https://www.godoshigen.co.jp/learn/gas/kanto/



*New bacterial species *Atribacter laminatus* RT761 strain (prokaryotic bacteria with DNA intracellular membrane)

Source: Godo Shigen, based on AIST data
Compiled by MGSSI

(4) CHALLENGES IN UPCYCLING AND RECYCLING

Upcycling and recycling involve efforts to reuse residues and other waste generated in the treatment process when upcycling, and to recycle as much as possible. In this section, we introduce two case studies that demonstrate the potential of upcycling and recycling: (1) the conversion of lignin contained in waste wood into a raw material for aviation fuel using a catalytic (molybdenum carbide catalyst) reaction, and (2) the production of ultra-hard lumber by treating waste wood with a chemical solution and compaction process[15].

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[12] The percentage of fishmeal in aquaculture feeds has declined over the past two decades due to declining aquatic resources and other factors. The average percentage of fishmeal in feed in 1995 was 10% for carp, 45% for salmon, and 50% for marine fish. In 2017, this decreased to 1% for carp, 12% for salmon, and 14% for marine fish. Therefore, an alternative aquaculture feed to fishmeal is required. https://www.nature.com/articles/s41893-021-00796-2

[13] The Global Methane Pledge, an international framework aimed at reducing methane gas, which has more than 25 times the greenhouse effect of carbon dioxide, was launched at COP26 with the goal of reducing global methane emissions by 30% from 2020 levels in 2030.

[14] The Minami-Kanto gas field is Japan's largest field of natural gas dissolved in water, with available reserves of 368.5 billion m^3. It is also one of the world's largest iodine deposits. The natural gas produced is also characterized by its high methane concentration, with more than 99% of the gas produced being methane. Kanto Natural Gas Development Co., Ltd., which is developing this gas field, has approximately 100 billion m^3 of natural gas reserves in the field. This is equivalent to about 600 years of current annual production.

[15] Jianwei Song et al. "Processing bulk natural wood into a high-performance structural material", Nature, volume 554, pp.224–228, February 8, 2018 https://www.nature.com/articles/nature25476

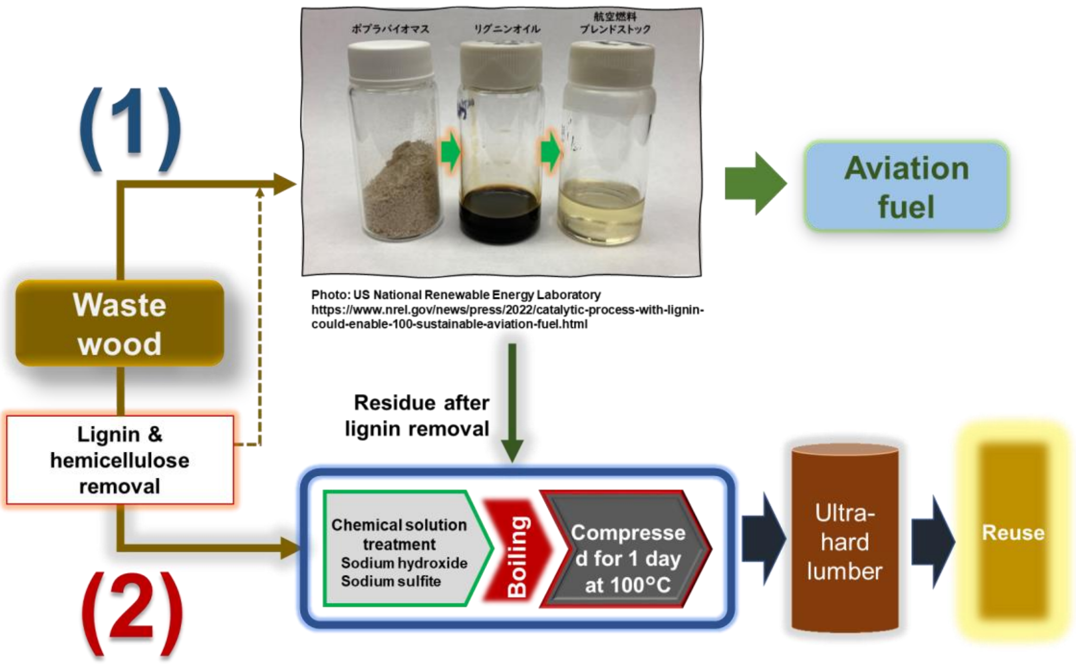
Wood is composed primarily of three elements: cellulose, hemicellulose, and lignin. A huge amount of waste wood is generated every year in the world, and effective utilization of this waste wood is necessary to achieve a recycling-oriented society.

(1) Lignin serves as the reinforcement that supports the plant structure and is an extremely hard biological substance, making it one of the most difficult substances to break down by chemical reaction. However, according to the US National Renewable Energy Laboratory, lignin can be converted into a feedstock for aviation fuel without the use of expensive catalysts[16]. The aviation industry consumes 106 billion gallons of jet fuel annually (2019) and is turning its attention to Sustainable Aviation Fuel (SAF), which is environmentally friendly. Japanese airlines have also set a goal of switching 10% of their existing aviation fuel to SAF by 2030. This form of upcycling and recycling has great social significance, as it may open up new avenues for the utilization of wood from Japanese forest thinnings and other resources[17].

(2) Wood from which lignin and hemicellulose have been removed is soaked in a chemical solution (sodium hydroxide (NaOH) and sodium sulfite (Na2SO3)), boiled for 7 hours, and then compressed at 100°C for a further 24 hours to one-fifth its original size, increasing its strength by 11.5 times. It has also been confirmed that simply press-compressing wood after boiling increases its strength by a factor of three. Upcycling/recycling waste wood into ultra-hard lumber in this way will enable higher wooden buildings and improve the earthquake resistance of detached houses. As such, this material is expected to be utilized in the construction field.

As shown in Figure 5, if the residues from the process of upcycling lignin into aviation fuel can be reused as an auxiliary material for upcycling into ultra-hard lumber, waste can be minimized. After ultra-hard lumber finishes use as a building material, it is returned to nature in a form that does not adversely affect the global environment. In the future, various industrial sectors will take up the challenge of upcycling/recycling along with 3R activities, with the aim of balancing economic activities with global environmental conservation.

Figure 5: Example of upcycling/recycling waste wood



Source: Compiled by MGSSI based on various data

[16] NREL, "Catalytic Process with Lignin Could Enable 100% Sustainable Aviation Fuel" Sept. 22, 2022
https://www.nrel.gov/news/press/2022/catalytic-process-with-lignin-could-enable-100-sustainable-aviation-fuel.html

[17] Lignin upcycling studies are underway, including enzymatic conversion to bioplastics based on phenylpropanone compounds*1 and direct conversion of lignin to diester plastic precursors by reacting lignin with glyoxylate*2.

*1 : https://www.jst.go.jp/pr/announce/20161220-2/index.html

*2 : https://actu.epfl.ch/news/new-pet-like-plastic-made-directly-from-waste-biom/

FUTURE PROSPECTS

The technologies to watch introduced in this report are mainly those that upcycle waste in simple ways. Upcycling technologies will continue to be developed around international commodities that generate large amounts of waste (e.g., waste tires, coffee, palm oil and fats, batteries, solar panels), and social experiments will be conducted to test their effectiveness and economic viability. Japan has announced the Circular Economy Vision 2020[18], which calls for a shift from a linear economy based on mass production, mass consumption, and mass disposal to a circular economy, and efforts toward a recycling-oriented society are gaining momentum. However, with the exception of highly valuable metals, the present business environment makes it difficult to secure profits from recycled products. Therefore, research and development of upcycling technologies that add value to waste materials and rapid social implementation are the issues moving forward.

Other points of note include the issue of municipal waste (household refuse collected by municipalities, food waste, cardboard, large-size refuse, etc.). According to the OECD, Japan produces 336 kg (as of 2019)[19] of general waste per capita per year, which is almost never recycled and is incinerated immediately after collection. This municipal waste issue is common worldwide, and the US has launched initiatives to solve it, such as the BOTTLE Project[20], which directly upcycles collected mixed plastics without requiring each household to sort its refuse. In addition, efforts are underway to use municipal waste and other materials as raw materials for the aforementioned production of SAF (Figure 6).

If awareness of the importance of upcycling from an ESG perspective, including not only industrial waste but also municipal waste, spreads in the future, investment into research and development of this technology will be actively pursued, and the world will take a step toward the realization of a recycling-oriented society.

Figure 6: Initiatives and studies of Sustainable Aviation Fuel (SAF) production from waste materials in the US

Classification	Waste utilized	Overview
Raw material procurement (survey)	Forest residues, algae utilization	South Carolina conducting survey on bioenergy production based on woody biomass and algae with funding from the US Department of Agriculture (Rural Business Enterprise Grant)
Raw material procurement (survey on transition to civilian initiative)	Municipal and agricultural waste	The State of Hawaii is evaluating fuel feedstock procurement and fuel production using food residues and other cellulosic municipal wastes, agricultural residues, and woody wastes. It is conducting a study on the feasibility of transitioning from a military to a civilian initiative.
Raw material procurement (Model construction)	Waste cooking oil made in Japan	JGC, REVO International, and Cosmo Oil are building a supply chain model for bio-jet fuel production from waste cooking oil.
SAF production	Waste starch	Archer Daniels Midland is producing isobutanol from waste starch from pulses for conversion to bio-jet fuel.
SAF production	Construction waste, forest vegetation	AVAPOCO is producing bio-jet fuel from construction waste, forest residues, etc.
SAF production	Food waste	The US National Renewable Energy Laboratory and quasar energy group are extracting volatile oils and fats from food waste to produce bio-jet fuel.

Source: Compiled by MGSSI based on various data

See here for the IP Report

18 METI, Circular Economy Vision 2020 https://www.meti.go.jp/press/2020/05/20200522004/20200522004-2.pdf
19 OECD, Municipal waste https://data.oecd.org/chart/6b1W
20 NREL, BOTTLE Project Outlines New Strategy for Valorization of Mixed Plastic Waste, Oct 13, 2022 https://www.nrel.gov/news/press/2022/bottle-project-outlines-new-strategy-for-valorization-of-mixed-plastic-waste.html

TECHNOLOGIES TO WATCH IN 2023

(3) METAMATERIALS — MATERIALS DESIGN TECHNOLOGY THAT CONTRIBUTES TO A COMFORTABLE AND SUSTAINABLE SOCIETY —

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ABOUT METAMATERIALS

Consumer products that use metamaterials are beginning to appear on the market, such as sheets that can cool objects without the need for a power source and air conditioners that reduce the noise of airflow without compromising on humidification or ventilation performance. Metamaterials technology is also being developed to provide solutions to energy conservation and efficiency issues, and contribute to a sustainable society. This section first gives the definition and explains the principles of metamaterials.

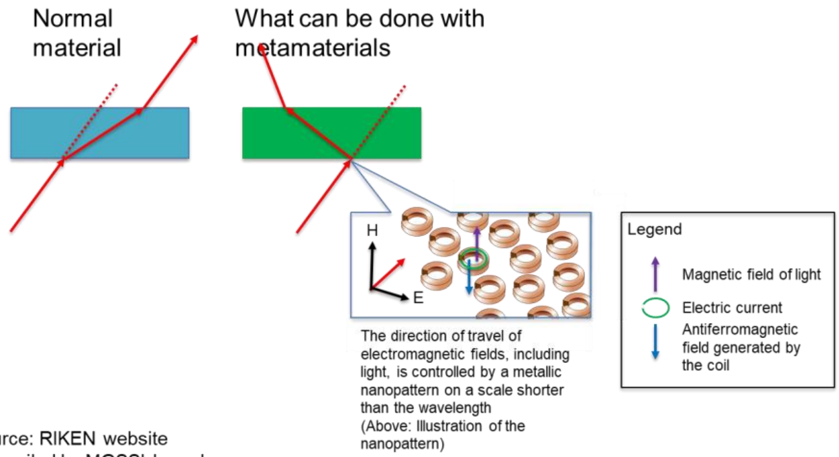
(1) DEFINITION OF METAMATERIALS

Metamaterials are defined as artificial materials that exhibit physical properties different from those inherent in the material by means of structures that are smaller than the wavelength of the phenomena they influence. By optimally designing and creating the microstructure of materials, it is becoming possible to change the behavior of heat, light, sound, and other waves into states that do not exist in the natural world.

(2) PRINCIPLES OF METAMATERIALS

Here we illustrate the principles using a metamaterial that redirects light (see Figure 1).

Figure 1: Principles of metamaterials (illustration)



Source: RIKEN website
(Compiled by MGSSI based on
(https://www.riken.jp/medialibrary/riken/pr/press/2006/20060113_1/20060113_1.pdf)

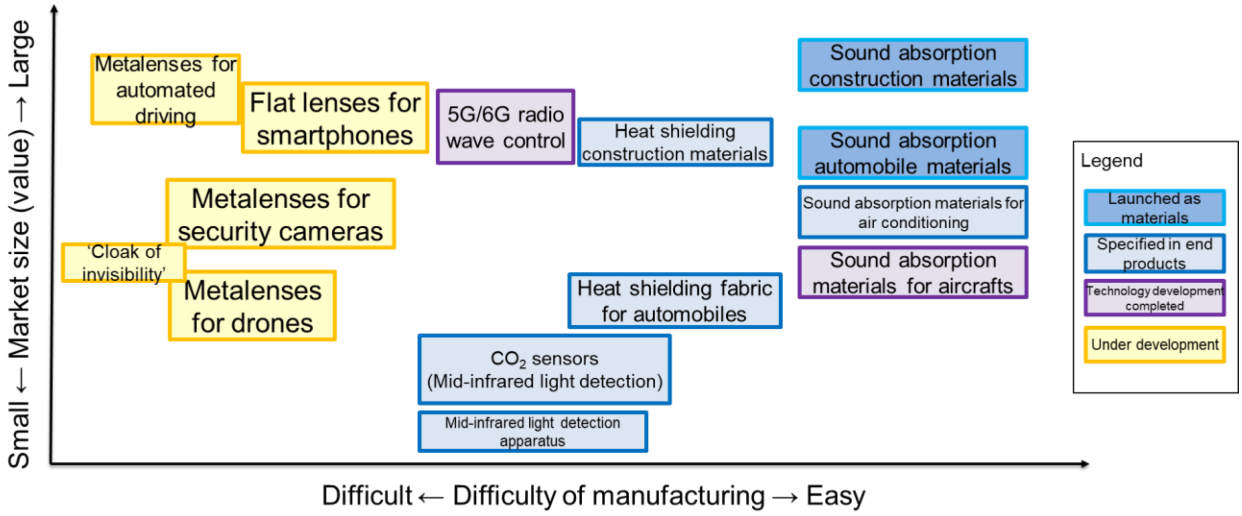
The refractive index of naturally occurring transparent objects is always positive, and the direction in which light entering from outside the material is bent is determined by the value of the refractive index. In contrast, in a metamaterial, a microstructure is formed on the surface of an object such that when light tries to pass through it, the light interacts with the structure and generates an electric current and a magnetic field. This interaction makes the light bent in a direction that could not be realized with a natural object unless it had a negative refractive index, which is not possible.

The behavior of electromagnetic waves, including visible and infrared light, can be expressed by the wave equation derived from Maxwell's equations, and the behavior of sound can be expressed by equations for sound waves. In the design of metamaterials, the shape and physical properties required for the microstructure are determined by solving these equations.

PROMISING FIELDS OF APPLICATION

Figure 2 shows a technology map for metamaterials. The difficulty of fabrication on the horizontal axis was estimated from the combination of the size of the microstructure, determined by the wavelength of the wave to be controlled, and the precision required for placement of the microstructure. Applications placed to the right are easier to mass-produce. The vertical axis represents the size of the market as currently envisioned. The higher the application is placed, the larger the market when the product is applied. Next, we introduce two applications that are already moving to mass production.

Figure 2: Metamaterials technology/market map



Source: Compiled by MGSSI from various data

(1) RADIATIVE COOLING METAMATERIALS (HEAT SHIELDING FABRICS/MATERIALS)

Temperature rise due to direct sunlight is an issue for transportation trucks and data center buildings. Covering these entirely with heat shielding fabrics or materials that use radiative cooling metamaterials is expected to improve the heat environment and reduce energy consumption for air conditioning. By adjusting the material composition and microstructure of the sheet surface, radiative cooling metamaterials convert the wavelength of infrared radiation emitted from objects to an atmospheric window of 8-13 μm, a wavelength that can pass into space without absorption by the air. This is called 'daytime radiative cooling' because objects covered by the sheet continue to undergo radiative cooling as they do at night in winter, even under the scorching sun. This phenomenon was discovered by a research team at Stanford University[21].

With radiative cooling metamaterials, the main focus is on converting the wavelength of infrared radiation, and there is no need to align the direction of travel of the infrared radiation. Therefore, although the structure is nanoscale, it is relatively easy to manufacture large areas by a coating process because alignment is not required. Nissan Motor and Radi-Cool Japan jointly developed sunshades, half-body covers, and other products to suppress the temperature rise inside vehicles, and launched them as genuine accessories in November 2021[22] (Figure 3).

[21] https://patents.google.com/patent/US20140131023A1/en
[22] Nissan Motor Co., Ltd., newsroom
https://global.nissannews.com/ja-JP/releases/211102-02-j

Figure 3: Sunshade (left) and half-body cover (right) using radiative cooling metamaterials

Source: Provided by Nissan Motor

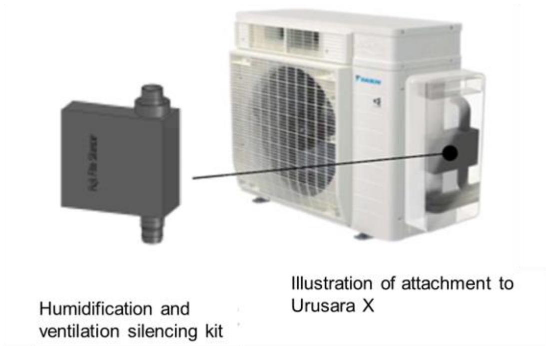
Source: Nissan Motor newsroom (https://global.nissannews.com/ja-JP/releases/211102-02-j) (Accessed December 13, 2022)

In addition, SPACECOOL, a company spun-out from Osaka Gas, conducted a three-month demonstration test on radiative cooling metamaterials from July to September 2022 in a joint project with ENEOS Holdings. Specifically, radiative cooling metamaterial film was applied to the roof and the exterior walls on all sides of a high-voltage substation (with internal air conditioning) installed outside at the ENEOS Sakai Refinery, in order to demonstrate its effectiveness in reducing air conditioning power consumption.

(2) ACOUSTIC METAMATERIALS (SOUND ABSORPTION MATERIALS)

Acoustic metamaterials are materials that enable wide-band sound absorption by creating a microstructure on the surface of soundproofing materials. Daikin Industries has adopted an acoustic metamaterial developed by Fujifilm as a ventilation soundproofing material for its humidification and ventilation silencing kit that can be installed in some of its air conditioners[23] (Figure 4). In the past, improved quietness was achieved by developing high-performance ventilation fans, but increasing the airflow required for ventilation increased the noise generated by the fan remained as the trade-off. Therefore, the focus of the design was expanded from the fan to the ventilation path, and the use of acoustic metamaterials for soundproofing made it possible to achieve both wide-band sound absorption and ventilation capacity.

Figure 4: Example of sound insulation metamaterial installed on an air conditioner



Source: Daikin Industries press release (https://www.daikin.co.jp/press/2022/20220118) (Accessed December 8, 2022)

In addition, acoustic metamaterials are being considered for use in absorbing road noise caused by friction between the road and tires. The main source of cabin noise used to be engine noise, but with the shift to EVs, the focus has moved to road noise. Since road noise does not consist of sound waves of a single wavelength like mechanical noise, but of various wavelengths depending on road surface conditions, the microstructure design is considered to be more difficult than that of sound absorption material for air conditioning. However, it is theoretically possible to achieve higher sound absorption performance with less weight than conventional sound absorption materials, and acoustic metamaterials are expected to be a technology that can achieve both quietness in the cabin and weight reduction of the car body.

[23] Daikin Industries press release
https://www.daikin.co.jp/press/2022/20220118

FUTURE PROSPECTS

Here we introduce two technologies that have been rapidly researched in recent years and are expected to be implemented in society in the near future. We also discuss the possibility that the use of AI, which is advancing in the field of materials development, will spread to the design of metamaterials.

(1) METALENSES/FLAT LENSES

A metalens is a lens made of metamaterials. Smartphones, automobiles, and drones are equipped with four to five concave lenses and convex lenses, but there are increasing hopes for replacing them with a single metalens. Metalenses are also called flat lenses because the design of the camera portion of the smartphone can be flattened by replacing conventional lenses with a metalens.

Visible light has a shorter wavelength than sound and radio waves, making it more difficult to form and mass-produce microstructures for control. In addition to this, the wavelength of visible light ranges from approximately 360 nm (violet) to 830 nm (red), making it much more difficult to design a flat lens for use in a camera that requires control over the entire wavelength range than when dealing with a single wavelength. However, Metalenz[24], a startup from Harvard University, has successfully designed a lidar that measures the distance to a specific object using light with a single wavelength in the form of a metamaterial that can be used in smartphones and other devices, gathering attention from smartphone manufacturers around the world. The technology is expected to be implemented within a few years. Since weight is directly related to fuel consumption in automobiles and drones, there are high expectations for the weight reduction offered by changing the lenses used in distance-measuring sensors to metalenses.

(2) TELECOMMUNICATIONS FIELD (5G/6G RADIO WAVE CONTROL)

In the communications field, the use of high-frequency bands will expand from 5G onwards, but high-frequency radio waves have issues such as a short propagation distance and being easily absorbed by obstructions, which limits the range covered by a single base station and also limits the range of use within buildings. Metamaterials are also viewed as a promising means to solve these issues. Since the wavelength of radio waves is much longer than that of visible light, on the order of tens of micrometers, the required metamaterial microstructure size is comparable to that of copper wiring in electronic circuits. Therefore, it can be said that the basic technology for manufacturing metamaterials for 5G communications has already been established. AGC, in collaboration with NTT DOCOMO, has developed window glass that allows radio waves to pass efficiently from the outside[25]. Dai Nippon Printing has also developed a radio wave reflector that has the effect of expanding the reach of 5G radio waves[26]. Since the direction and angle of reflection varies depending on the reflector installation location, the microstructure of the metamaterial deployed also varies. Accordingly, ingenuity may be necessary on the manufacturing side, such as the construction of an on-demand manufacturing system, to secure mass production. Since 5G is still in the process of spreading, it is unclear whether 6G will be put into practical use in 2030 as expected. However, since 6G is expected to utilize even higher frequency bands than 5G and to have a shorter propagation distance, the importance of metamaterials technology to expand the reach of radio waves will increase.

(3) DESIGN SUPPORT BY AI

Designing metamaterials requires solving the wave equation, but the wave equation generally cannot be solved by manual calculation. For this reason, design and development have been conducted using computers, such as by creating in-house calculation programs or using analysis software. In order to implement metamaterials,

[24] https://capasso.seas.harvard.edu/
[25] AGC Inc. press release
https://www.agc.com/news/detail/1201960_2148.html
[26] Dai Nippon Printing Co., Ltd. press release
https://www.dnp.co.jp/news/detail/10161328_1587.html

it is important to perform optimization through product design, including the concoction of ideas on how to use waves, and matching the composition and structure of the metamaterial to the performance required of the product. Since AI is good at optimization, it is expected that the scope of design support by AI will gradually expand as more research and development is conducted and data is accumulated moving forward.

Traditionally, Japanese manufacturers have excelled at implementation to mass production and further refining conditions optimized in development and design. If the manufacturing industry adopts AI-based design assistance, the application of metamaterials in promising fields can be accelerated and more sophisticated.

See here for the IP Report

TECHNOLOGIES TO WATCH IN 2023

(4) QUANTUM COMMUNICATION — TOWARD THE REALIZATION OF THE QUANTUM INTERNET —

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The Nobel Prize in Physics 2022 was awarded to three researchers who demonstrated the existence of the intriguing phenomenon of quantum entanglement. Quantum communication makes use of this quantum phenomenon, and is expected to be used in areas where a high level of security is required due to its excellent security. In addition, it is envisioned to serve as a foundation to support a quantum Internet that connects quantum-related technologies. In Japan, not only research institutions including universities, but also some leading companies, such as Mercari, are working on the R&D, with the aim of commercializing this technology in the next 20 to 30 years. It is certainly a technology to watch in the coming years.

ABOUT QUANTUM COMMUNICATION

(1) THE DIFFERENCE BETWEEN QUANTUM AND CLASSICAL COMMUNICATIONS: QUANTUM BITS AND DIGITAL

The network we currently use is called a classical communications network. It is a digital communication network that sends and receives bits with a value of 0 or 1. Mobile communication via devices such as smartphones, satellite-based communication, and cable communication using devices such as optical fiber all fall into the category of classical communications. In contrast, quantum communication sends and receives qubits[27] rather than bits of 0 or 1, enabling end-to-end quantum communication on the network. Therefore, it is expected to function as a completely different communication system than what has existed so far. Quantum communication uses quantum entanglement, described in the next section, and verification of each elemental technology is currently in progress.

(2) QUANTUM PROPERTIES: QUANTUM SUPERPOSITION AND QUANTUM ENTANGLEMENT

A quantum is the smallest discrete unit of matter or energy. Specifically, this refers to atoms, electrons, photons (which are the smallest units of light), neutrinos (which are one of the smallest elementary particles that make up matter) and the like. A Quantum behaves in a manner that differs completely from the physical laws of the world we see, such as by having both properties of matter (particle nature) and waves (wave nature). Quantum communication utilizes interesting quantum phenomena that includes quantum superposition and quantum entanglement.

Quantum superposition is the property whereby a quantum can take two or more states simultaneously. Thus, whereas a conventional computer can take either a 0 or 1 state, a quantum computer using superposition can take on both 0 and 1 at the same time. The quantum state is also determined by the act of observation.

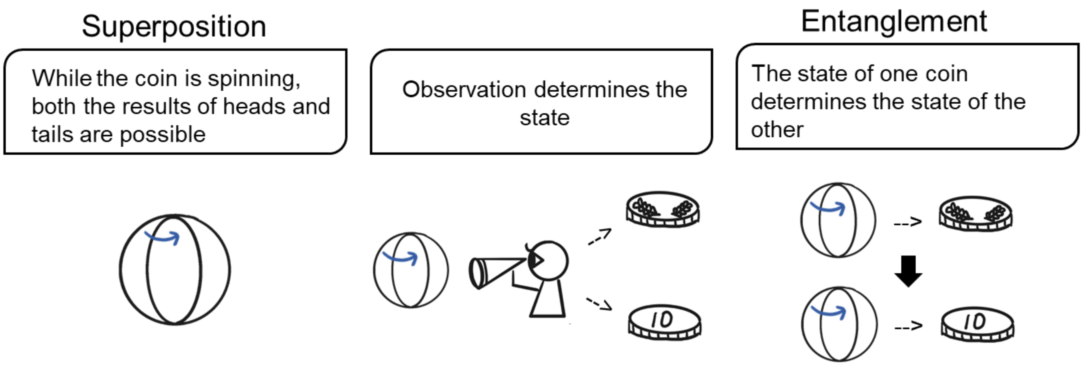
Quantum entanglement is a state in which multiple quanta are in a strong interrelationship, and when the state of one quantum changes, the state of entangled quanta also changes instantaneously. This relationship also

[27] The basic unit of calculation by a quantum computer. Both 0 and 1 states can exist at the same time as a result of quantum properties.

holds no matter how far apart they are (even from one end of the galaxy to the other, for example).

As an example, when you spin a coin, you do not know whether it will land face up or face down. In other words, both outcomes are possible. This is quantum superposition. Next, suppose two coins are spun. At this time, the moment one coin falls and the outcome is determined, the outcome for the other coin is also determined at the same time. This is quantum entanglement (Figure 1).

Figure 1: Quantum properties

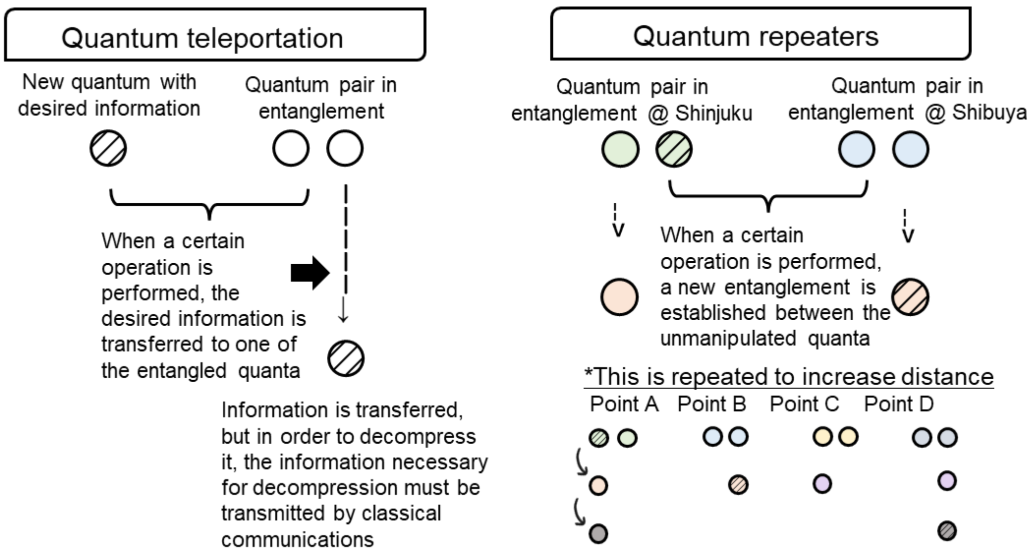


Source: Compiled by MGSSI

(3) QUANTUM COMMUNICATION USING QUANTUM ENTANGLEMENT: THE MECHANISM, TECHNOLOGY, AND CHALLENGES

With quantum entanglement, information about a coin in one's possession can be transmitted to a coin at a distance instantaneously, but the desired information cannot be transmitted by entanglement alone. This is because it is not known whether the state of the coin in one's possession was determined by one's own observation or by the observation of the other coin by another person. This is where the technique known as quantum teleportation comes in, whereby a certain operation is performed on a quantum pair in an entanglement and a quantum with the desired information to transfer the information. However, entanglements are very fragile, and it is difficult to maintain stable relationships between remote locations, therefore a little ingenuity is required. Currently, quantum repeaters based on quantum teleportation are a promising method of creating a quantum entanglement between remote locations. This is done by performing a certain operation on two quantum pairs in an entangled state to create a new entanglement, which is then repeated, and the distance is increased (Figure 2).

Figure 2: Quantum teleportation and quantum repeaters



Source: Compiled by MGSSI

Quantum communication can be achieved using only optical fibers from existing fiber optic facilities, excluding routers, etc. In addition, it is envisioned that photons will be utilized as the communication medium because their entanglement is less susceptible to deterioration than electrons, etc., and they can easily travel long distances, but the distance is still insufficient for practical use. There are two methods of relaying by photons: one is to relay by manipulation between quantum memories, and the other is to relay by manipulation between photons. The former can relay with 100% probability, while the latter cannot, but both have their advantages and disadvantages, and research is still ongoing. Communication over a distance of about 33 km with one repeater has been reported with the latter, but the distance is still not far enough.

Next, we introduce two of the most typical elemental technologies required for quantum repeaters. One is a quantum entanglement light source to put photons into an entangled state, and the other is a quantum memory to store quantum states. Especially for quantum memory, further improvements are needed to relay photon entanglement farther, such as long-time storage of quantum states, lower error probability, and higher probability of success of photon emission and extrication. To develop better memory, research on materials, such as materials with added diamond and rare earth element, and on all-optical repeater systems that do not require quantum memory is also underway.

Although not by quantum repeater but quantum entanglement distribution, a Chinese research team has reportedly succeeded in a ground-to-satellite distribution of more than 1,000 km using a satellite and laser light, and a distribution of about 100 m using a drone.

(4) CHARACTERISTICS OF QUANTUM COMMUNICATION: INCREASED SECURITY AND COMPUTATIONAL PROCESSING SPEED

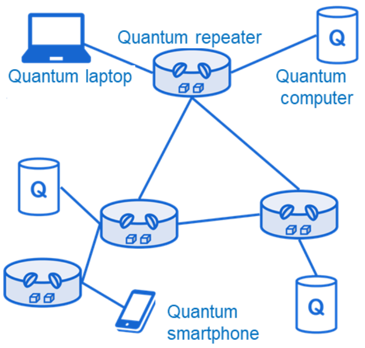
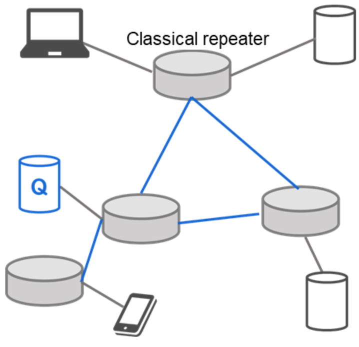
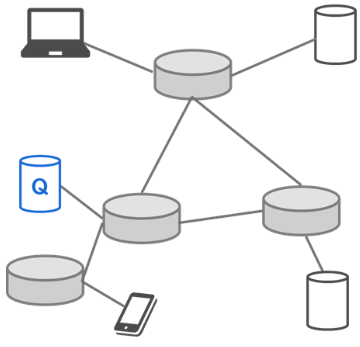
One of the characteristics of quantum communication is its high level of security. Since end-to-end quantum entanglement can be achieved, it is only necessary to generate cryptographic keys at the ends of the communication, and since the keys are broken upon observation, any eavesdropping will always leave a trace, making hacking theoretically impossible.

A communication method similar to quantum communication is quantum key distribution network. With this communication method, the information to be transmitted itself is no different from that in classical communications, but a quantum mechanism is used to encrypt it. It should be noted that quantum key distribution network employs the same mechanisms as classical communications at the communication relay points, therefore at that part its security is the same as the classical communication except for the communication passing through fiber.,.

Another feature is the speed of the calculation process. By connecting multiple quantum computers[28] in remote locations, it is possible to generate exponentially large computational power relative to the number of qubits, which in the future could enable processing of calculations that require enormous resources in a short time. Figure 3 shows the differences between quantum communication and the other types of communications described so far.

[28] A quantum computer is a computer that can handle qubits, information that is both 0 and 1. It has a calculation mechanism that differs completely from that of current computers. For instance, a quantum computer can solve in four minutes a calculation that would take a current supercomputer 10,000 years.

Figure 3: Differences between quantum and other forms of communications

Communication type	Quantum communication	Quantum key distribution network	Classical communications
Overview	Capable of sending and receiving quantum bits; uses quantum entanglement	Information itself is sent and received using existing bits (0 or 1), and only the encryption part uses the quantum mechanism	Existing bits (0 or 1) are sent and received
Application principle	Quantum entanglement	Not quantum entanglement	-
Illustration of network	 ・Allows handling of qubits all over the network ・Devices connected to the network can input/output quantum information	 ・Quantum mechanism utilized in the network connecting repeaters ・Classical communication in the repeater itself and from the repeater to the device	 ・Digital information handled all over the network
Remarks	Quantum key distribution network is also possible on a quantum communication infrastructure	-	Includes fiber optic, satellite, mobile communications, etc.

Source: Compiled by MGSSI based on various data

PROMISING FIELDS OF APPLICATION

(1) AREAS REQUIRING HIGH SECURITY: STATE SECRETS, FINANCE, MEDICAL AND GENOME FIELDS, ETC.

The security of current encryption technology is maintained by ensuring that the computation required to decrypt the data cannot be completed in a realistic amount of time (computational security). However, as quantum computers become more practical, computational security will be easily overcome, and eavesdropping may become rampant. Therefore, it is said that quantum communication technology is a critical security item for state-level information communication.

Quantum communication technology is expected to be used in the field of national intelligence such as diplomatic secrets, for which security is particularly important, as well as financial information, and personal genome, biometric, and medical information, and then to spread to individual-level networks. Incidentally, it is said that China has already achieved quantum key distribution network and the government is already using it.

(2) FURTHER POSSIBILITIES IN THE FUTURE: REALIZATION OF A GIANT QUANTUM COMPUTER

If quantum computers can be connected across regions and countries through quantum communication, and if information can be exchanged using quantum bits, it will be possible for a large number of quantum computers to cooperate in real time to perform enormous calculations. In other words, huge quantum computing power would be available from anywhere.

This could lead to the following in the future. For example, quantum computers would excel at calculations to optimize delivery routes, etc., but as they become more advanced, they may lead to urban transportation without any traffic congestion. In drug discovery, various simulations could be performed in an instant, and it may be possible to quickly develop a cure for a new type of viral infection. If natural disasters could be predicted through highly accurate weather forecasts, proactive measures could be taken to minimize damage. Further into the future, if, in combination with automated driving, quantum computing decreases the probability of accidents, vehicle bodies may no longer need to be made of hard materials to protect human life, and instead may be designed with softer materials and more innovative designs. Also, the ability to conduct quantum communication on personal devices would open up many more possibilities. Just as how the way in which the Internet is deployed throughout the world today could not have been predicted when it was in its early conceptual stage, once quantum communication is established as a network infrastructure, the applications that can be created from it could have unlimited possibilities.

FUTURE PROSPECTS

(1) TRENDS IN EACH COUNTRY

The US has shown active moves to utilize quantum communication in recent years, including a bill submitted in 2020 to provide more generous support related to the quantum Internet[29] made possible by quantum communication. The US Department of Energy is promoting the construction of a nationwide quantum Internet, and a budget of $61 million has been set aside for the policy. The University of Chicago and other research institutions will play a central role in this project. The same year, the US National Science Foundation (NSF) also announced a research and development project, with a budget of $26 million distributed over five years through 2025. Both projects will provide support for everything from basic research to the creation of testbeds.

Europe is moving more quickly, with the Quantum Internet Alliance (QIA), an alliance of universities and companies from around the region on quantum-related technologies, starting to build a quantum Internet testbed from 2018. In addition, a project has been initiated to build a quantum network connecting major cities over a seven-year period beginning in 2022. The project has been allocated a budget of 24 million euros for the first three and a half years, which is a larger budget than past projects, indicating the degree of resources they are putting in. In addition, independent research is underway at research institutes in Spain, Germany, and other countries.

Although there are no large quantum-Internet-related projects in China as far as known, the country is investing a large amount of money in research and development of quantum technology in general. For example, China has published many advanced research results in the field of quantum key distribution network, including the world's first demonstration of quantum entangled distribution and satellite quantum key distribution network. Pan Jianwei, a student of Anton Zeilinger, one of the 2022 Nobel Prize winners in physics, is leading the quantum research in the country, and the abovementioned demonstration of the world's first quantum cryptographic communication is also believed to have been carried out by Pan with the cooperation of Zeilinger.

In Japan, research on quantum key distribution is particularly active, but research projects on quantum communication have also started. In the Moonshot Research and Development Program launched by the Japan Science and Technology Agency (JST) to subsidize advanced research, elemental technologies and architectures for quantum communication are being studied and testbeds are being constructed with an eye toward the quantum Internet. These research activities are mainly conducted by universities and other research institutions, but have also been initiated by the private sector, as illustrated by the participation of researchers belonging to mercari R4D.

Although there has been no official move toward international collaboration in research and development of quantum technology, exchanges of researchers in Japan, the US, and Europe are being conducted on an individual level, partly because quantum technology is positioned as a critical technology on par with AI and the like.

[29] When various devices are connected by quantum communication, they become a network, and when networks are further connected to each other, they become an Internet.

Figure 4: Quantum communication related movements in each country and region

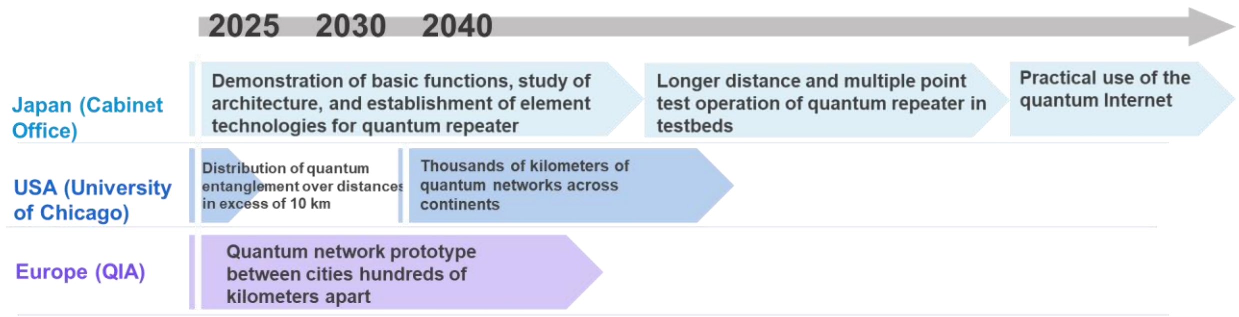
Country/ Region	Japan	USA	Europe	China
Representative support organization	Japan Science and Technology Agency (JST)	US Department of Energy (DOE)	Quantum Internet Alliance (QIA)	—
Outline of support	Related research is included in several projects in Moonshot Goal 6: Realization of a fault-tolerant universal quantum computer that will revolutionize economy, industry, and security by 2050. Research on elemental technologies for quantum repeaters, construction of testbeds for quantum communication networks and demonstration of their architectures, etc.	Supporting several R&D projects with the aim of connecting all 17 national laboratories under the department's jurisdiction as the backbone network of the quantum Internet.	A seven-year project that aims to build a quantum network connecting major cities.	Although there are no large projects with the goal of building a quantum Internet, China is ahead in research on quantum key distribution. China is conducting experiments on fundamental technologies for quantum communication, such as quantum repeaters.
Support budget	For reference: The supplementary budget for FY2021 was 68 billion yen for moonshot-type research as a whole, including targets other than Goal 6. Quantum communication related research is part of that.	61M USD (approx. 8.3 billion yen)	24M euros (approx. 3.5 billion yen) *Budget for 3.5 years from October 2022 *The QIA budget for the past three years through 2022 was 10M euros (approx. 1.4 billion yen), therefore it has more than doubled.	For reference: China planned to spend approximately 7 billion yuan (approx. 140 billion yen) on research related to quantum technology over the five-year period beginning in 2016, and is developing a separate quantum research center. The budget related to quantum key distributionn is part of that.
Related organizations	Keio University, Osaka University, Waseda University, etc.	- Research institutions: University of Chicago, Caltech, Cornell University, etc. - Companies: Boeing, IBM, Intel, Google, etc.	- Qutech (Dutch quantum technology research institute) - ICFO (Spanish institute for research on photonics, etc.) - University of Innsbruck (Austria) - 40 research institutes, companies, startups, etc., led by the Paris Centre for Quantum Computing (French quantum technology research institute)	- University of Science and Technology of China, University of Chinese Academy of Sciences, etc.
Other initiatives	- The Quantum Internet Task Force was formed with researchers of the current generation, who are expected to remain active in 20 to 30 years, when the quantum Internet is expected to be realized. White paper was published in 2021. Researchers from Mercari, Osaka University, Yokohama National University, and the University of Tokyo and other institutions are participating. - There are also moves in the area of startups, such as the establishment of LQUOM as a university venture in 2020.	- National Science Foundation (NSF) budget of $26M over 5 years to build a testbed in Arizona, etc. - AWS has announced the AWS Center for Quantum Networking to study quantum networks and the quantum internet.	- ICFO, together with Catalan research institutes, is planning a research budget of 15M euros (approx. 2.2 billion yen) for quantum communication-related technologies, both software and hardware. - The Federal Ministry of Education and Research funded Q.Link.X (a joint project of research institutes and companies for the development of quantum technology in Germany) with approximately 15M euros (approx. 2.2 billion yen) over three years starting in 2018.	- A research team led by Pan Jianwei of the University of Science and Technology of China succeeded in quantum entanglement distribution by satellite. - Nationwide quantum key distribution network to be established by 2025.

Source: Compiled by MGSSI based on various data

(2) ROADMAP FOR REALIZATION OF QUANTUM INTERNET

According to the Cabinet Office of Japan, the quantum Internet is expected to be put to practical application around 2040 (Figure 5). Before then, the establishment of elemental technologies, test operations on testbeds, and realization of long-distance quantum repeaters are planned. The roadmap set forth by the University of Chicago, which is participating in the US Department of Energy project, aims to build a quantum network of several thousand kilometers across continents within the next 10 years. In Europe, as mentioned above, QIA aims to build a quantum network between cities hundreds of kilometers apart over seven years starting from 2022. As for China, while research on quantum key distribution is progressing, there is no roadmap for the quantum Internet.

Figure 5: Roadmap for realization of the quantum Internet in each country and region



Source: Compiled by MGSSI based on various data

(3) SUMMARY

At present, research and development into quantum communication, quantum computers, quantum key distribution network, and other quantum-related technologies is still limited to the study of elemental technologies and small-scale demonstration experiments, but if these are organically linked and the quantum Internet is realized as a secure information infrastructure with high-speed, advanced computational processing capabilities, the impact on the economic world will be significant. In Europe and the US, further research will be conducted hereon, and in Japan, there are moves toward collaboration led by young researchers. Attention to this field is gradually increasing, but support in terms of people, resources, and capital is still insufficient. In preparation for the era of the quantum Internet, which may arrive sooner than expected, businesspeople should also pay attention to trends in both technology and applications.

See here for the IP Report

INTELLECTUAL PROPERTY REPORT ON TECHNOLOGIES TO WATCH IN 2023

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Mitsui & Co. Global Strategic Studies Institute

This report investigates, analyzes, and reports on international trends in intellectual property concerning the four topics (mycelium, upcycling technology, metamaterials, and quantum communication) featured in Technologies to Watch in 2023. All investigations and analyses were conducted using PatSnap Analytics, a global patent search and analysis tool provided by PatSnap, and PatSnap Discovery, a search tool for various kinds of technical information. The date of acquisition of the various data is December 5, 2022.

<u>How to read each figure</u>

Figure 1: Related patent application trends

The vertical axis represents the number of patent families, and the horizontal axis represents the year of application, showing the trend in the number of applications per year from 2006 to 2022. A patent family is a group of applications derived from the same patent application and filed in different countries. For example, if a patent application filed in the US is also filed in China, these are not counted as two patent applications, but as a single patent family.

In principle, a patent application is published 18 months from the filing date. Therefore, as of January 2023, some of the patent applications submitted in 2021 and later have not been published. However, due to the nature of this report, it is preferable to refer to the latest patent application status, and therefore the number of patent applications from 2021 onward is provided as a forecast.

Figure 2: Top ranking countries of application

This shows how many patent applications were filed by applicants in which countries from 2003 to 2022, i.e., a ranking of the source (country) of the invention. The size of the bubble is proportional to the number of applications.

Figure 3: Top ranking patent holders

This shows the ranking of the top patent holders with currently active patents for patent applications from 2003 to 2022.

TECHNOLOGIES TO WATCH IN 2023
— INTELLECTUAL PROPERTY REPORT —

Mycelium

01/2023

Total number of applications (2003-2022)

20,985 Patent family

Figure 1: Trends in mycelia-related patent applications

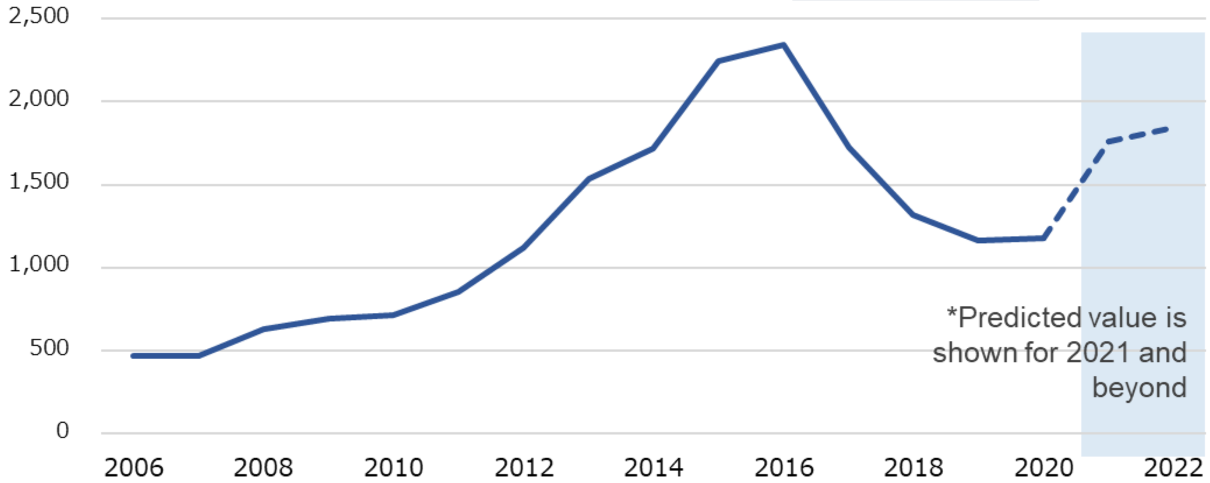


Figure 2: Top 10 countries of applicants

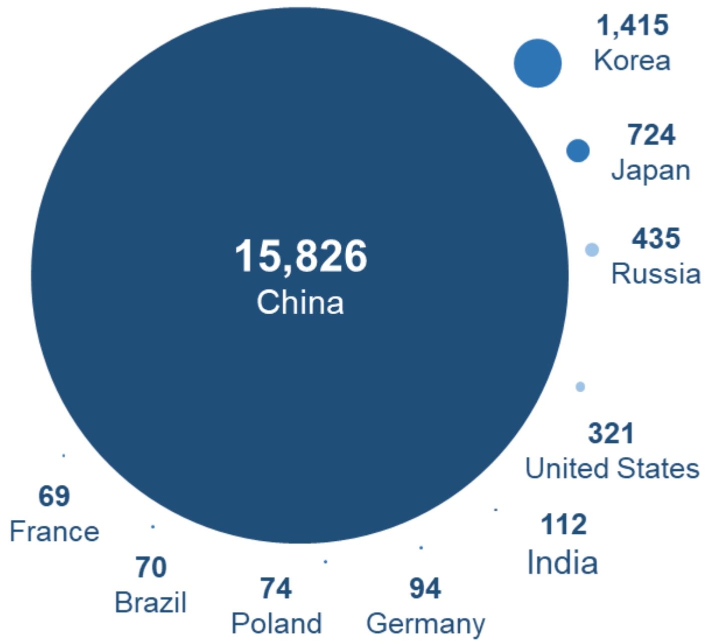
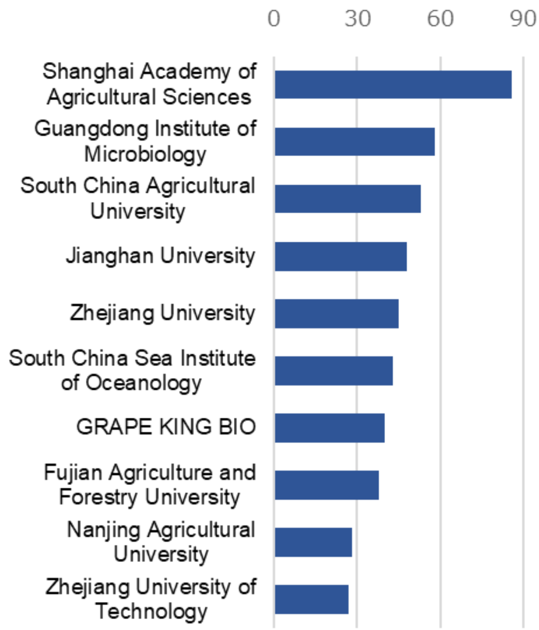


Figure 3: Top 10 patent holders



Number of academic papers (2017-2022) **7,816**

Amount of funds raised (2017-2022) **524M (USD)**

TECHNOLOGIES TO WATCH IN 2023
— INTELLECTUAL PROPERTY REPORT —

Upcycling technology

01/2023

Total number of applications (2003-2022)

485 Patent family

Figure 1: Trends in upcycling technology related patent applications

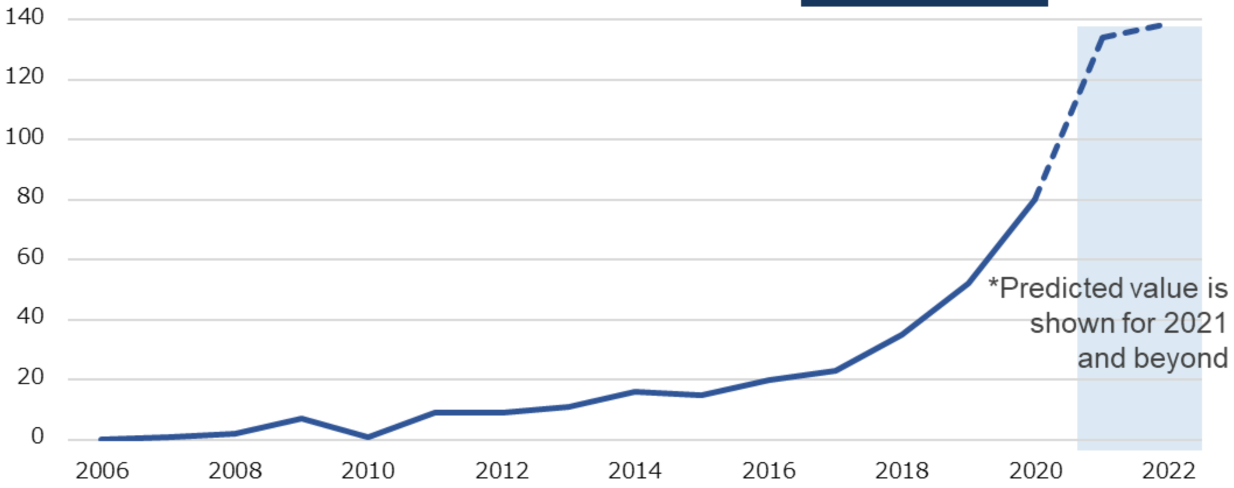


Figure 2: Top 10 countries of applicants

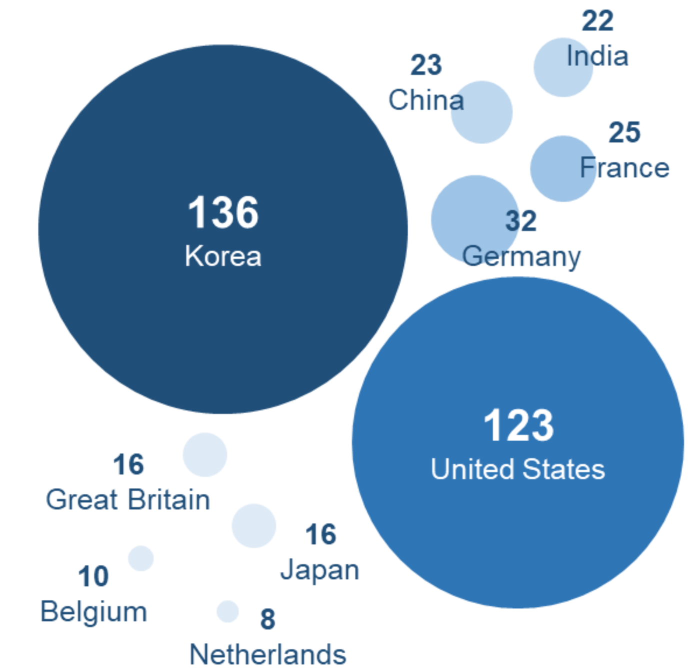
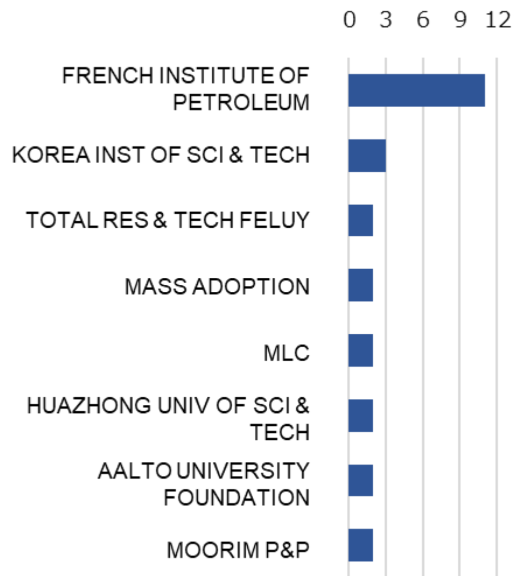


Figure 3: Top 8 patent holders



Number of academic papers (2017-2022) **1,369**

Amount of funds raised (2017-2022) **634M (USD)**

TECHNOLOGIES TO WATCH IN 2023
— INTELLECTUAL PROPERTY REPORT —

Metamaterials

01/2023

Total number of applications (2003-2022)

3,875 Patent family

Figure 1: Trends in metamaterial-related patent applications

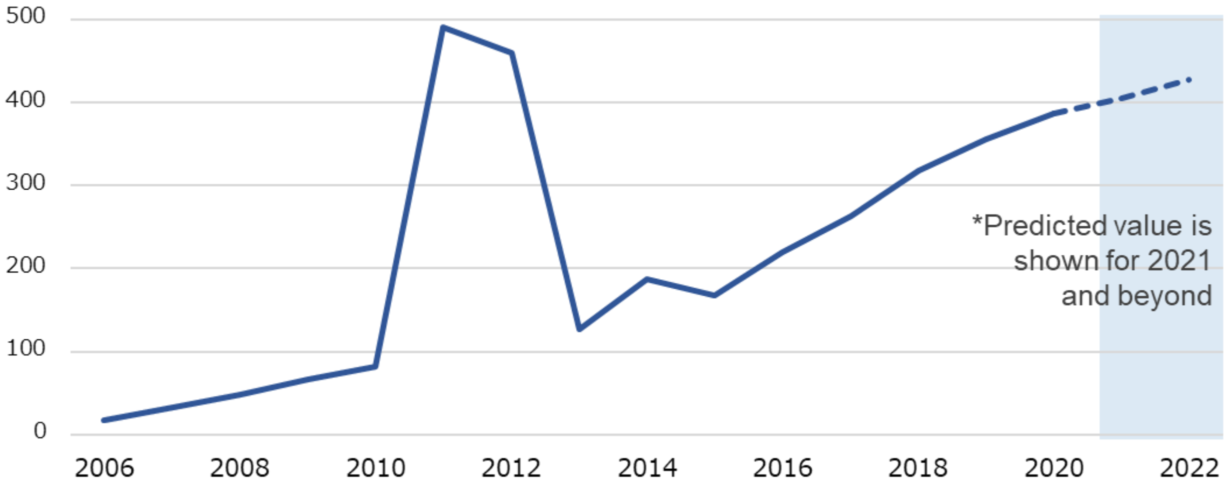


Figure 2: Top 10 countries of applicants

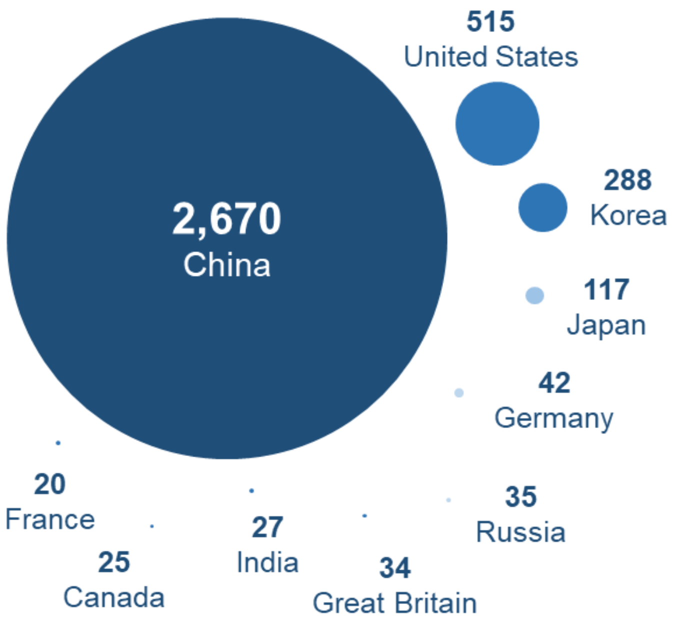
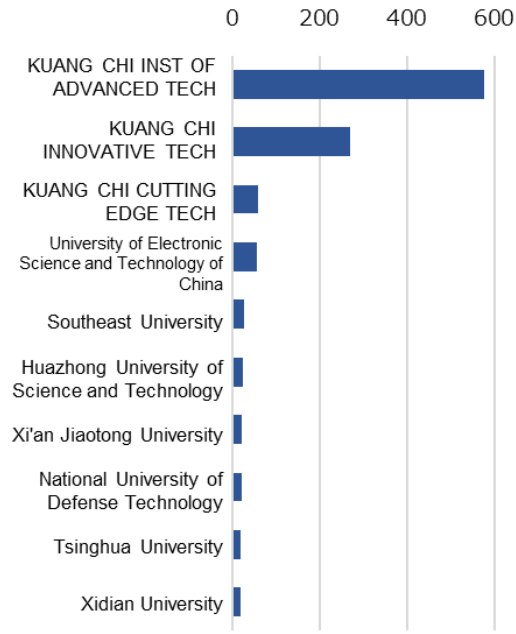


Figure 3: Top 10 patent holders



Number of academic papers (2017-2022) **19,811**

Amount of funds raised (2017-2022) **1,221M (USD)**

TECHNOLOGIES TO WATCH IN 2023
— INTELLECTUAL PROPERTY REPORT —

Quantum communication

01/2023

Total number of applications (2003-2022)

5,172 Patent family

Figure 1: Trends in quantum communication related patent applications

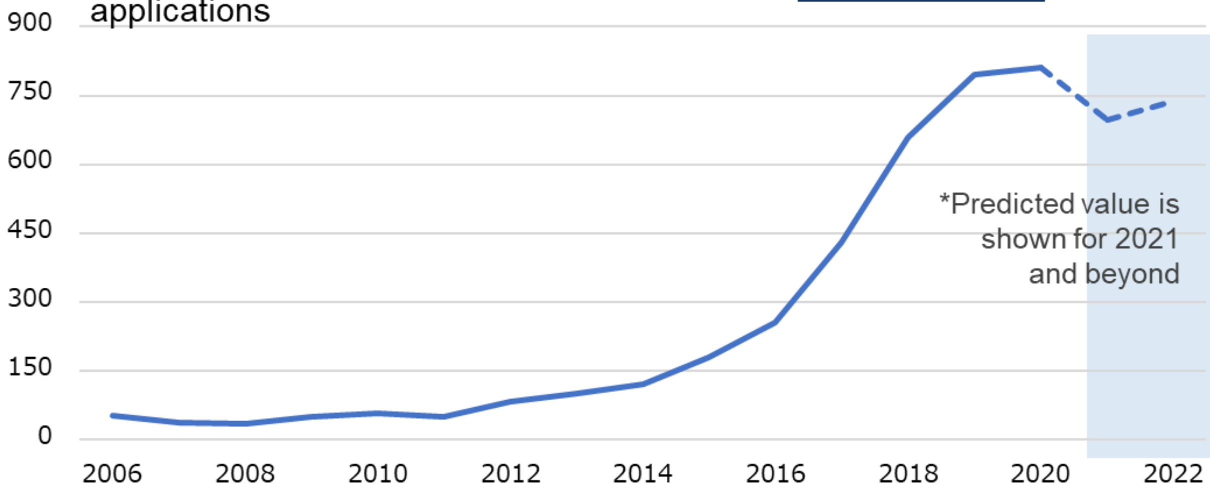


Figure 2: Top 10 countries of applicants

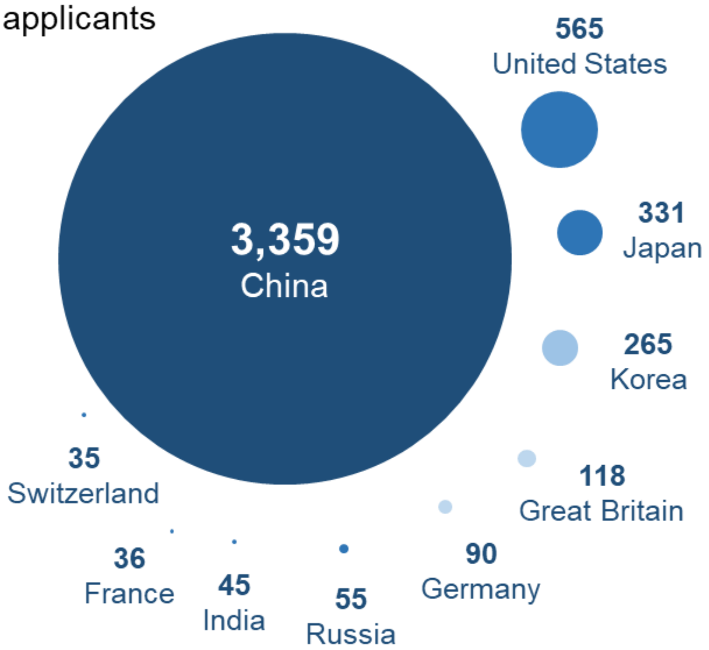
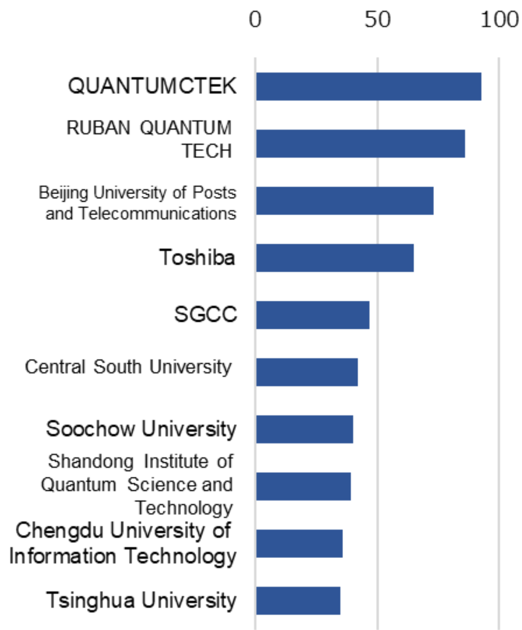


Figure 3: Top 10 patent holders



Number of academic papers (2017-2022) **7,753**

Amount of funds raised (2017-2022) **950M (USD)**