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Non-ferrous metals

Toward reducing transmission and distribution losses through the widespread adoption of superconducting cables

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Industry Research Department
Mizuho Bank

Summary

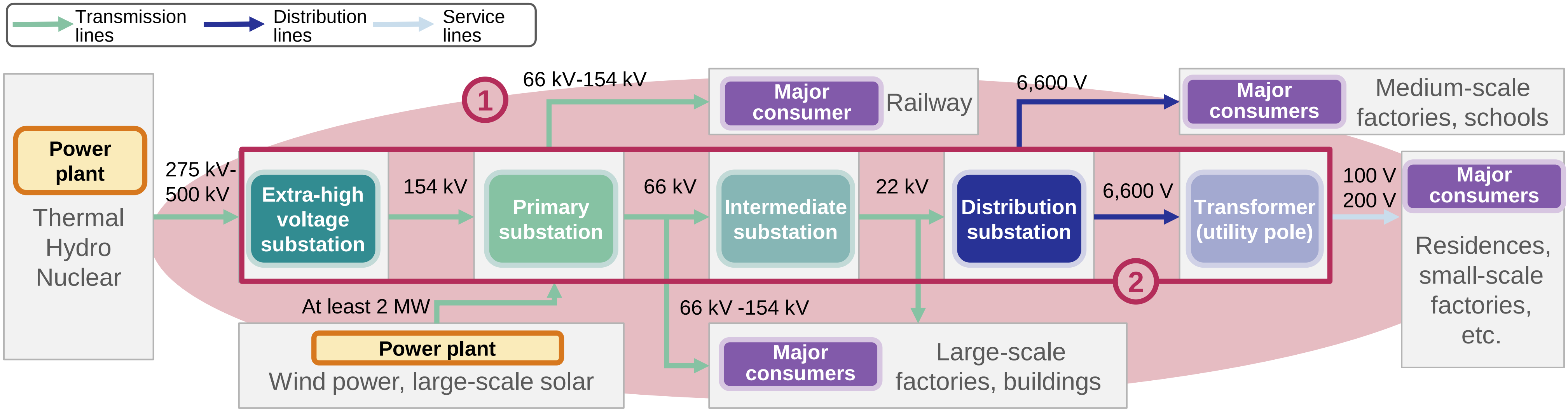
- Due to the existence of electrical resistance, transmission and distribution losses occur during long-distance power transmission and voltage conversion at substations. Japan's transmission and distribution loss rate is approximately 4.8%, with annual transmission and distribution losses of about 43.5 billion kWh, equivalent to the power generation of approximately 6 nuclear power plants. In Japan, the occurrence of transmission and distribution losses is an important challenge in terms of energy constraints.
- Traditionally, Japan has pursued efforts to suppress transmission and distribution losses through the utilization of new technologies such as HVDC (High Voltage Direct Current) transmission and "extra-high voltage" systems. However, in Japan, where land area is limited, suitable sites for HVDC introduction are restricted, and there are currently limits to suppressing transmission and distribution losses based on existing technologies.
- The application of superconducting technology, which reduces electrical resistance to zero by lowering the temperature of materials to extremely low levels, in the transmission and distribution field is attracting attention as an initiative contributing to further suppression of transmission and distribution losses. Through the utilization of superconducting cables, approximately 95% of transmission and distribution losses can be suppressed (using the example of SWCC superconducting cables), and significant suppression of transmission and distribution losses is expected.
- However, superconducting cables are more expensive than existing cables, and investment in peripheral equipment such as refrigeration systems used to cool superconducting cables is necessary. Due to these cost barriers, it is difficult for consumers to identify cost benefits from introduction, which impedes widespread adoption.
- The railway sector, where the number of substations can be reduced through the introduction of superconducting cables, and the data center sector, where substantial increases in power consumption are anticipated and the effect of suppressing transmission and distribution losses through superconducting cable introduction is likely to appear, have clear introduction benefits and are considered promising areas where superconducting cables can be put to particularly wide use. However, even in cases with high power consumption, areas suitable for superconducting cable installation are limited, making it difficult to advance consideration of dissemination in large-scale factories where introduction benefits are unclear. Meanwhile, cable manufacturers face technical barriers such as the high difficulty of manufacturing long superconducting cables for transmission and distribution applications.
- Going forward, a conceivable policy measure for the dissemination of superconducting cables is for large-scale factories, railways, and data centers utilizing superconducting equipment to collaborate in forming "superconducting industrial zones" and jointly invest in equipment such as refrigeration systems to suppress investment costs. On the other hand, for further technological innovation, potential directions include collaboration between cable manufacturers for joint development of long cables, attracting external funding through partnerships with venture capital, and accelerating investment.

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Transmission and distribution losses are one of the challenges of energy constraints in Japan

- When electric current passes through materials, part of the electrical energy is converted to thermal energy due to the existence of electrical resistance, resulting in transmission and distribution losses. Hereafter, we will discuss measures for suppressing transmission and distribution losses.

Overview of Japan's power network and background of occurrence of transmission and distribution loss



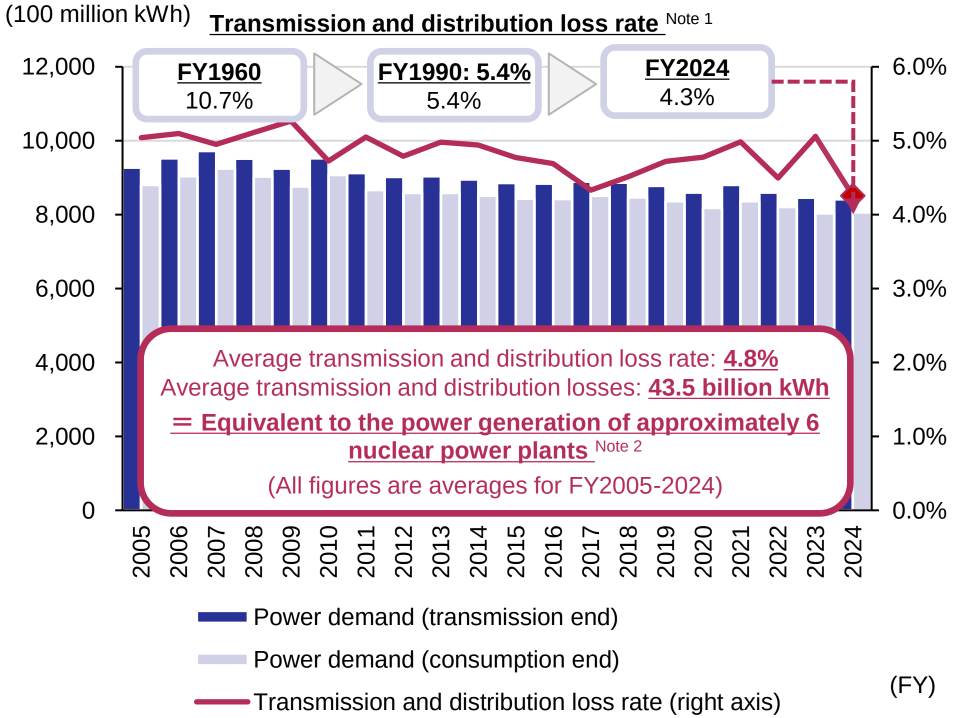
	Location of transmission loss occurrence	Overview
1	**During power transmission**	✓ Losses occurring during the process of long-distance transmission of power after generation ✓ Losses occurring at demand locations involving long-distance transmission, such as railways
2	**During voltage conversion at substations, etc.**	✓ Losses occurring when converting from high voltage to low voltage

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Suppressing transmission and distribution loss rates is a challenge for countries around the world, including Japan

- In Japan, transmission and distribution loss rates have been on a declining trend for approximately half a century, but have recently plateaued in the 4% range.
- Overseas, many countries have transmission and distribution loss rates higher than Japan's. We believe that suppressing transmission and distribution loss rates is a common challenge for all countries.

Trends in power demand and transmission and distribution loss rates in Japan



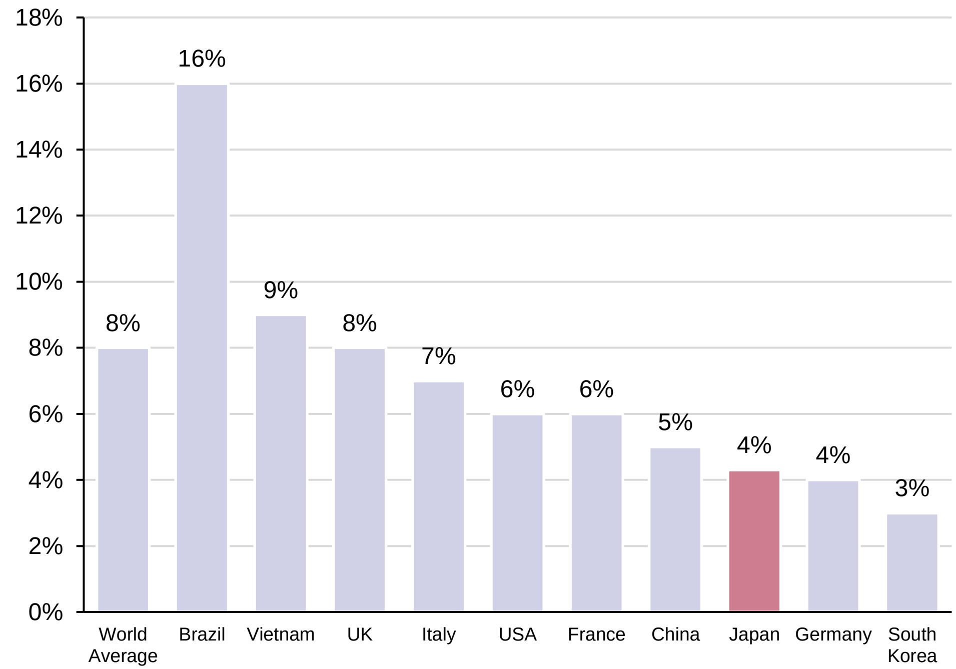
In Japan, transmission and distribution loss rates continue to plateau in the 4% range

Note 1: The definition of transmission and distribution loss rate is "(Power demand (transmission end) - Power demand (consumption end)) ÷ Power demand (transmission end) × 100." FY2024 figures are estimated results. FY1960 and FY1990 data are from Tokyo Electric Power Company.

Note 2: Calculated assuming a nuclear power plant with generation capacity of 1 million kW and a capacity factor of 80%.

Source: Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials from Organization for Cross-regional Coordination of Transmission Operators (OCCTO) and Tokyo Electric Power Company website.

International comparison of transmission and distribution loss rates



Many countries overseas have transmission and distribution loss rates that exceed Japan's
We believe that suppressing energy losses is a common challenge worldwide

Note: Data for Japan consists of estimated results for FY2024; data for other countries is from 2014

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on World Bank data and materials from Organization for Cross-regional Coordination of Transmission Operators (OCCTO)

There are limits to existing efforts aimed at suppressing transmission and distribution losses

- In Japan, technological development, product deployment, and policy implementation contributing to the suppression of transmission and distribution losses have advanced for approximately the past 50 years. However, we believe that we are now at a stage where new measures are needed for further reduction of transmission and distribution losses.

Conventional efforts toward suppressing transmission and distribution losses

Initiatives	Overview	Remaining challenges, etc.
1 Private sector **Introduction of HVDC** Note	✓ HVDC is a system that transmits power using direct current at high voltage ✓ Features include higher efficiency during transmission compared with alternating current and suitability for long-distance transmission applications ✓ Already widely adopted globally; operation began in Japan from the 1970s	✓ In Japan, where land area is limited, suitable sites for HVDC utilization for long-distance transmission are also limited ✓ Investment costs for converters are substantial
2 Private sector **"Extra-high voltage" concept**	✓ While 500,000 V extra-high voltage is in use in Japan, 1 million V "ultra-high voltage" is conceived as next-generation transmission technology ✓ Demonstration experiments began at Tokyo Electric Power Company in the 1990s ✓ Initiatives are being promoted through the introduction of insulators capable of withstanding high voltage	✓ While practical-level technology has been established, equipment expansion and investment costs have become bottlenecks, preventing widespread adoption
3 Private sector **Deployment of low-loss transformers**	✓ After receiving power at 6,600 V voltage from electric power companies, transmission and distribution losses are suppressed by operating various electric equipment through low-loss transformers ✓ Already commercialized by transformer manufacturers — Intended for use in office buildings, schools, hospitals, etc.	✓ Main application areas are locations that do not involve high current usage, making it difficult to achieve significant loss suppression
4 Government **Support for suppression of transmission and distribution loss**	✓ With the aim of suppressing the deterioration of transmission and distribution losses through improved utilization efficiency of transmission networks, the "Core System Investment Efficiency Enhancement and Transmission/Distribution Loss Suppression Measures" initiative was launched in April 2024	✓ Since this is a system aimed at suppressing the deterioration of transmission and distribution losses, it is difficult to achieve significant loss suppression

Note: HVDC: Abbreviation for High Voltage Direct Current, referring to high-voltage direct current transmission

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on Tokyo Electric Power Company website and public information

Utilization of superconductivity - Technology contributing to the suppression of energy losses during electrical conduction

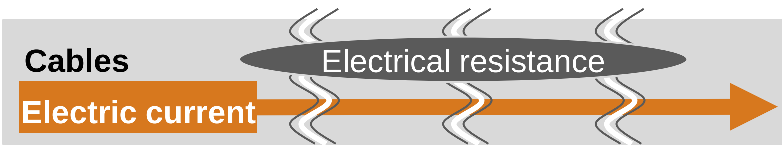
- Superconductivity refers to a phenomenon where electrical resistance becomes zero when the temperature of a material drops to extremely low levels.
- In the superconducting state, electrical resistance during conduction becomes zero. By utilizing this phenomenon, it becomes possible to suppress the occurrence of energy losses during electrical conduction.

Mechanism of superconductivity and fundamental principles (examples of electrical cables)

What is superconductivity?

A phenomenon where electrical resistance becomes zero when the temperature of a material drops to extremely low levels

Conventional cables



Electrical resistance occurs

Energy is released as heat ⇒ transmission and distribution losses occur

Cause of electrical resistance

- ✓ Electrons moving individually and randomly through the material collide with metal atoms during electrical conduction

Superconducting cables

Zero electrical resistance

No transmission and distribution losses occur

Background of zero electrical resistance in superconductivity

- ✓ At extremely low temperatures, electrons form pairs (Cooper pairs) and no longer scatter

Since no electrical resistance exists in the superconducting state, large currents can be conducted without loss

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on International Superconductivity Technology Center website and public information

With the advancement of technological innovation, the critical temperature of superconductivity is tending to rise

- Superconductivity was discovered approximately 115 years ago. While industrial applications were limited for a long time, the discovery of high-temperature superconductivity approximately 40 years ago became the catalyst for full-scale utilization.

History of R&D in superconductivity

Early 20th century
Discovery of superconductivity

- ✓ 1911: Dutch physicist Onnes discovered superconductivity
  - It was found that mercury's electrical resistance disappears below -269° C (liquid helium temperature)
  - The temperature at which a material becomes superconducting is called the "critical temperature" (hereafter, Tc)

Progress in theoretical framework of superconductivity

1930s-1960s
Progress in R&D

- ✓ 1933: It became clear that superconductors have strong diamagnetism (Meissner effect)
- ✓ 1957: The mechanism of superconductivity was elucidated (BCS theory)
- ✓ 1962: Quantum theory of superconductivity developed (discovery of Josephson effect)

Industrial applications remained limited due to the high cost of liquid helium

Discovery of superconducting phenomena at higher Tc compared with conventional materials

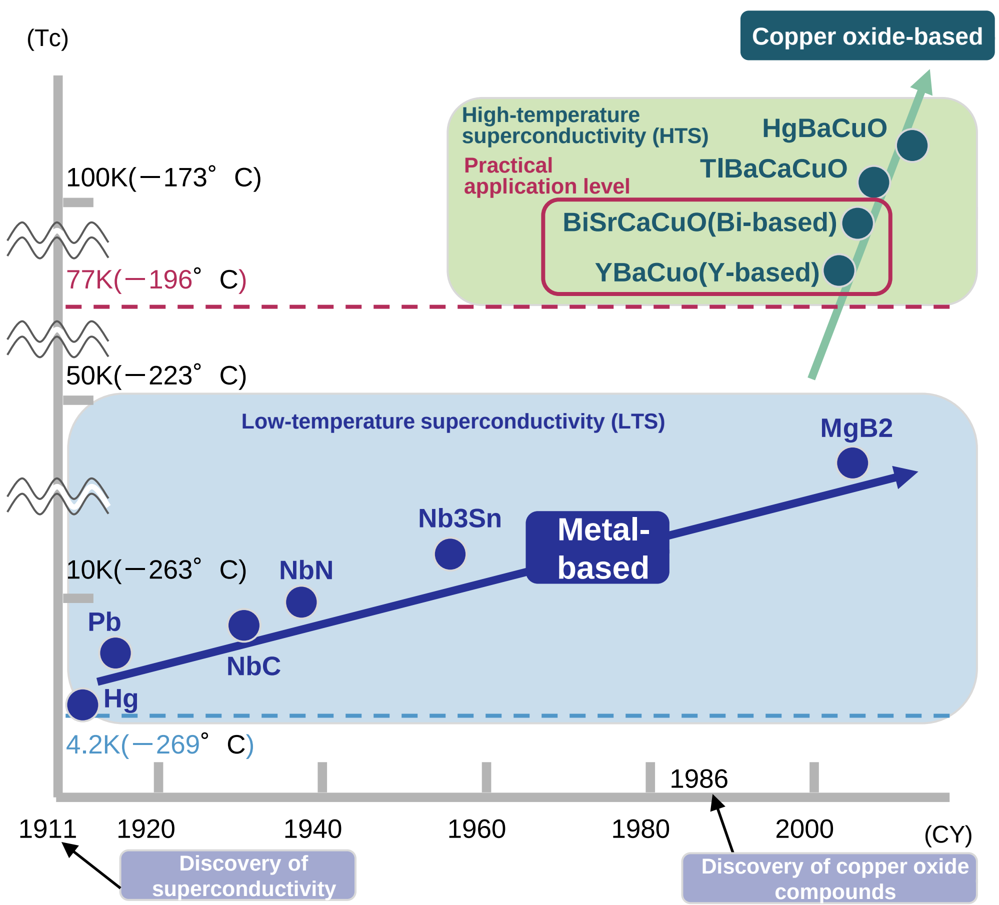
1980s
Discovery of high-temperature superconductors

Technological breakthrough

- ✓ 1986: It was discovered that copper oxides have a Tc of -243° C. Within the same year, a Tc of -181° C was achieved
- ✓ Now, superconducting materials with Tc: -138° C have been discovered

The discovery of high-temperature superconductivity approximately 40 years ago became the catalyst for full-scale utilization of superconductivity in various industries

Historical changes of Tc



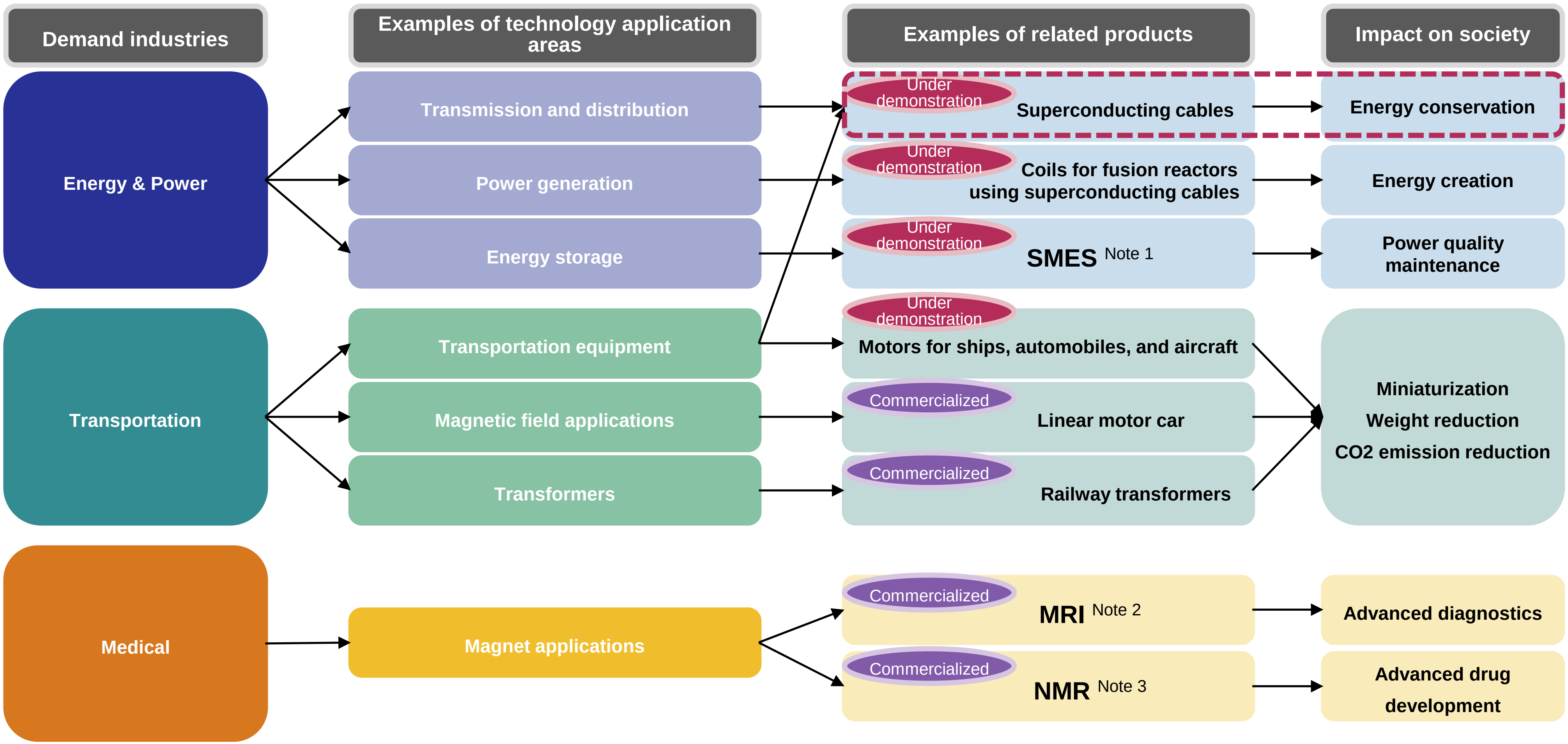
Currently, Y(Yttrium)-based materials are a particular focus area for cable manufacturers

Note: Tc: Abbreviation for Critical Temperature. Generally, superconductivity that requires liquid helium (-269° C) for cooling is called "low-temperature superconductivity," while superconductivity that can be achieved by cooling with liquid nitrogen is called "high-temperature superconductivity"
Source: Both figures were compiled by Industry Research Department, Mizuho Bank, Ltd. based on Tohoku University website, International Superconductivity Technology Center website, and various other public information sources

While superconducting technology has been commercialized for some products, it remains at the demonstration stage in the power transmission field

- Superconducting technology is expected to be utilized across various industries. While it has been commercialized for some products in each industry (e.g., linear motor cars), its application in the power transmission and distribution field is still at the demonstration stage, with expectations for future progress in demonstration experiments and social implementation.

Main applications of superconducting technology



Note 1: Abbreviation for Superconducting Magnetic Energy Storage, referring to superconducting magnetic energy storage systems
Note 2: Abbreviation for Magnetic Resonance Imaging
Note 3: Abbreviation for Nuclear Magnetic Resonance, referring to nuclear magnetic resonance
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials from International Superconductivity Technology Center

Superconducting cables are expected to offer higher utility compared with HVDC, a similar product already on the market

- HVDC already exists as a commercialized cable technology that, like superconducting cables, is expected to suppress transmission and distribution losses. While superconducting cables face bottlenecks, including still being at the demonstration stage, they are expected to offer greater utilization benefits than HVDC in terms of transmission and distribution loss suppression rates and other aspects.

Comparison of characteristics: superconducting cables and HVDC

	Superconducting cables	HVDC
Technical overview	Cables are cooled to extremely low temperatures such as -196° C to achieve a superconducting state (zero electrical resistance) for power transmission	Power transmission by passing high-voltage current of 200 k-500 kV through cables
Main application areas (including anticipated)	Theoretically, utilization can be anticipated in a relatively diverse range of scenarios: ・Long-distance transmission, factory internal wiring, equipment such as coils, etc....	Application scenarios for high-voltage transmission are relatively somewhat limited ・Long-distance transmission (e.g., overhead transmission lines, submarine cables for offshore wind power)
Transmission and distribution loss suppression effect	Capable of suppressing approximately 95% of transmission losses compared with pre-introduction levels	Capable of suppressing approximately 20% of transmission losses compared with pre-introduction levels
Business phase	Demonstration stage	Commercialized
Business cost	Investment in peripheral equipment such as cooling facilities is necessary Various costs including maintenance of peripheral equipment	Voltage conversion for direct current is high-cost compared with alternating current
Competitive environment	Globally at the demonstration stage, with no company yet dominating the market Japanese companies are considered to be in a position to potentially dominate the global market	Many companies participate globally Power balance among cable manufacturers is already clarified Top Japanese manufacturer Sumitomo Electric Industries is 4th in the global market share ranking
Remarks	Enables significant suppression of transmission and distribution losses Compact design contributes to reducing civil engineering costs	Enables suppression of transmission and distribution losses to a certain extent

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Initiatives by Japanese cable manufacturers - Promoting technological development through public-private partnerships and other means

- In Japan, demonstration experiments have been conducted through collaboration between cable manufacturers and industries with demand for superconducting cables. Years of R&D have been successful, with steady progress in the development of products that use superconductivity.

Trends of major superconducting cable manufacturers

	Furukawa Electric Co., Ltd.	SWCC	Fujikura Ltd.	Sumitomo Electric Industries, Ltd.
Main products	Y-based superconducting wire	Y-based superconducting wire	Y-based superconducting wire	Bi-based superconducting wire (Planning to transition to Y-based wire in the future)
Characteristics	**Accumulated technology as strength** ✓ Started R&D in the 1960s, ahead of other companies	**Considering business expansion** ✓ Established a roadmap for commercialization ahead of other companies	**Considering business expansion** ✓ Considering commercialization of not only superconducting wires but also peripheral equipment	**Accumulated technology as strength** ✓ Accumulated long-length technology through development of Bi-based wires
Recent major initiatives	✓ Development of wire for fusion reactors — Collaboration with UK's Tokamak Energy ✓ Development of kiloampere-class cables — Joint development with Kyoto University and Japan Science and Technology Agency (JST) ✓ Development of AC loss reduction technology — Joint development with Kyoto University and SuperPower	✓ Development of superconducting cable systems for electric aircraft — Ongoing collaboration with NEDO (New Energy and Industrial Technology Development Organization) (Development of Innovative Aircraft Propulsion Systems) ✓ Demonstration experiments relating to superconductivity applications in transmission and distribution lines — Conducted in collaboration with BASF Japan and NEDO	✓ Development of wire for fusion reactors — Supply of superconducting wire to US-based Commonwealth Fusion Systems ✓ Investment in fusion startups — Investment in Kyoto Fusioneering	✓ Demonstration experiments relating to superconductivity applications in transmission and distribution lines — Participation in METI's "Demonstration Project for High-Efficiency Power Transmission Systems Using High-Temperature Superconducting Technology" — Demonstration of power transmission from solar power plants to data centers
Future direction	✓ Sales policy — Replacement of medical field wire with HTS (high-temperature superconductivity) — Supply for fusion reactors ✓ Investment policy — Expects to formulate plan to increase production of fusion reactor wire at appropriate time	✓ Sales policy — Policy to aim for practical application of superconducting power transmission by FY2026 ✓ Investment policy — Policy to double HTS manufacturing capacity by 2027	✓ Investment policy — Plans to invest in HTS production increase (investment amount: 4 billion yen) — In anticipation of expanding demand for fusion reactor wire ✓ Other — Considering commercialization of coils and electromagnets, which are applications of superconducting wire	✓ Investment policy — Plans to review superconducting business and shift focus to Y-based wire development — While mass production technology is already available, actual mass production depends on demand

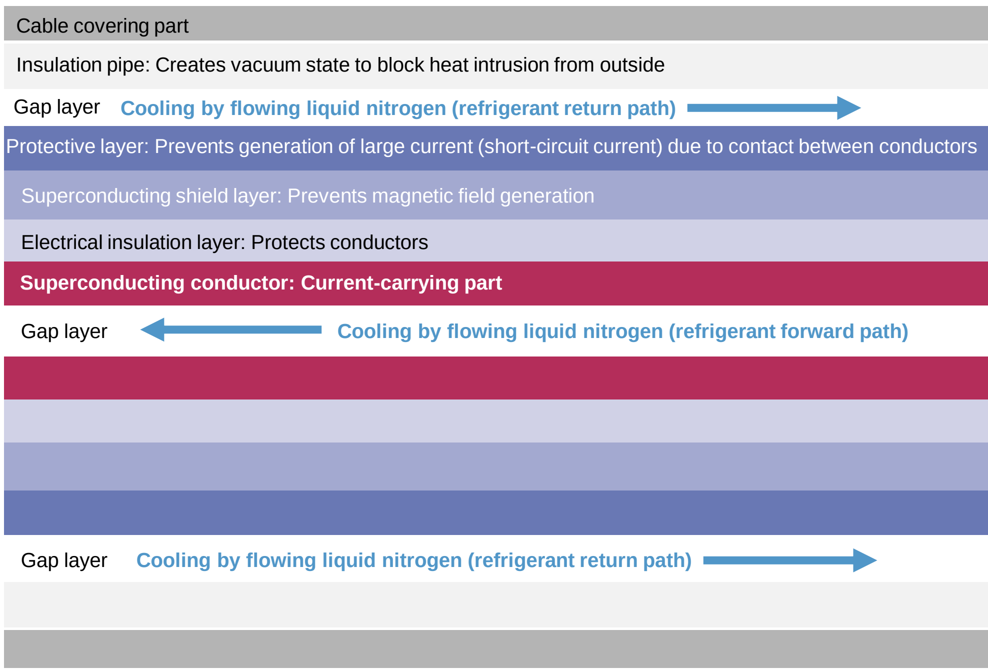
Note: AC loss: Refers to energy loss that occurs during AC power transmission
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on public information and various media reports

Superconducting cables face manufacturing challenges due to structural complexity. Conductors are important materials that affect transmission efficiency and other factors

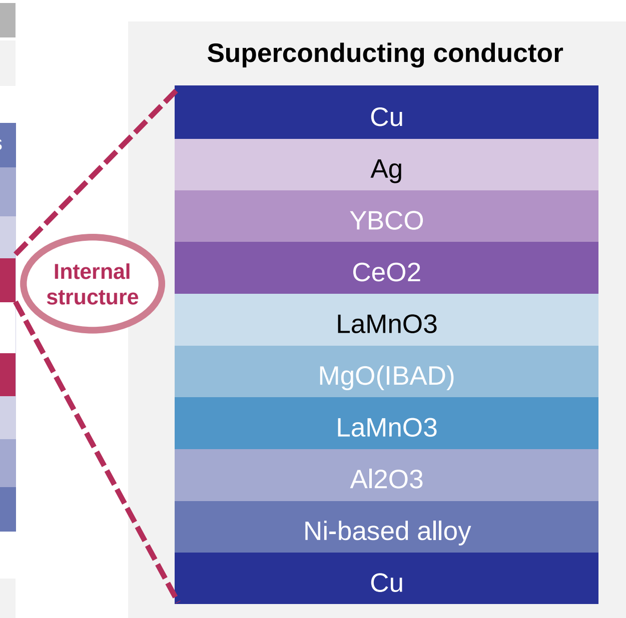
- The structure of superconducting cables is complex. For example, the conductor, which is the current-carrying part of the cable, needs to be manufactured by layering various metals, resulting in characteristics such as prolonged production lead times and high difficulty in manufacturing long cables.

Structure of superconducting cables

Structure of typical high-temperature superconducting cable (cross-section)



Structure of superconducting conductor (cross-section, example of SWCC cable)



- ✓ Various metals are layered through thin film formation and other methods
- ✓ Conductors are important materials that affect the Ic Note 1 and Tc Note 2 of superconducting cables

✓ Due to the complex structure of superconducting cables, production lead times tend to be prolonged, and manufacturing long cables is difficult

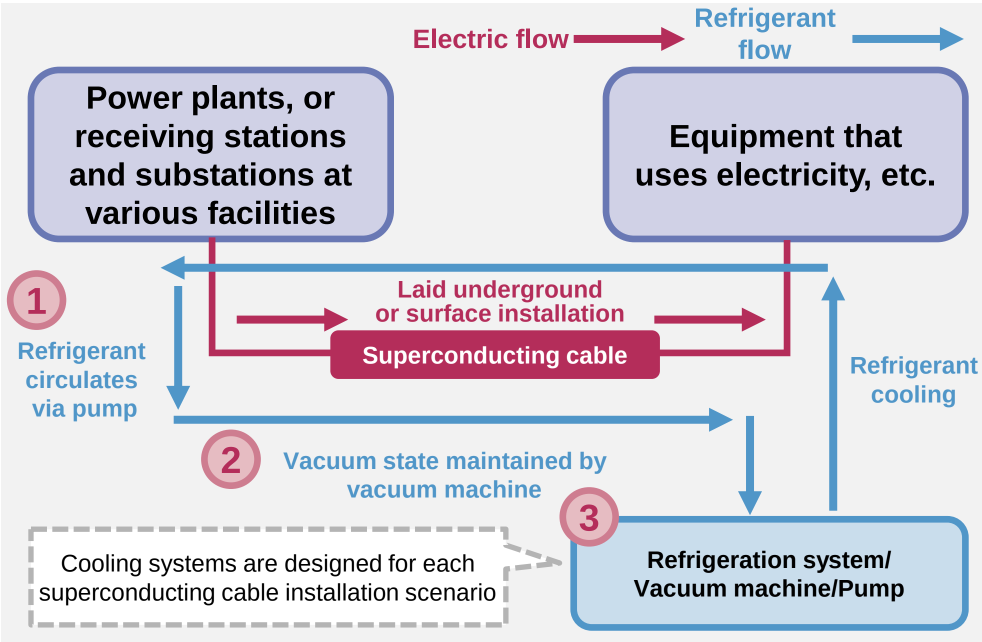
✓ Further R&D of conductors is essential for increasing transmission capacity through Ic enhancement and suppressing cooling costs through Tc improvement

Note 1: Abbreviation for Critical Current, referring to the maximum current that can flow in a superconducting state
Note 2: Abbreviation for Critical Temperature, referring to the temperature at which a material becomes superconducting
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on SWCC materials, public information, and various media reports

Various investment costs also act as a bottleneck for the widespread adoption of superconducting cables

- Investment in refrigeration systems and other equipment used for cable cooling is essential for operating superconducting cables. The presence of investment and operating costs creates a bottleneck for widespread adoption.

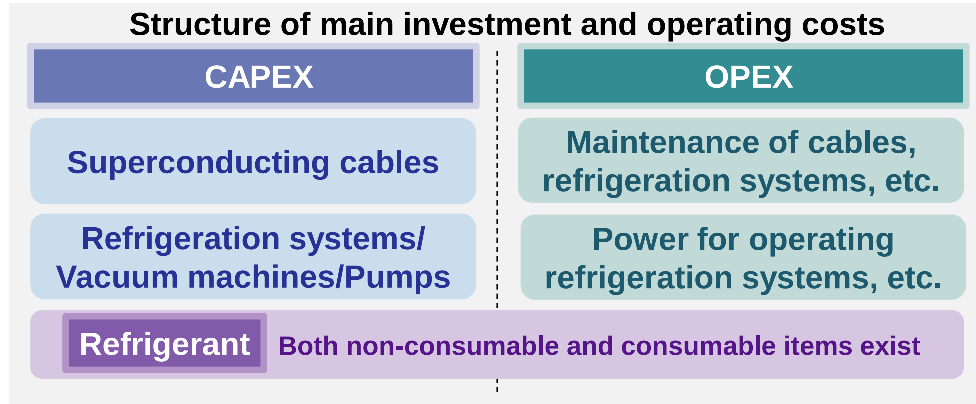
Image of operating superconducting cables



1. ✓ Superconducting state is maintained by circulating refrigerant inside the superconducting cable
2. ✓ A vacuum is created in the outer edge of the cable using a vacuum machine, to block heat intrusion coming into the cable interior from outside
3. ✓ The number of peripheral equipment installations such as refrigeration systems is adjusted according to the installation distance of superconducting cables

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on public information

Main investment and operating costs incurred when introducing superconducting cables



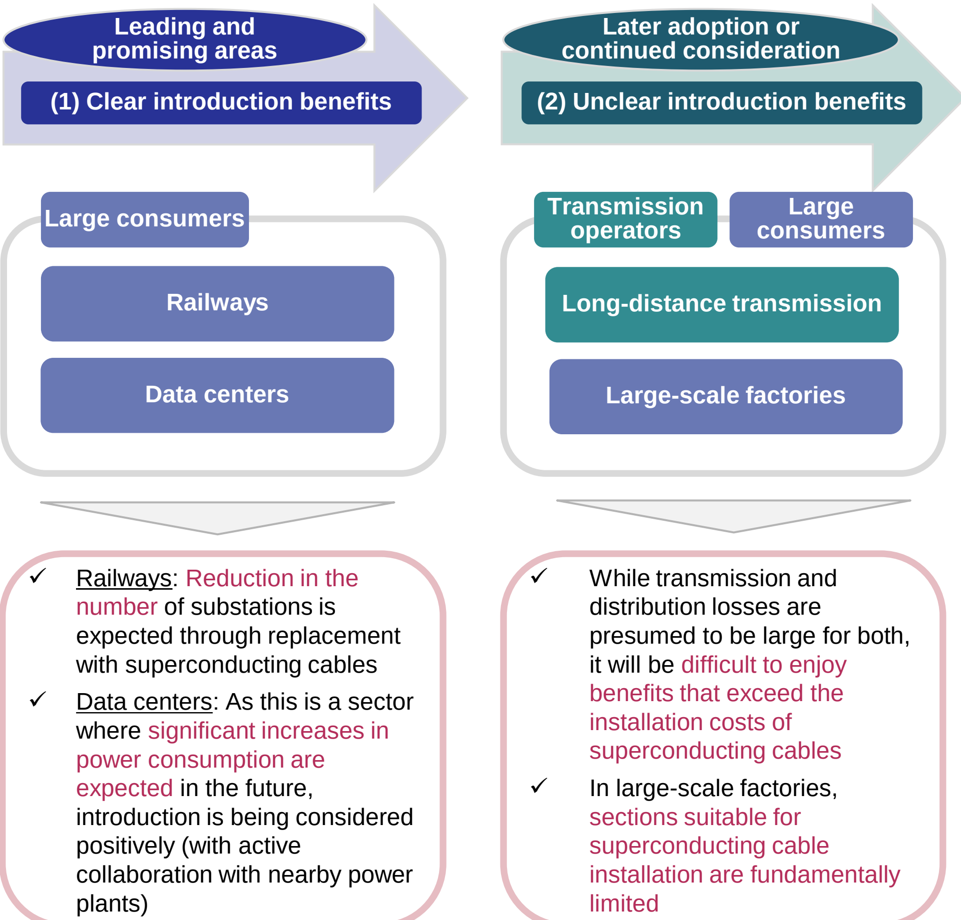
CAPEX (excluding refrigerant)	✓ Since superconducting cables for transmission and distribution are in pre-commercialization status, specific prices are unknown, but they are expensive compared with existing transmission and distribution cables ✓ Prices of peripheral equipment such as refrigeration systems are also unknown, but will create additional costs when introducing superconducting cables
OPEX (excluding refrigerant)	✓ Inspections are needed to check for any liquid nitrogen leakage from cables, aging of peripheral equipment such as refrigeration systems, etc. ✓ Power costs for operating cooling systems
Refrigerant	✓ With the spread of HTS, refrigerant costs are on a declining trend (Note 1, Note 2) ✓ Refrigerants are recycled, but replacement types also exist ✓ Suppressing operating costs through further reduction of refrigerant costs is key

Note 1: The refrigerant unit price for LTS, which was previously mainstream, is several thousand yen/L (liquid helium price)
Note 2: The refrigerant unit price for HTS, which is currently mainstream, is several tens of yen/L (liquid nitrogen price)
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Superconducting cables are expected to achieve initial widespread adoption in areas such as railways where clear introduction benefits are recognized

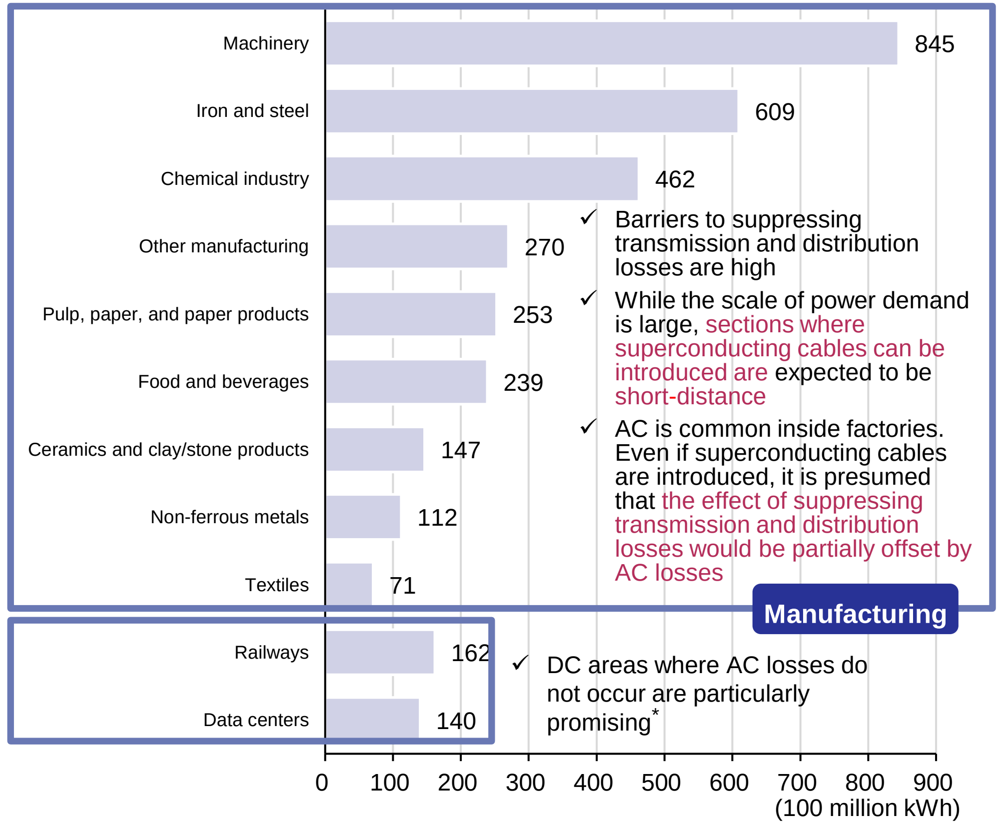
- Superconducting cables are expected to be adopted first in areas where cost benefits from introduction (e.g., reduction in the number of substations) are clear.
- While manufacturing industries also consume large amounts of electricity, the current situation is such that it is difficult to actively consider introduction due to factors such as short installation sections for superconducting cables.

Adoption process for superconducting cables for transmission and distribution lines (our bank's hypothesis)



Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Power consumption trends by industry (FY2023)



*Railways have both DC and AC systems. The significance of introduction is expected to be large even for AC systems based on the benefits of reducing the number of substations through superconducting cable introduction. Data center interiors commonly have DC structure.

Note: Railway data is from FY2022, data center data is from 2018

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials from Ministry of Economy, Trade and Industry and Ministry of Land, Infrastructure, Transport and Tourism

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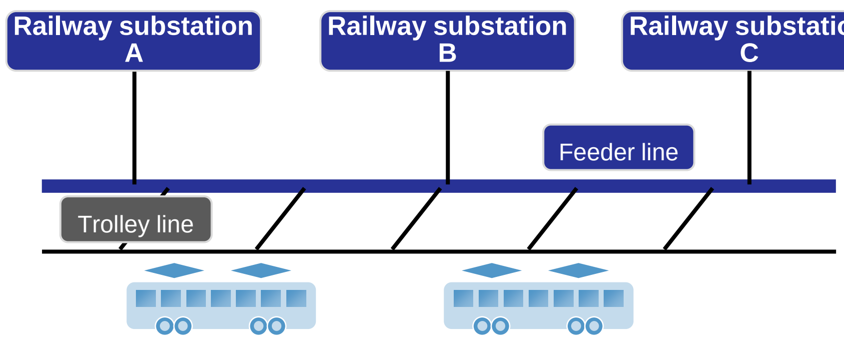
Superconducting cable introduction case study (1) - Utilization of superconducting cables in the railway sector

- The Railway Technical Research Institute has conducted demonstration experiments toward the introduction of superconducting cables to feeder lines in a section of the Izuhakone Railway.
- The introduction of approximately 100 m of superconducting cable has been demonstrated. Going forward, efforts will focus on introduction over kilometer-scale distances and other initiatives.

Izuhakone Railway: Demonstration experiments for utilizing superconducting cables in feeder lines

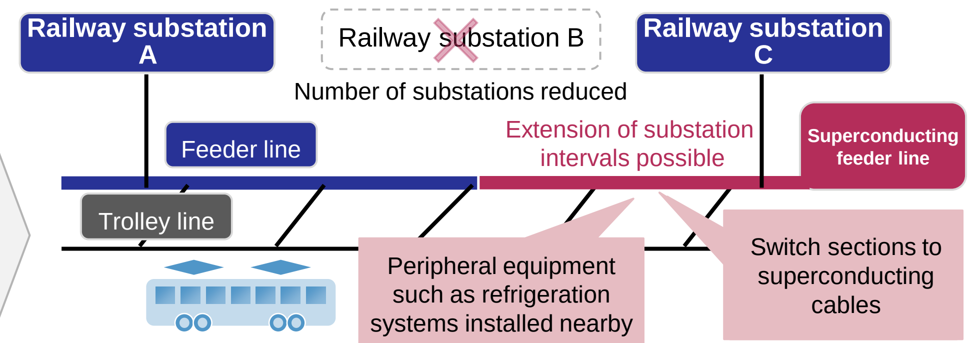
Implementing company	Overview of initiatives	Remarks
Railway Technical Research Institute	✓ In March 2024, conducted demonstration experiments relating to the utilization of superconducting feeder line systems on the Izuhakone Railway (world's first attempt) ✓ Power supply to vehicles using 102 m of superconducting cable	✓ Policy to continue development of the same system and aim for technical establishment within 5 years ✓ Also aims to contribute to solving similar transmission and distribution loss issues that railway companies face (demonstration experiments also conducted on JR East's Chuo Main Line)

Image of conventional power transmission system



✓ **Railway substations are installed at regular intervals to maintain voltage during transmission**
— **When voltage drops, power cannot be supplied to vehicles**

Image of demonstration experiment on Izuhakone Railway



✓ **Cost benefits expected from reduction in number of substations and suppression of transmission and distribution losses**

Cost reduction through substation reduction and transmission/distribution loss suppression provides incentives, making it easier to advance consideration of superconducting cable introduction. In particular, since AC losses do not occur, introduction to DC electrified railways where the benefits of superconducting cables are less likely to be impaired is considered promising.

(About **70%** of private railways and about **36%** of **JR** conventional lines use DC electrification.)

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on public information and various media reports

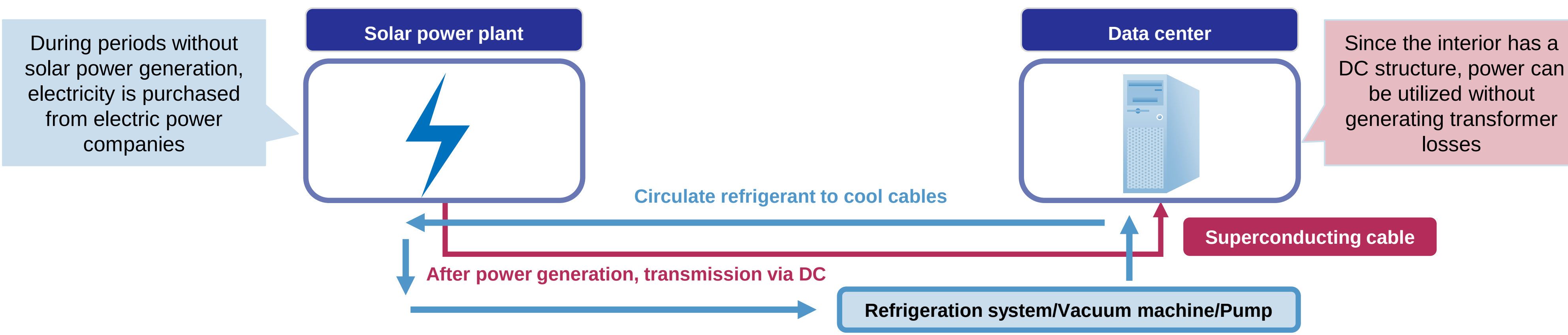
Superconducting cable introduction case study (2) - Utilization of superconducting cables in data centers

- Sakura Internet, a data center operator, utilizes superconducting cables for power supply to its data center in Ishikari City, Hokkaido.
- Through the utilization of solar power-derived electricity, the company achieves not only suppression of transmission and distribution losses but also responds to society's demands for green transformation.

Sakura Internet: Demonstration experiments for utilizing superconducting cables at Ishikari Data Center

Implementing company	Overview of initiatives	Remarks
Sakura Internet Inc.	✓ In December 2023, procured 500 m of superconducting cable, refrigeration system, and other equipment for Ishikari Data Center — Commissioned by METI for demonstration research on superconductivity (2013), which served as the catalyst	✓ Background of working on demonstration experiments through utilization of Sumitomo Electric Industries' superconducting cables ✓ Focused on utilization of superconducting cables in data centers where significant increases in power consumption are expected ✓ Currently exploring practical application of superconducting cables

Image of power supply to Ishikari Data Center through utilization of superconducting cables



In data centers where large currents flow, suppression of transmission and distribution losses tends to become a key issue. Collaboration with renewable energy-derived power plants can better respond to society's demands for green transformation, making such considerations highly significant.

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on public information

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Electricity consumers and cable manufacturers may find it difficult to make bold investments

- Various barriers stand in the way of the introduction of superconducting cables, including high investment costs. Measures to promote widespread adoption are particularly needed in areas such as manufacturing, where it is difficult to identify benefits that exceed the barriers to introduction.

Main Barriers Expected When Considering the Adoption of Superconducting Cables

	Electricity Consumers	Cable Manufacturers
1 Cost-related Barriers	✓ CAPEX and OPEX associated with introducing superconducting cables ✓ Unless used for long-distance transmission or high-power sections, only limited transmission and distribution loss suppression effects can be enjoyed, making it difficult to enjoy cost benefits	✓ Due to unclear market timing, it is difficult to invest high R&D costs
2 Technical Barriers	✓ Because technology for long-length superconducting cables is immature, the sections where they can be introduced are limited	✓ It is difficult to create long-length superconducting cables manufactured by layering various metals ✓ There is room for improvement when it comes to increasing the amount of power that can be transmitted in the superconducting state
3 Sales-related Barriers	✓ This is a new technology, and electricity consumers find it difficult to make introduction decisions unless they have sufficient trust and confidence in the introduction (Cable manufacturers find it difficult to promote sales unless they can gain sufficient trust and confidence from electricity consumers for introduction)	

- ✓ **In areas where it is unclear whether the benefits of superconducting cable introduction exceed costs, it is difficult to advance consideration of introduction**
- ✓ **Cable manufacturers find it difficult to make bold investments when it is difficult to establish revenue prospects**

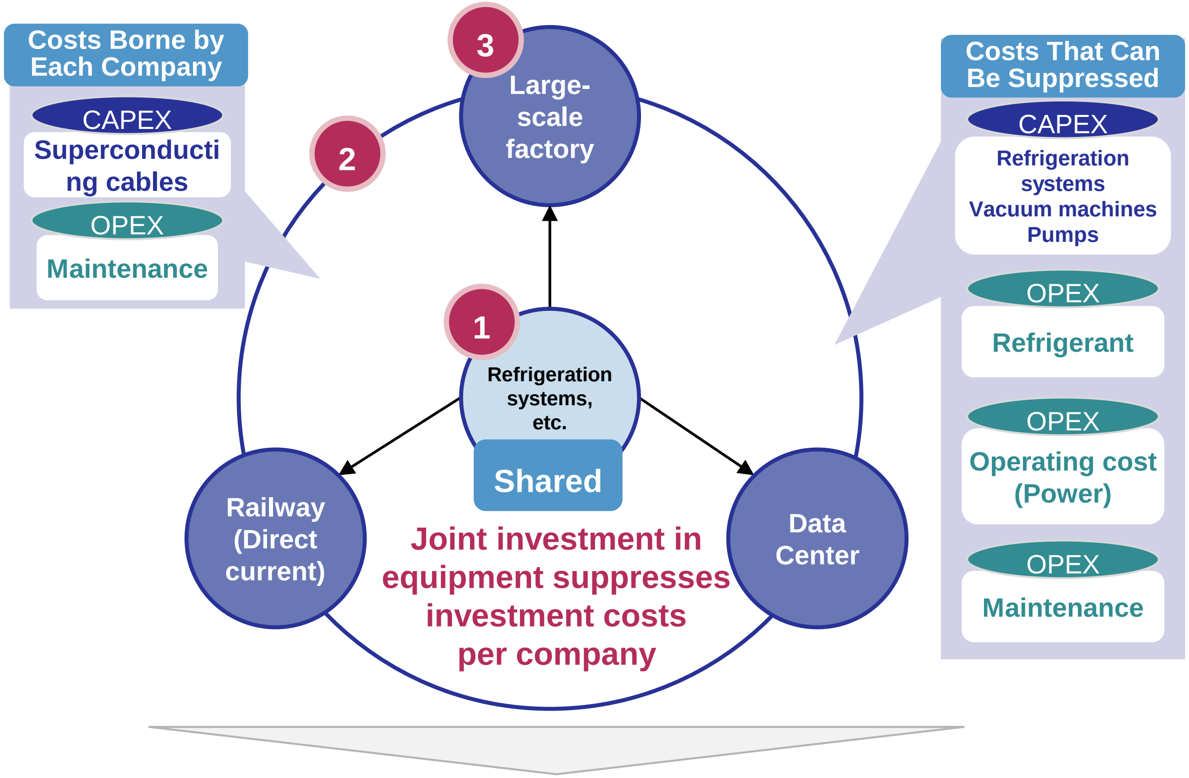
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Measure (1) - Suppression of investment costs for superconducting cables through development of "Superconducting Industrial Zone" concept

- Large-scale factories that can utilize superconducting cables collaborate and make joint investments in equipment such as refrigeration systems, which may reduce the barriers to introducing superconducting cables.

Measures to Suppress Investment Costs of Introducing Superconducting Cables - Development of "Superconducting Industrial Zone" Concept (Mizuho Bank's Hypothesis)

Companies utilizing superconducting equipment collaborate to form industrial zones



Redesigning existing industrial zones to be more energy-efficient to suppress investment costs for superconducting cables

1 Sharing Equipment Among Neighboring Electricity Consumers

- ✓ Large-scale factories, railway companies, and data centers make joint investments in equipment and share facilities

2 Development Based on Location Characteristics of Each Facility

- ✓ Development is also envisioned in areas other than those where all three - large-scale factories, railways, and data centers - are present
- ✓ Development is also anticipated in areas across the country where factories are concentrated (such as coastal areas in various regions) and areas where data centers are concentrated (e.g., Inzai City, Chiba Prefecture)

3 Tailwind for Superconducting Cable Introduction in Large-scale Factories

- ✓ Even in large-scale factories where it seems difficult to anticipate cost benefits through superconducting cable introduction compared with railways and data centers, widespread adoption may gain momentum

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Measure (2) - Collaboration among cable manufacturers is key to achieving further innovation

- Initiatives that promote research and development for the production of long-length superconducting cables for transmission and distribution are considered important.

Measures to Accelerate Innovation in Superconducting Cables (Mizuho Bank's Hypothesis)

1 Partnerships Among Superconducting Cable Manufacturers

- ✓ We anticipate partnerships in the field of long-distance transmission where technical barriers remain high
- ✓ Companies collaborate toward the development of long-length cables that can be used for transmission and distribution

2 Utilization of Materials Informatics (MI)

- ✓ Cable manufacturers partner with MI companies to develop superconducting materials and inexpensive refrigerants
- ✓ Through lobbying the government, there is also the prospect of developing this as a demonstration project with government support

Joint Development with Electricity Consumers Also Under Consideration

3 Collaboration with Venture Capital (VC)

- ✓ Superconducting cable manufacturers spin off their superconducting business into subsidiaries
- ✓ They attract external funding through external VCs to accelerate investment and product development in the superconducting business

1 Advancement of Technological Innovation

- ✓ Examples of anticipated technological innovations
  - — Improvement of production processes to shorten production lead times
  - — Development of new superconducting wire materials that contribute to increasing Ic (aiming to improve transmission efficiency)
  - — Development of refrigerants that are less expensive compared with liquid nitrogen
- ✓ By collaborating with electricity consumers from the development stage, gain trust and confidence in superconducting cables

2 (Secondary Effects) Improved Presence of Superconducting Cables

- ✓ If partnerships with prominent overseas investors are realized, this could lead to promotion of Japan's superconducting business
  - — This is an effective means when promoting business based on new technology on a global scale

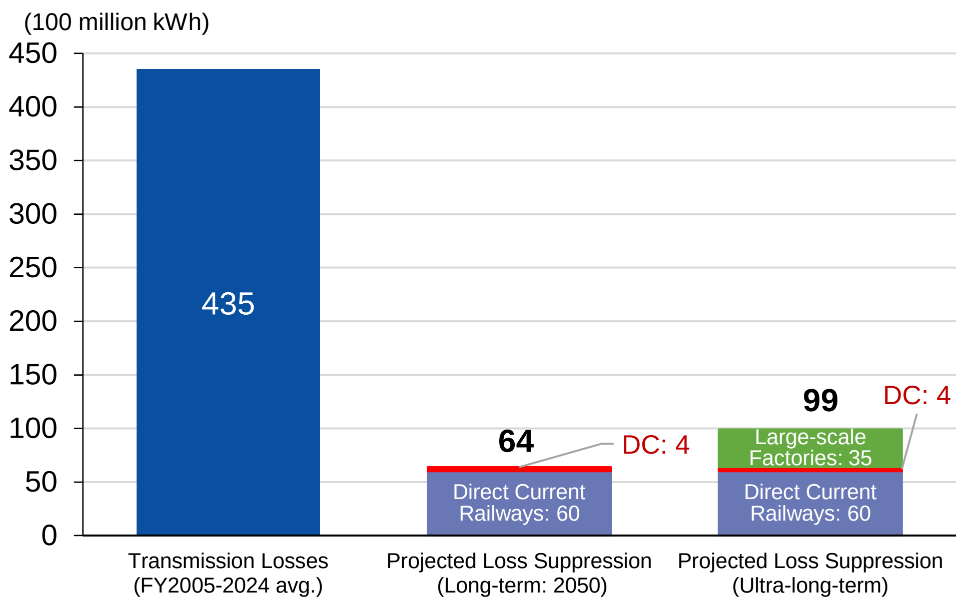
The advancement of technological innovation is considered a factor that will further promote the adoption of superconducting cables among electricity consumers.

Note: VC: Venture Capital
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

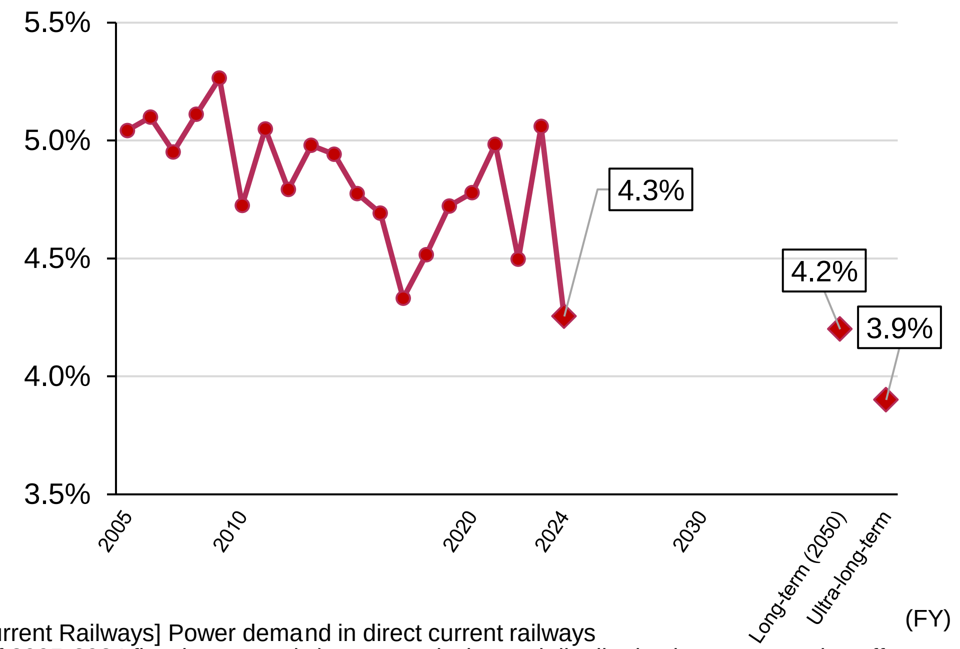
Image of changes in transmission and distribution loss suppression - Loss suppression progresses over time in the long term and ultra-long term

- Through the introduction of superconducting cables to railways (direct current), data centers, and large-scale factories, transmission and distribution losses equivalent to approximately one nuclear power plant are expected to be suppressed.
  - Long-term (2050): Widespread adoption of superconducting cables in railways and data centers progresses
  - Ultra-long-term: Widespread adoption of superconducting cables in large-scale factories also progresses
  - Promotion of research and development (shortening production lead times, increasing Ic, developing new refrigerants, etc.) contributes to widespread adoption

Outlook for Transmission and Distribution Loss Suppression



Outlook for Transmission and Distribution Loss Rate



Note 1: Method for creating outlook for transmission and distribution loss suppression: [Direct Current Railways] Power demand in direct current railways (approximately 8 billion kWh) × transmission and distribution loss rate (4.8%, average of 2005-2024 fiscal year results) × transmission and distribution loss suppression effect through utilization of superconducting cables (assumed to suppress 95% of loss). [Data Centers] Power demand in data centers (approximately 150 billion kWh, our bank's estimated value for 2050) × transmission and distribution loss rate (4.8%, same as above) × transmission and distribution loss suppression effect through utilization of superconducting cables (same as above). [Large-scale Factories] Power demand in large-scale factories (approximately 3.5 billion kWh) × transmission and distribution loss rate (4.8%, same as above) × transmission and distribution loss suppression effect through utilization of superconducting cables (same as above).

Note 2: "Power demand in direct current railways" assumes no significant changes in the future, using actual values of recent power demand. Performance values of SWCC-manufactured superconducting cables are utilized for "transmission and distribution loss suppression effect through utilization of superconducting cables." "Power demand in data centers" is estimated by our bank based on the data center power demand outlook published by the Organization for Cross-regional Coordination of Transmission Operators. "Power demand in large-scale factories" is estimated by considering manufacturing industries using extra high voltage power as large-scale factories (approximately 40% of all manufacturing industries).

Note 3: Transmission and distribution loss rates for long-term (2050) and ultra-long-term periods are estimated based on the outlook for transmission and distribution loss suppression and power demand outlook estimated by our bank.

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials from the Ministry of Land, Infrastructure, Transport and Tourism and Organization for Cross-regional Coordination of Transmission Operators, and public information.

Reference: Implementation of nuclear fusion power generation is expected to contribute to improving Japan's energy self-sufficiency rate

- Nuclear fusion power generation is a power generation method that is attracting attention from the perspective of enabling more efficient power generation compared with existing power generation methods such as thermal power generation, while alleviating resource procurement constraints.

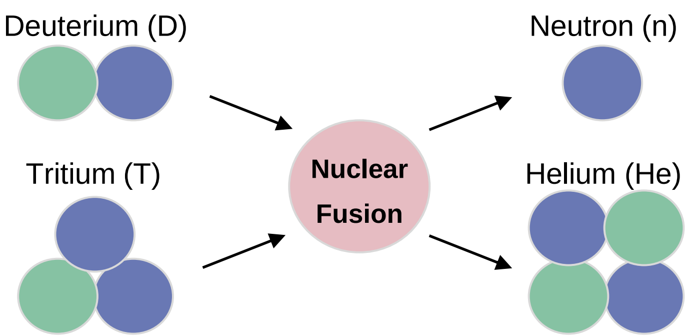
Principles of Nuclear Fusion

1

Deuterium and tritium, which are gases,
are heated to high temperatures and turned into plasma.

2

Through plasmaization, the nuclei of deuterium and tritium are exposed and collide and fuse with each other, producing neutrons and helium (= DT nuclear fusion reaction).



3

The mass of neutrons and helium is lighter than that of deuterium and tritium.
This difference in mass is converted to thermal energy.

Power generation is carried out based on the thermal energy produced

Note: Deuterium is contained in seawater at approximately 0.015%. Tritium can be recovered from lithium in seawater.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on National Institutes for Quantum Science and Technology website

Advantages of Nuclear Fusion Power Generation

1	Ease of Fuel Procurement	✓ Deuterium and tritium can be recovered from seawater Note ✓ Few concerns about resource procurement constraints
2	Enormous Energy Generation	✓ The amount of energy that can be generated from 1 gram of fuel in nuclear fusion power generation is equivalent to the amount of energy obtained from thermal power generation using 8 tons of oil
3	Fewer Concerns About Radioactive Material Treatment	✓ The period required for treating radioactive materials generated during nuclear fusion power generation is approximately 100 years ✓ This is a short period compared to approximately 100,000 years for nuclear power generation

It is thought that the practical application of nuclear fusion power generation will contribute to improving Japan's energy self-sufficiency rate and ensuring energy security

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on public information

Reference: In the nuclear fusion field, superconducting cables are utilized for coils

- Nuclear fusion reactors that utilize superconductivity are "magnetic confinement" reactors. Superconducting cables are utilized in coils that generate the magnetic field necessary to maintain the plasma state of nuclear fusion fuel.

Background of Superconducting Cable Utilization in Nuclear Fusion Reactors

Background of Superconducting Cable Utilization in Nuclear Fusion Reactors

- ✓ After nuclear fusion fuel deuterium and tritium are turned into plasma, a magnetic field is necessary to maintain the plasma state
- ✓ Coils are utilized to form magnetic fields, and current must flow through the coils at all times; if power loss occurs when energizing the coils, the benefits of power generation may be impaired

Main types of nuclear fusion reactors and major players responsible for research and development

Magnetic Confinement Type (Utilizing superconductivity)

Current flows through coils to form magnetic fields.
Plasma is maintained inside the reactor to generate electricity continuously.

Tokamak Type
- ✓ Japan / JA-DEMO
- ✓ US / Commonwealth Fusion Systems
- ✓ UK / Tokamak Energy
- ✓ China /ENN

Helical Type
- ✓ Japan / National Institute for Fusion Science
- ✓ Japan / Helical Fusion

Reverse Field Configuration Type
- ✓ US / Helion Fusion
- ✓ US / TAE Technologies

Mirror Type
- ✓ US / Lockheed Martin

Inertial Confinement Type

Laser irradiation of nuclear fusion fuel
Utilizing the "implosion"* phenomenon generated by heating

Laser Type
- ✓ US / Lawrence Livermore National Laboratory
- ✓ US / Blue laser fusion
- ✓ Japan / Osaka University Institute of Laser Engineering
- ✓ Japan / EX-Fusion

Others
- ✓ UK / First Light Fusion
- ✓ US / Zap Energy

Magnetic Inertial Fusion
- ✓ Canada / General Fusion

Others
- ✓ Japan / Chubu University
- ✓ Japan / Clean Planet

- ✓ **Research and development of nuclear fusion reactors is promoted by startup companies and research institutions both domestically and internationally**
- ✓ **Cable manufacturers such as Furukawa Electric are collaborating with nuclear fusion reactor manufacturers domestically and internationally to supply superconducting wire materials**
- ✓ **Currently, LTS (Low-Temperature Superconductivity) utilization is mainstream in magnetic confinement types, but attention is focused on whether suppression of cooling costs through substitution with HTS (High-Temperature Superconductivity) will progress in the future**

Note: When laser heating is successful, the outside of the fuel pellet expands rapidly, but the inside is rapidly compressed by the momentum (= inertia) of the outside’s expansion. By rapidly heating the compressed interior, an ultra-high temperature state is created.
Source: Both diagrams were compiled by Industry Research Department, Mizuho Bank, Ltd. based on Ministry of Economy, Trade and Industry materials and public information

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