PL3 Overview of Superconducting Power Applications in Japan

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The 37th International Symposium on Superconductivity

ISS2024 December 4, 2024

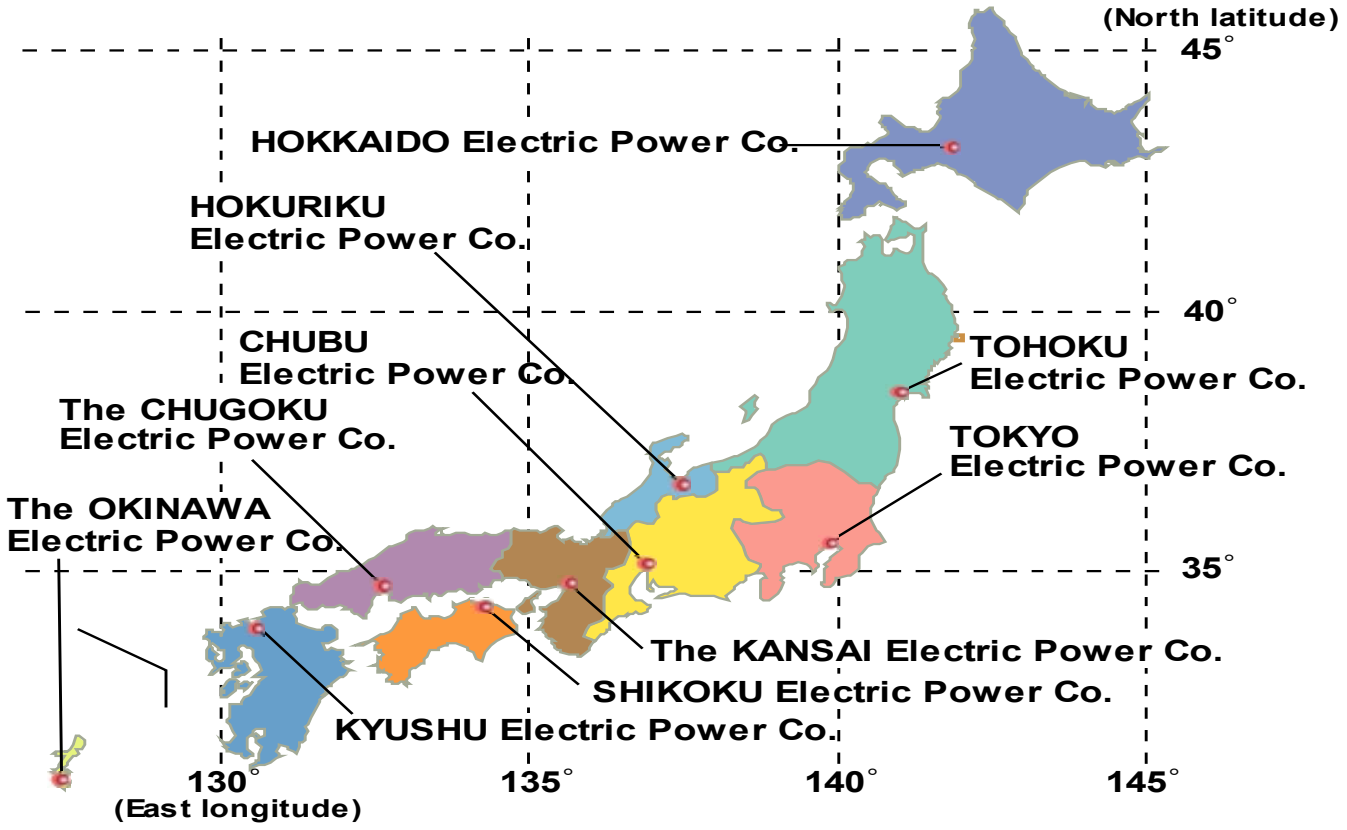
CRIEPI
Central Research Institute of Electric Power Industry

IEEE CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 58, Feb. 2025.
Plenary presentation given at ISS 2024, Kanazawa, Japan, Dec. 4, 2024.

Japanese Power Industry before Liberalization

Sales Area up to March 2000

Encompassing All of Japan–The Ten Electric Power Companies by Service Areas

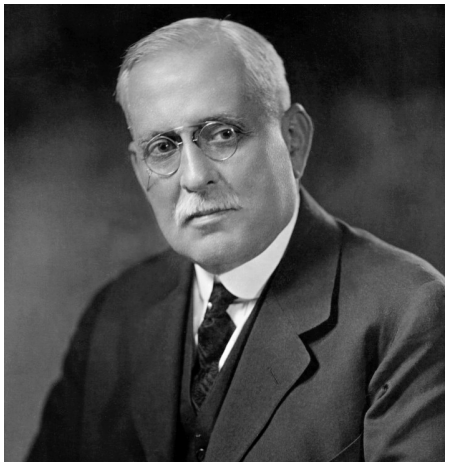


(Ten Electric Companies have covered Japan)

Electricity Business to Date

It was a business to gather different types of loads, **improve daily and annual capacity utilization** rates, and cut down fixed costs.

Example: "We are grateful for the ice-making industry in winter.“ by Mr. Samuel Insull in Chicago



President of Commonwealth Edison
1907～

Efforts of Electric Power Industry

- **Late-night** power **rate** setting
- Subsidy for **thermal storage** air conditioning system
- Promoting the spread of Eco Cute (Air to Water **Heat Pump**)

（ Efforts were made to increase the facility utilization rate ）

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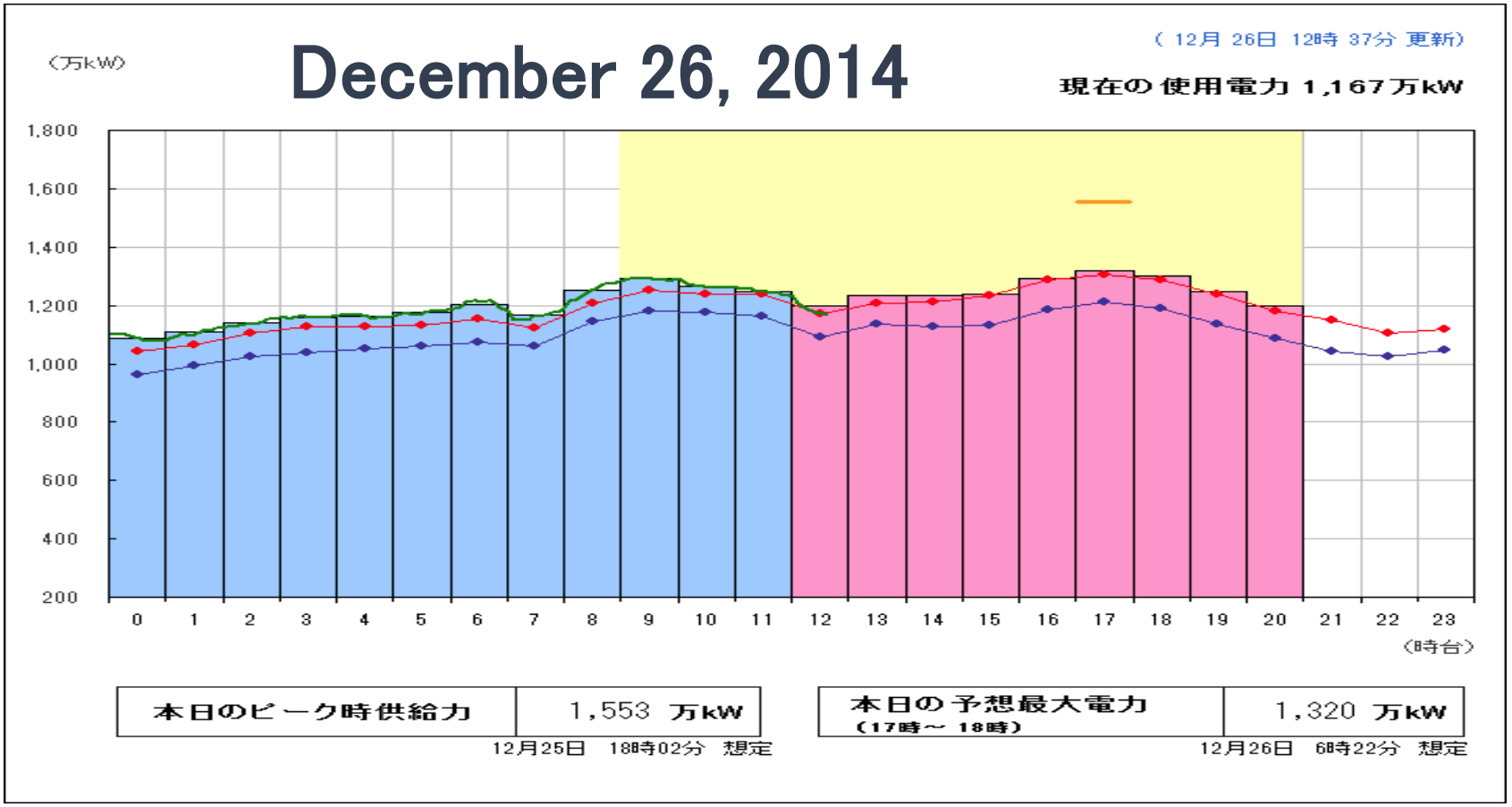
Winter Electricity Demand in Tohoku



（ Electricity demand is almost the same during the day and night ）

Electricity Business Today in Japan

Challenge to a Low-carbon Society

① Low-carbon emission power sources

② Energy-saving technology

demand side

high efficiency equipment

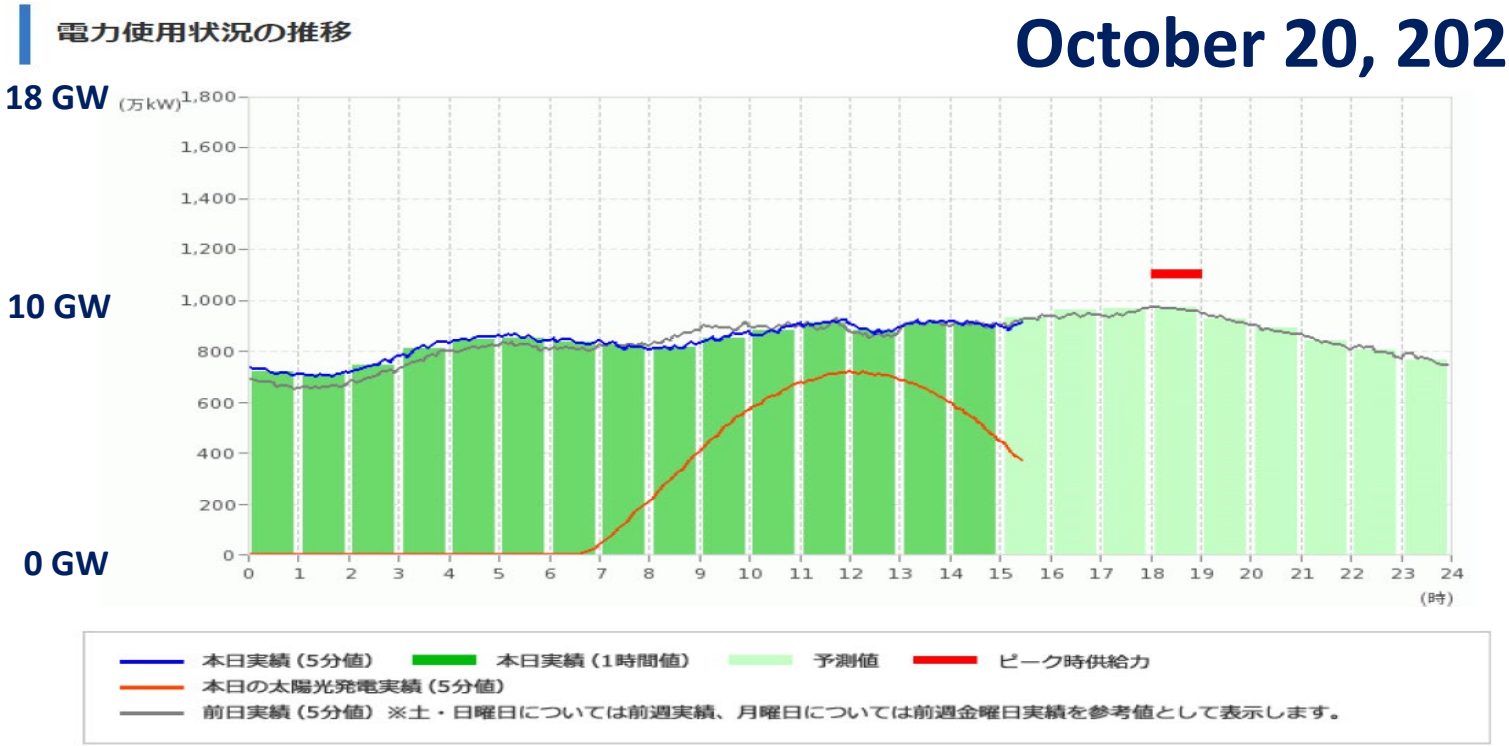
supply side

Low CO_2 intensity

Significant CO_2 emission reduction

（ Prime Minister announced carbon neutrality in 2050 ）

Supply and Demand Results of Kyushu Electric Power



（ Almost the world's largest percentage of solar power generation in large power system ）

Detailed Supply and Demand Results of Kyushu Electric Power

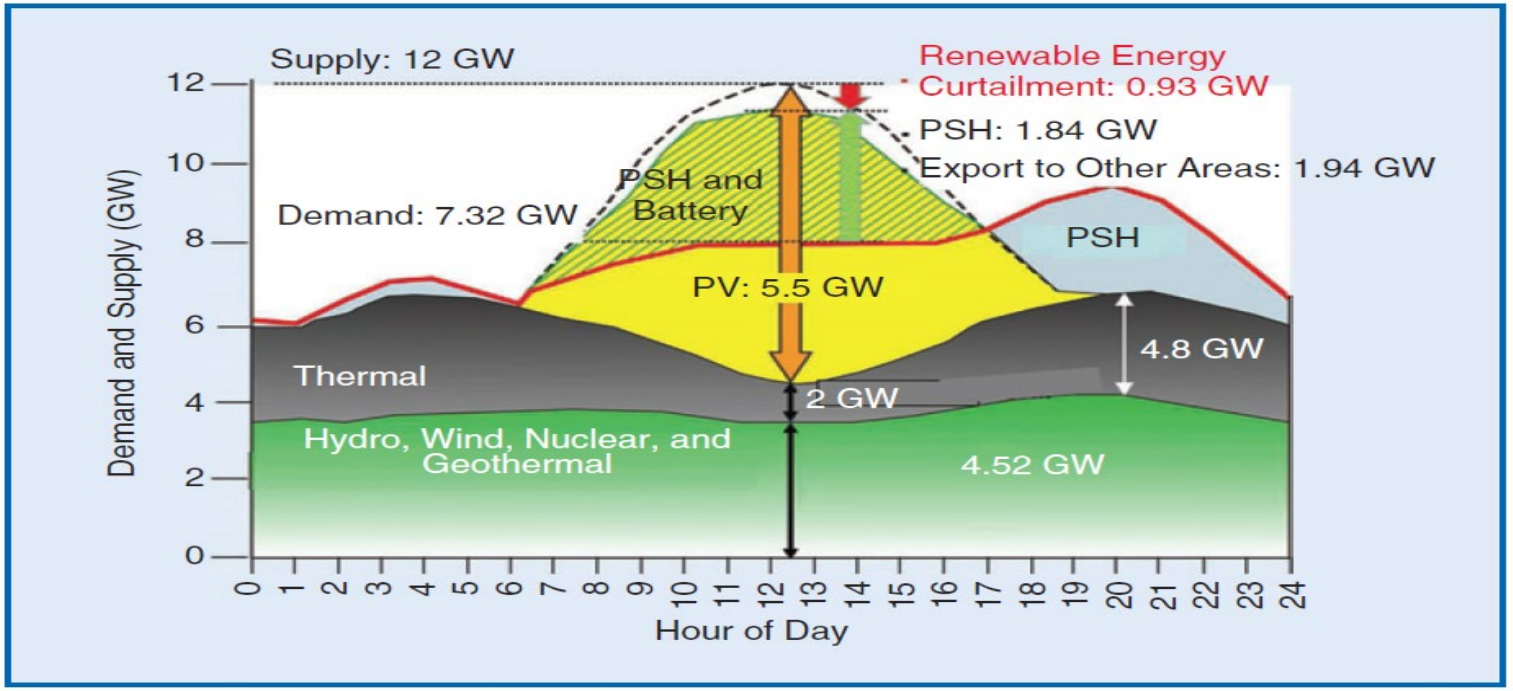


figure 5. The demand and supply operation on 21 October 2018. (Source: Kyushu EPCO; used with permission.)

(PSH : pumped-storage hydropower)

(Absorb surplus solar power by PSH)

"Making Renewables Work", by Kazuhiko Ogimoto and Hiroshi Wani IEEE Power & Energy Magazine November/December 2020 p.51

LTS field Winding Generator Development by Super-GM Project in Japan (FY1988～FY1999)

（Always watching HTS technology and including HTS wire R&D）

Advantages of Superconducting Field Winding Synchronous Rotating Machine

- **High efficiency** is possible (low excitation loss) .
- **High field flux density** can be generated with an **air core**.
- **Miniaturization** is possible.
- **lightweighted** is possible.
- Synchronous impedance can be reduced.

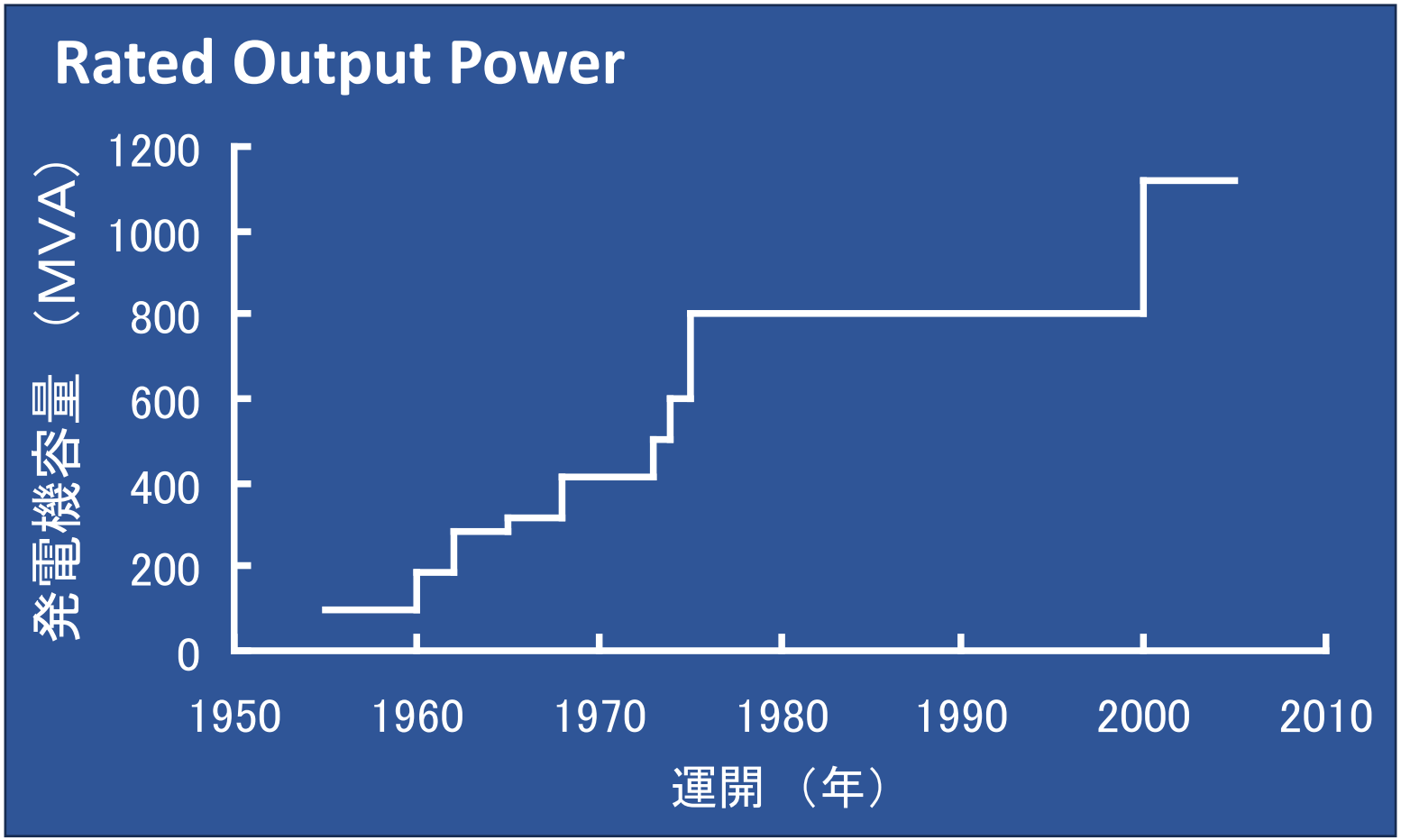
（HTS is same as LTS）

Development Challenges of Large-Capacity Turbine Generators

(Motivation for starting the Super-GM project)

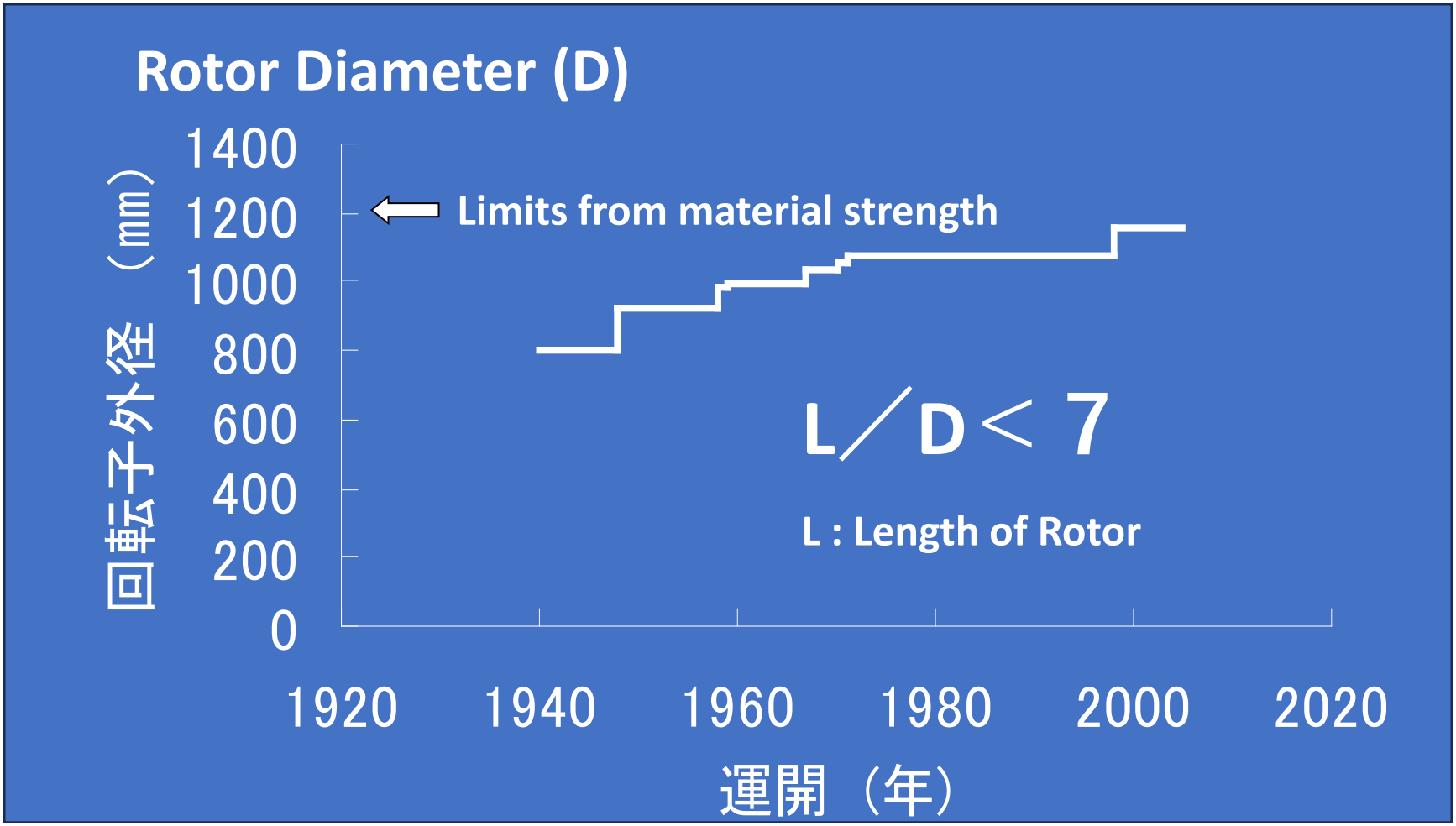
- Rapid Progress in Increasing the Capacity of Turbine Generators
- Manufacturing Issues
  - Rotor manufacturing limits
  - Cooling Constraints
- Operational Issues
  - Increased synchronization reactance
    ⇒ Increased voltage fluctuations
  - Remote Power Supply Location
    ⇒ Limitations of Static Stability

Rapid Progress in Increasing the Capacity of Turbine Generators (3600rpm)



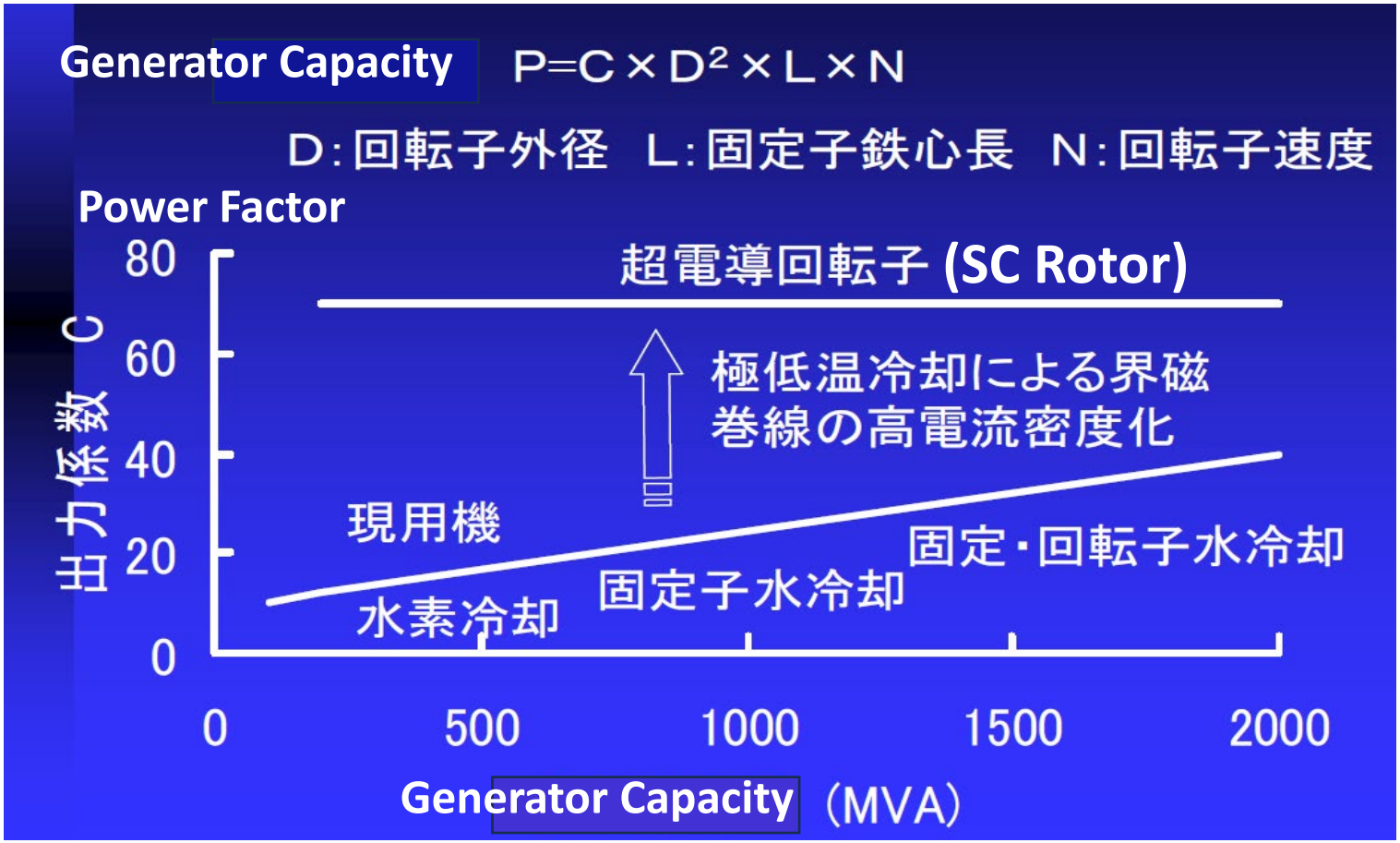
Rotor manufacturing limit

（for 3600 rpm machines）



Problems in the manufacture of turbine generators

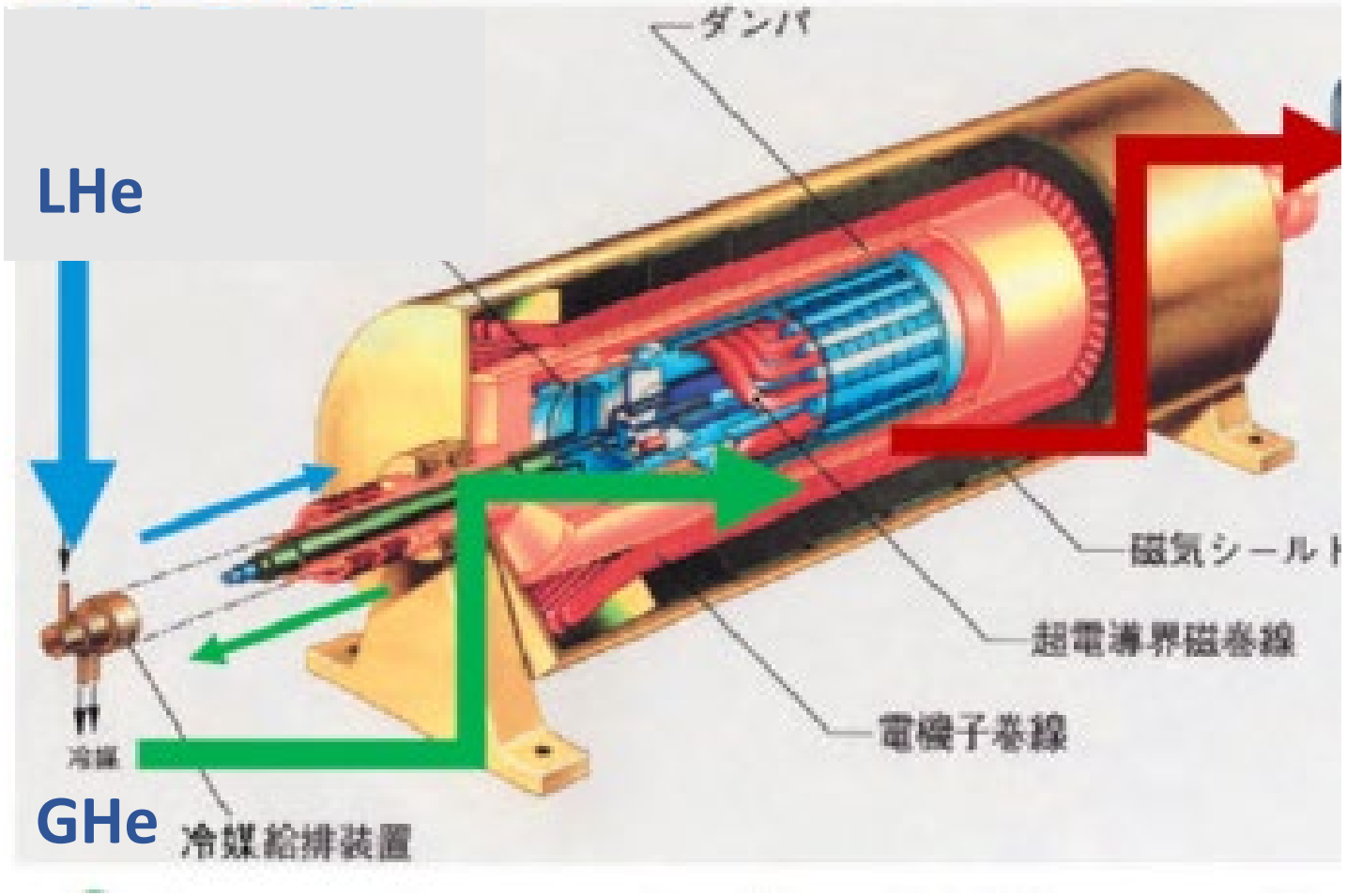
-Cooling Constraints-



Goals of the R&D plan in Super-GM

70MW Model=1/3 of 200MW rotor L and the same D

		Speed of excitation	
		Slow Response	Quick Response
Developed Model Generator	Output Power Synchronous reactance Field Current	70MW 0.4pu 1pu/10s	70MW 0.5pu 1pu/1s
SC Conductor	Rated Current Current Density Maximum Magnetic Field	3,000 A 120 A/mm^2 4.5 T	
Cooling System	Liquefaction capacity Continuous operation time	100 L/h 10,000 h	



200MW LTS field Winding Pilot Generator

Testing Center at KEPCO Osaka Power Station

（The KEPCO Osaka Power Plant has already been decommissioned）

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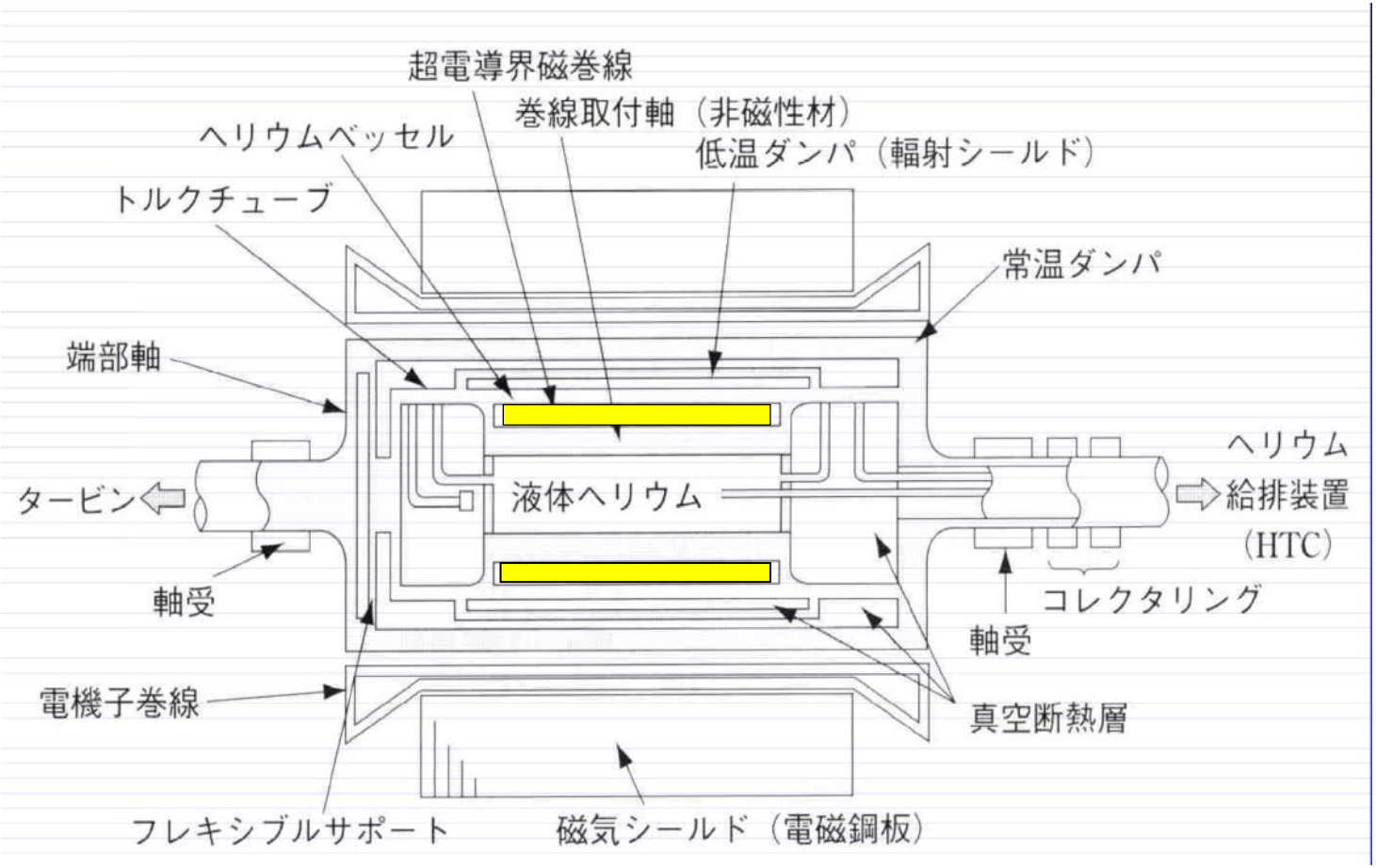
Installation status of SC generators

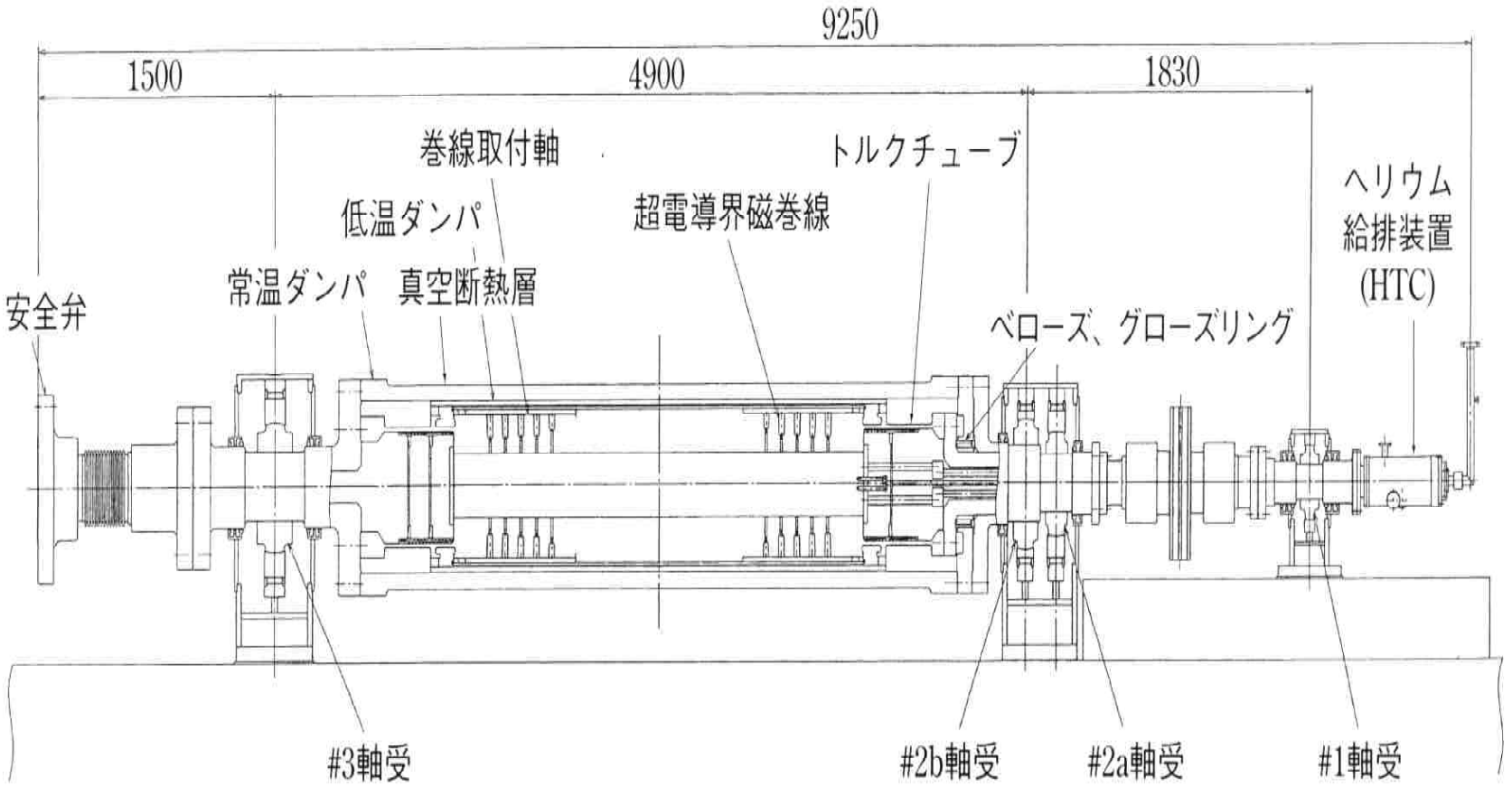
Exterior of 70MW SC Generator

Structure of a SC generator



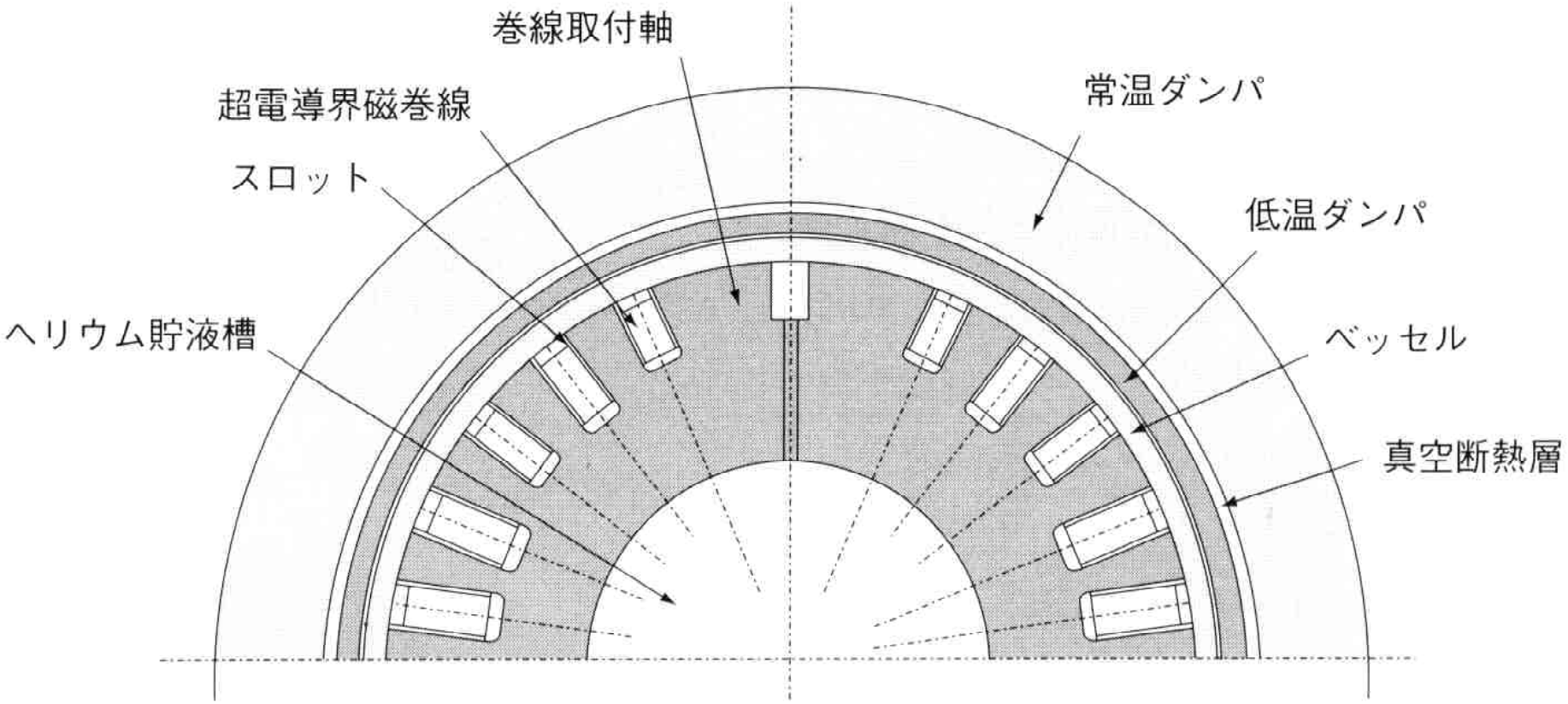
(It has a multi-cylindrical structure, with the center at liquid helium temperature and the outer surface at room temperature.)

Rotor structure by Super-GM



（The bearing on the side of the helium feeder is composed of two stages to absorb heat shrinkage.）

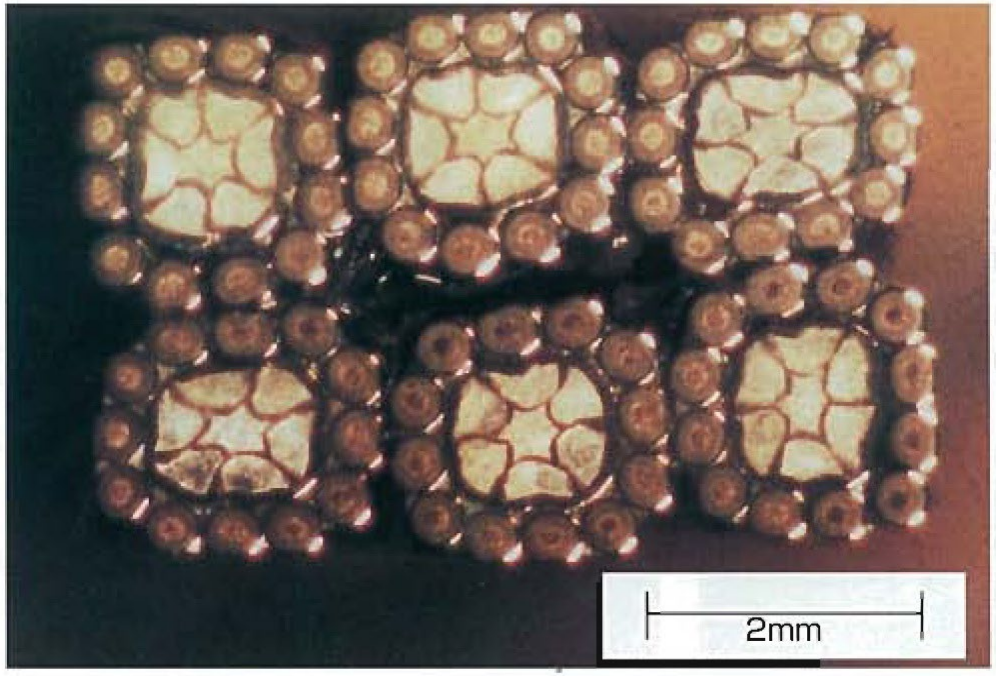
Cross-sectional structure of rotor



（In order to bring the output electric waveform closer to a sine wave, the number of field windings differs for each slot.）

SC conductors for field windings (A,B)

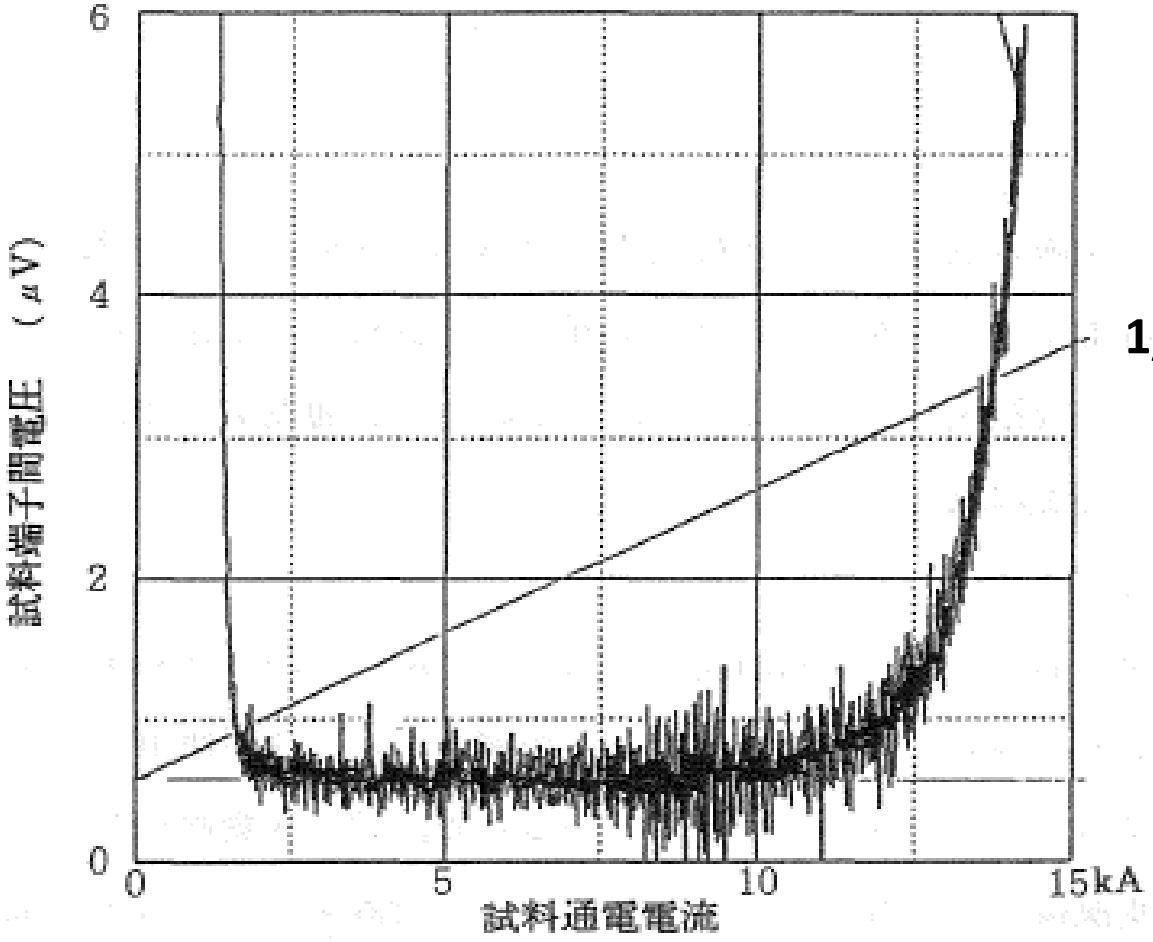
Slow Response NbTi (High Stability)



低速応型NbTi導体（高安定型導体）

(Aluminum Alloy is used as a transport current stabilizer, and the primary stranded wire is soldered.)

Critical current measurement results

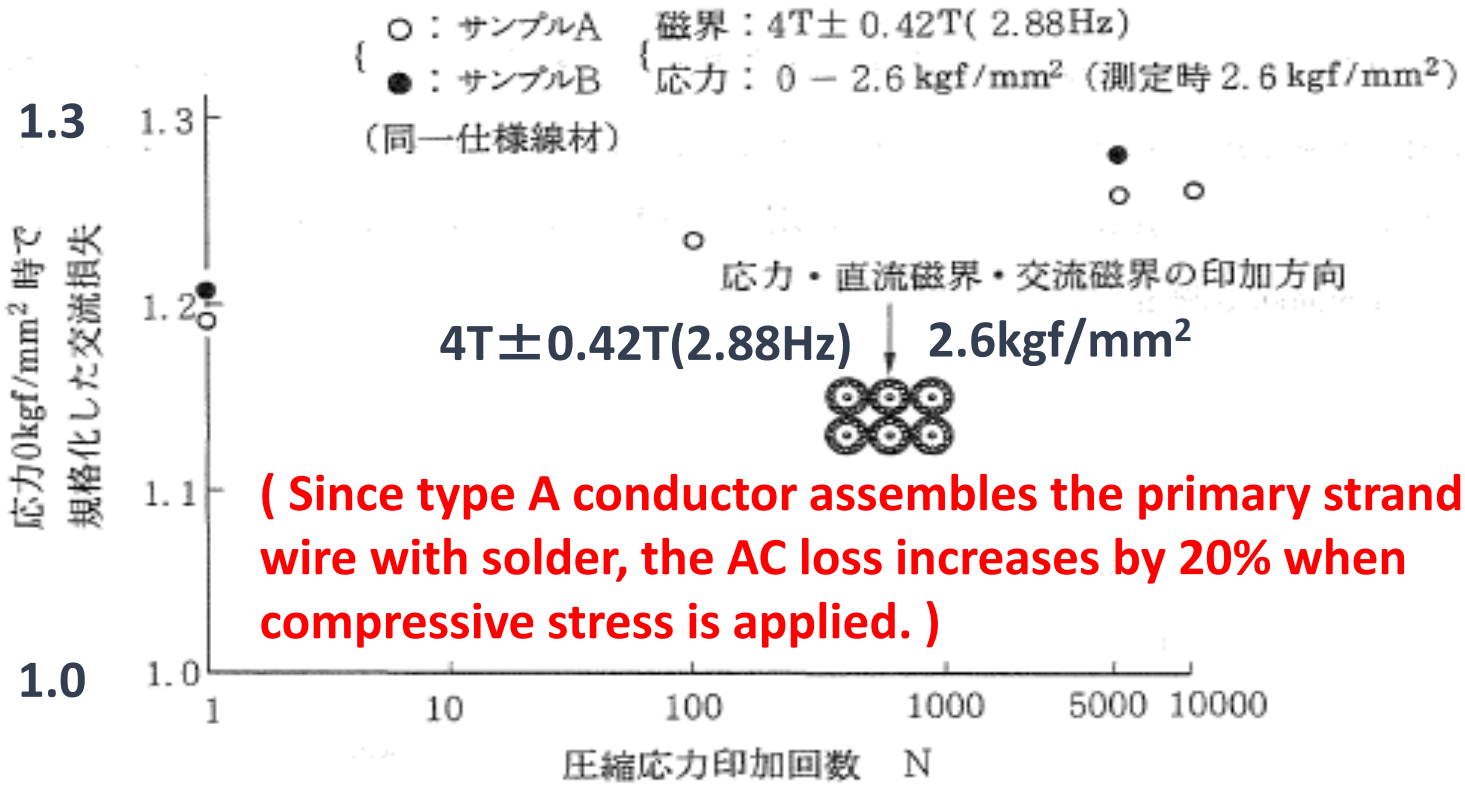


第12図　電流－電圧特性の一例

$1/8 \times 10^{-13}\Omega m$

15kA

Effect of recycled compressive stress on AC loss

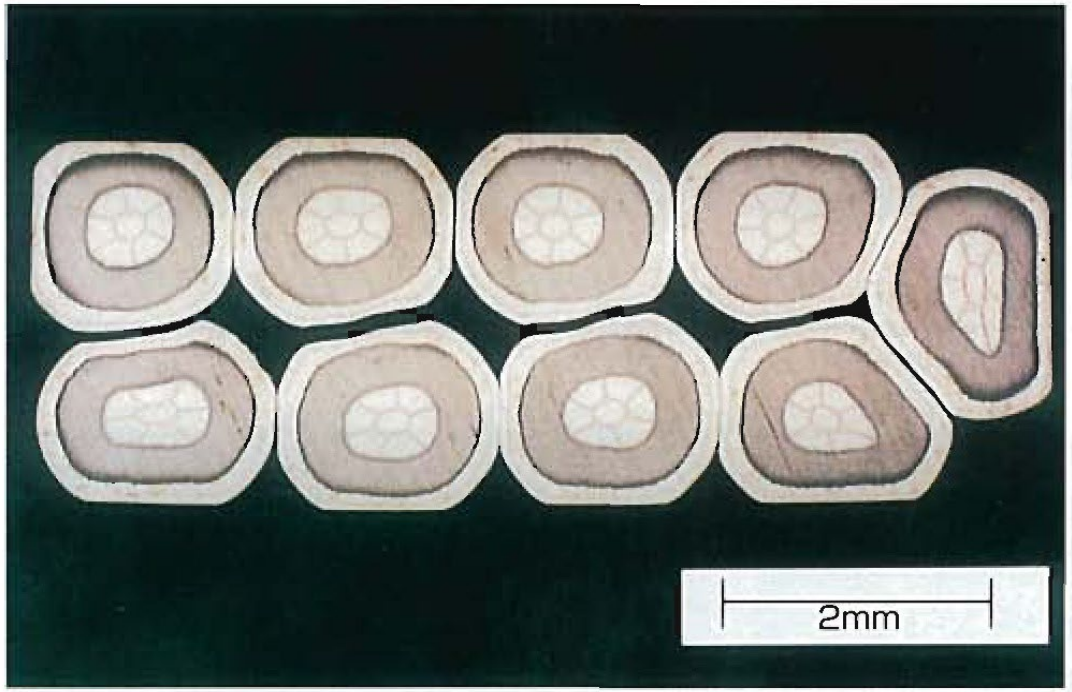


(Since type A conductor assembles the primary stranded wire with solder, the AC loss increases by 20% when compressive stress is applied.)

第17図　繰り返し圧縮応力印加時の交流損失

SC conductors for field windings (C,D)

Slow Response NbTi (High Current Density)

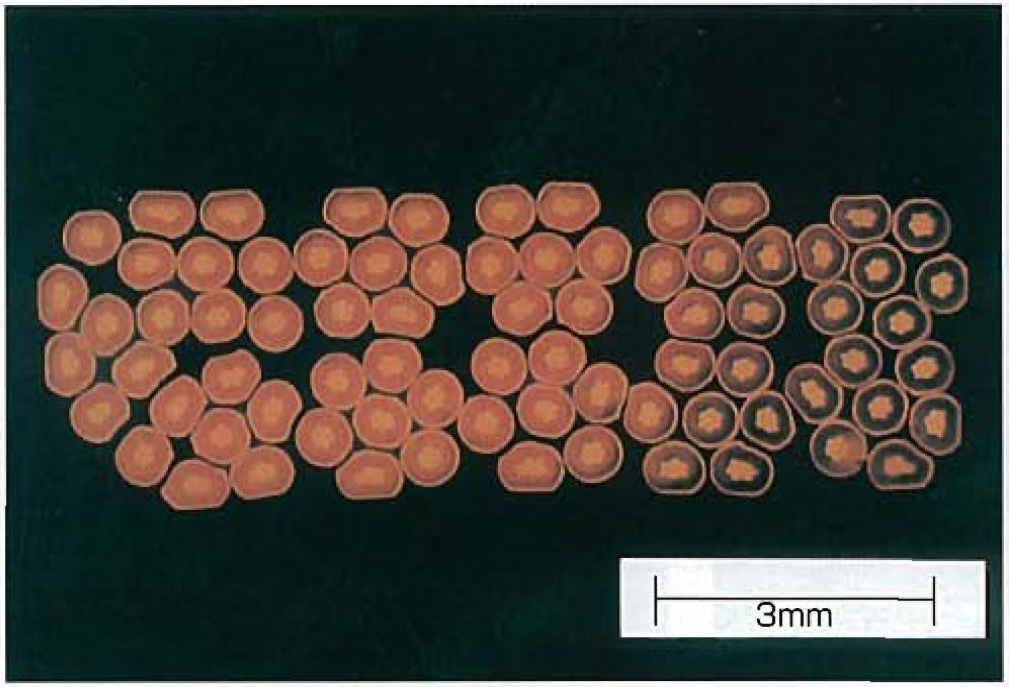


低速応型NbTi導体（高電流密度型導体）

(It has a Rutherford cable structure and high rigidity.)

SC conductors for field windings (E,F)

Quick Response NbTi



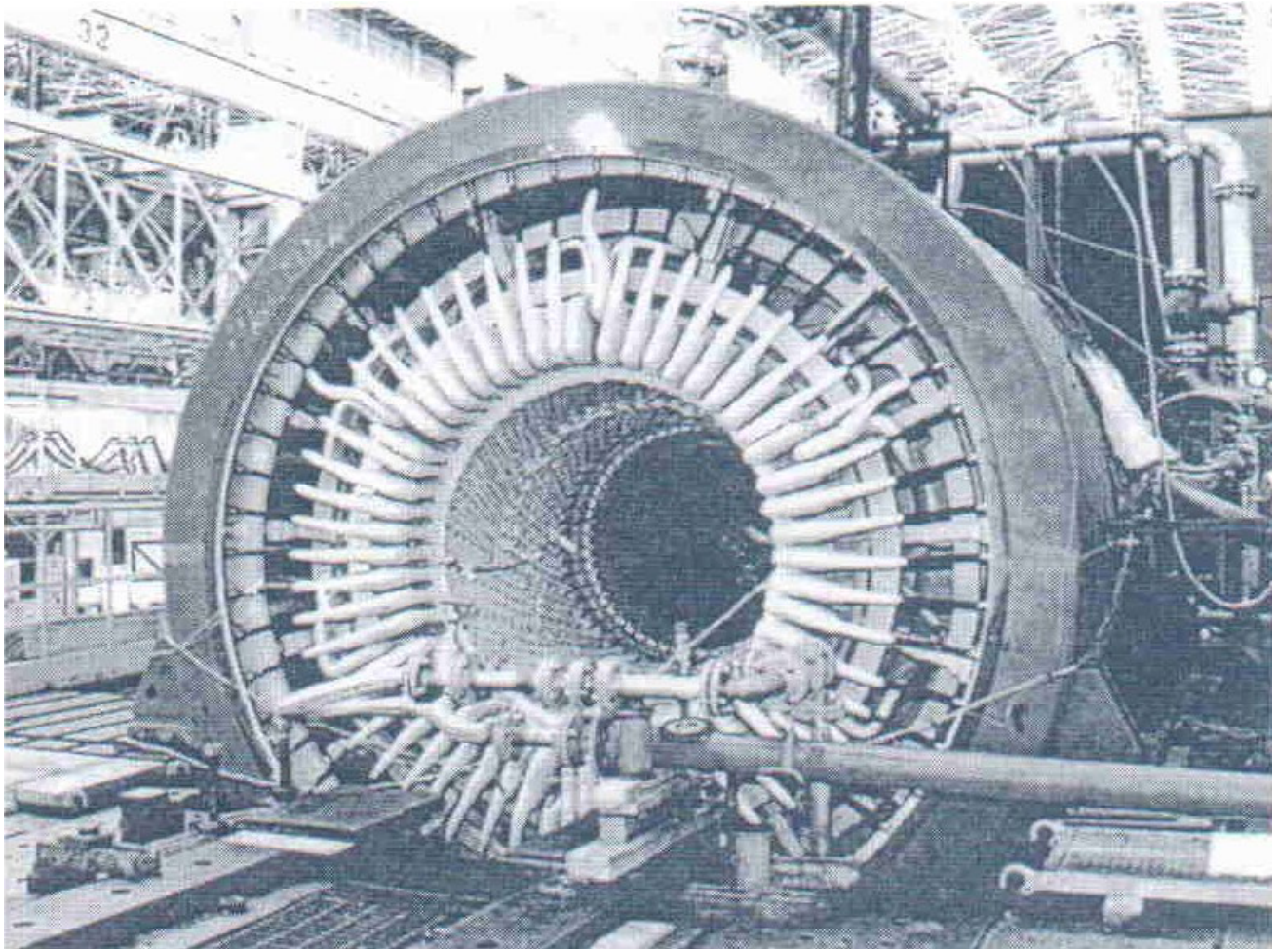
超速応型NbTi導体（低損失型導体）

（In order to reduce AC loss, it is made into a Rutherford cable using a primary stranded wire.）

Insertion of rotor into armature

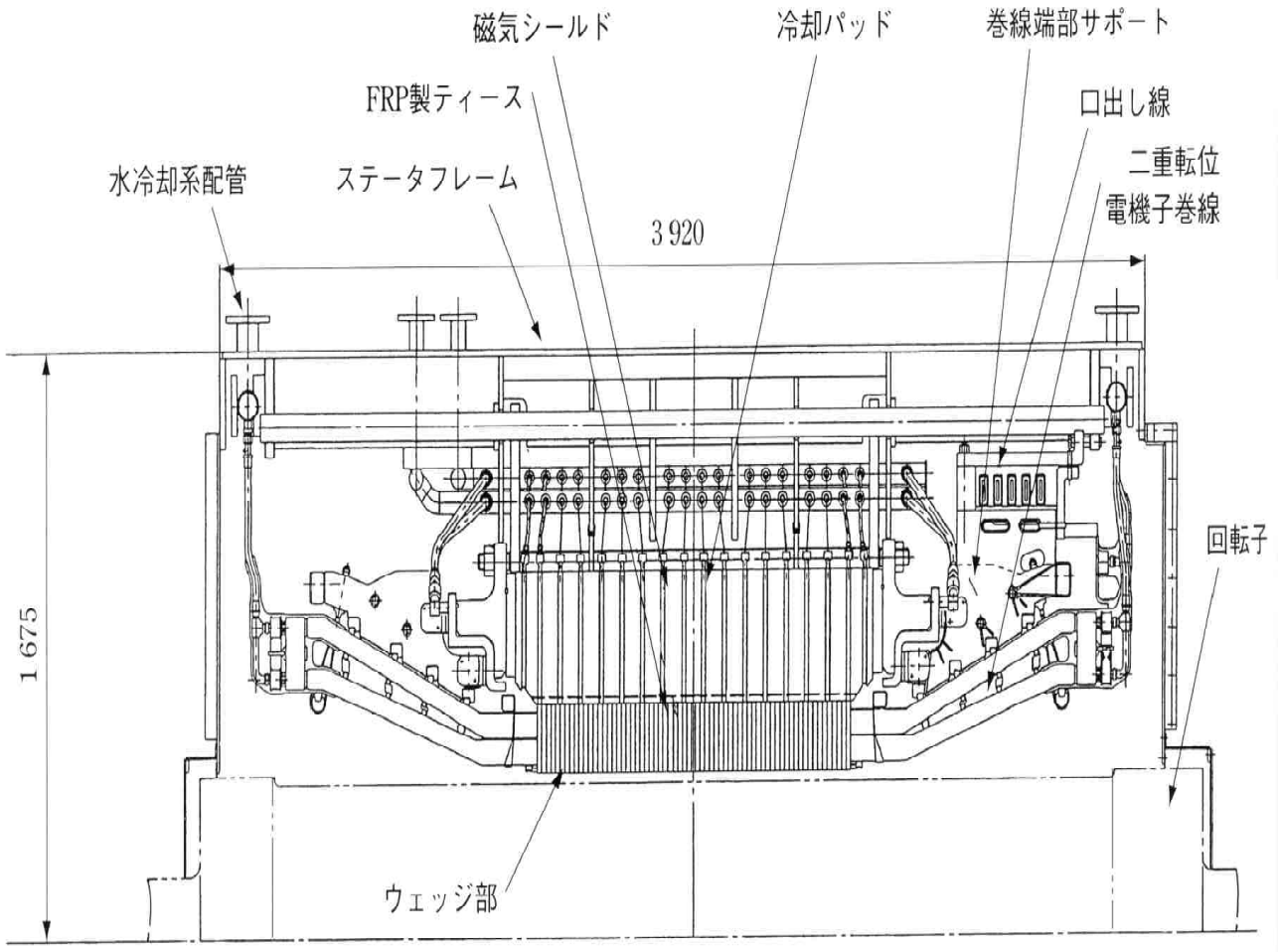
（Super-GM developed 3 types of superconducting rotors）

Developed armature



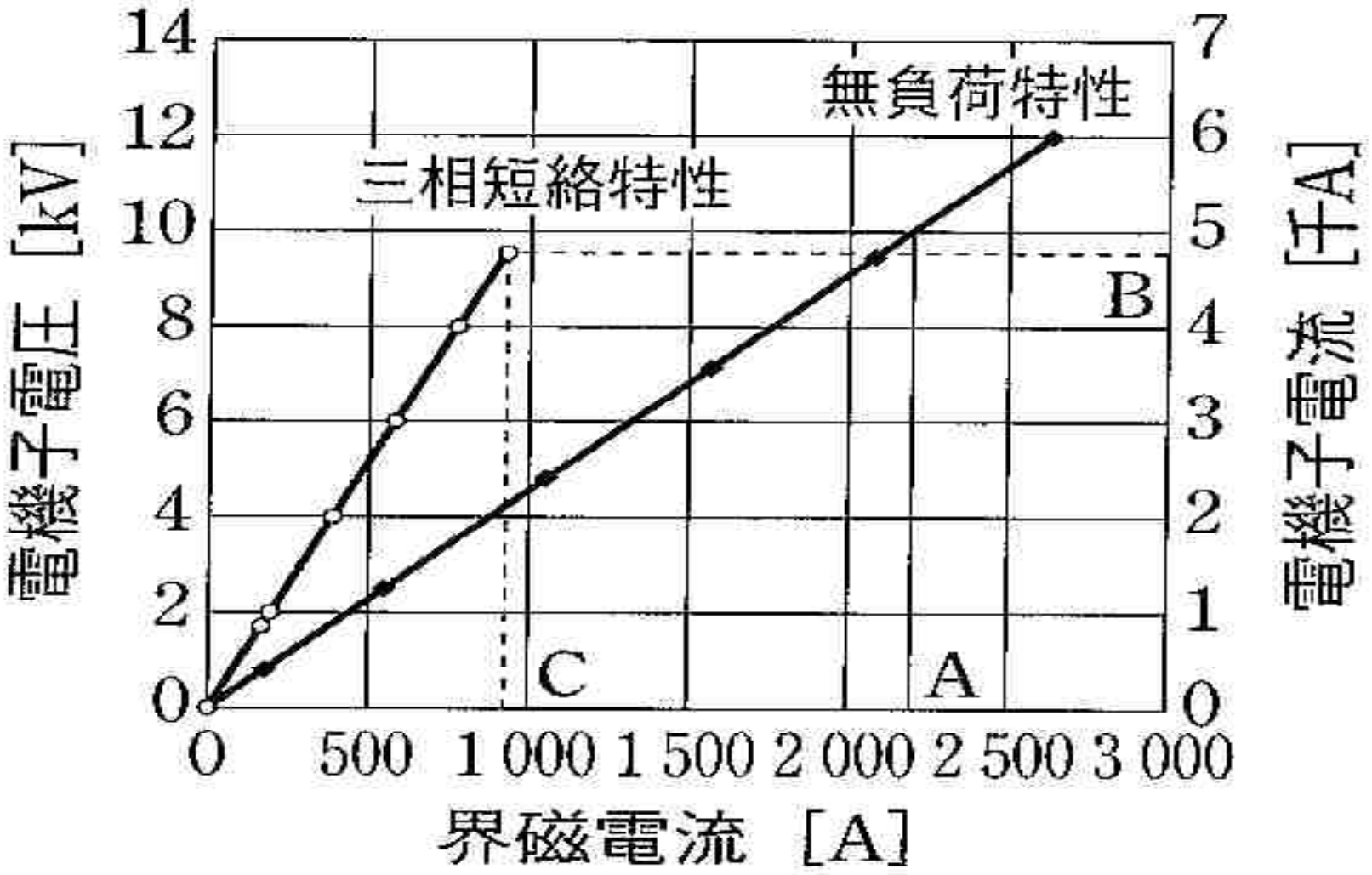
（Super-GM developed air core armature）

Cross-sectional structure of armature

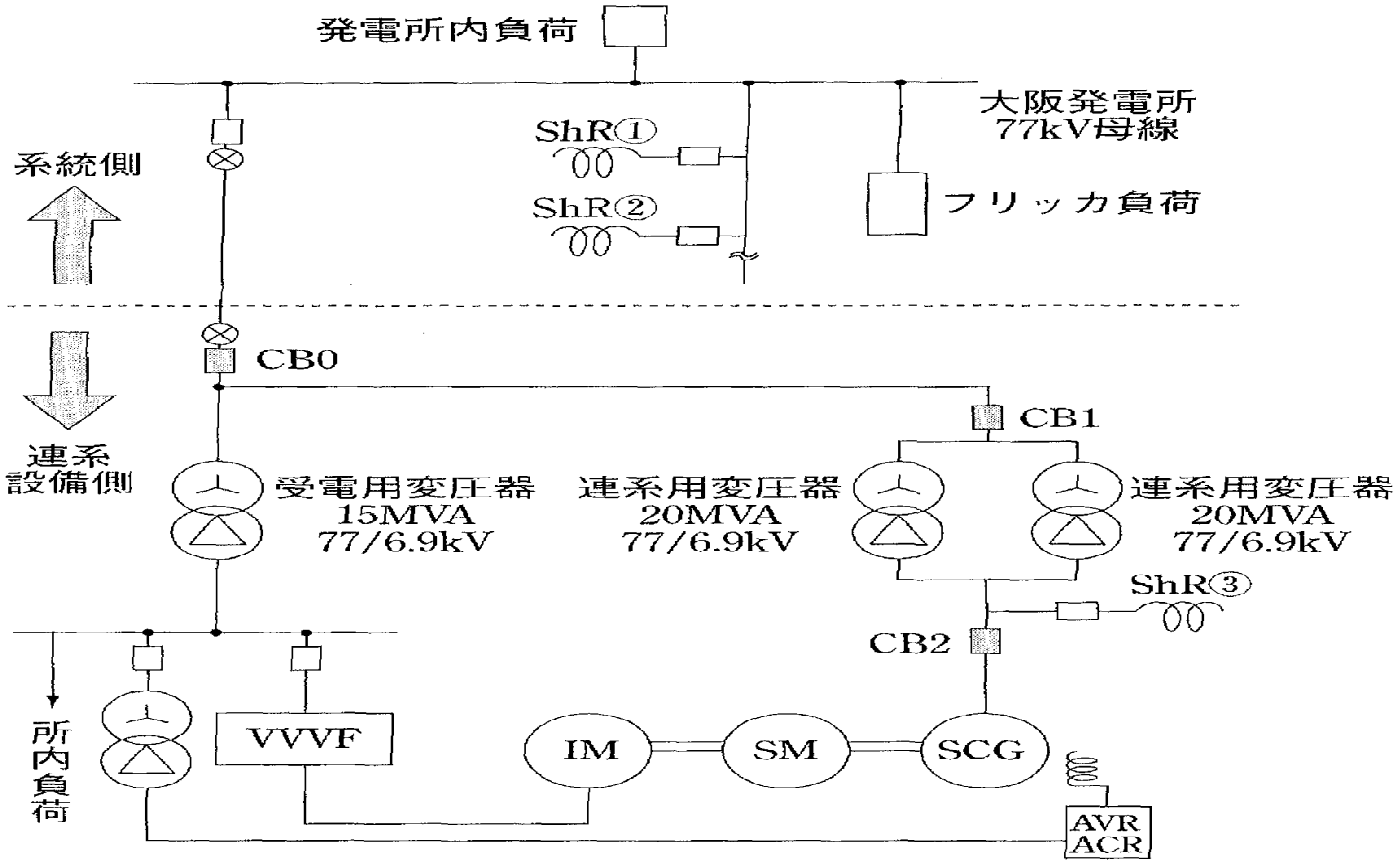


（The teeth of armature winding are FRP, a non-magnetic insulator.）

No-load and short-circuit Test

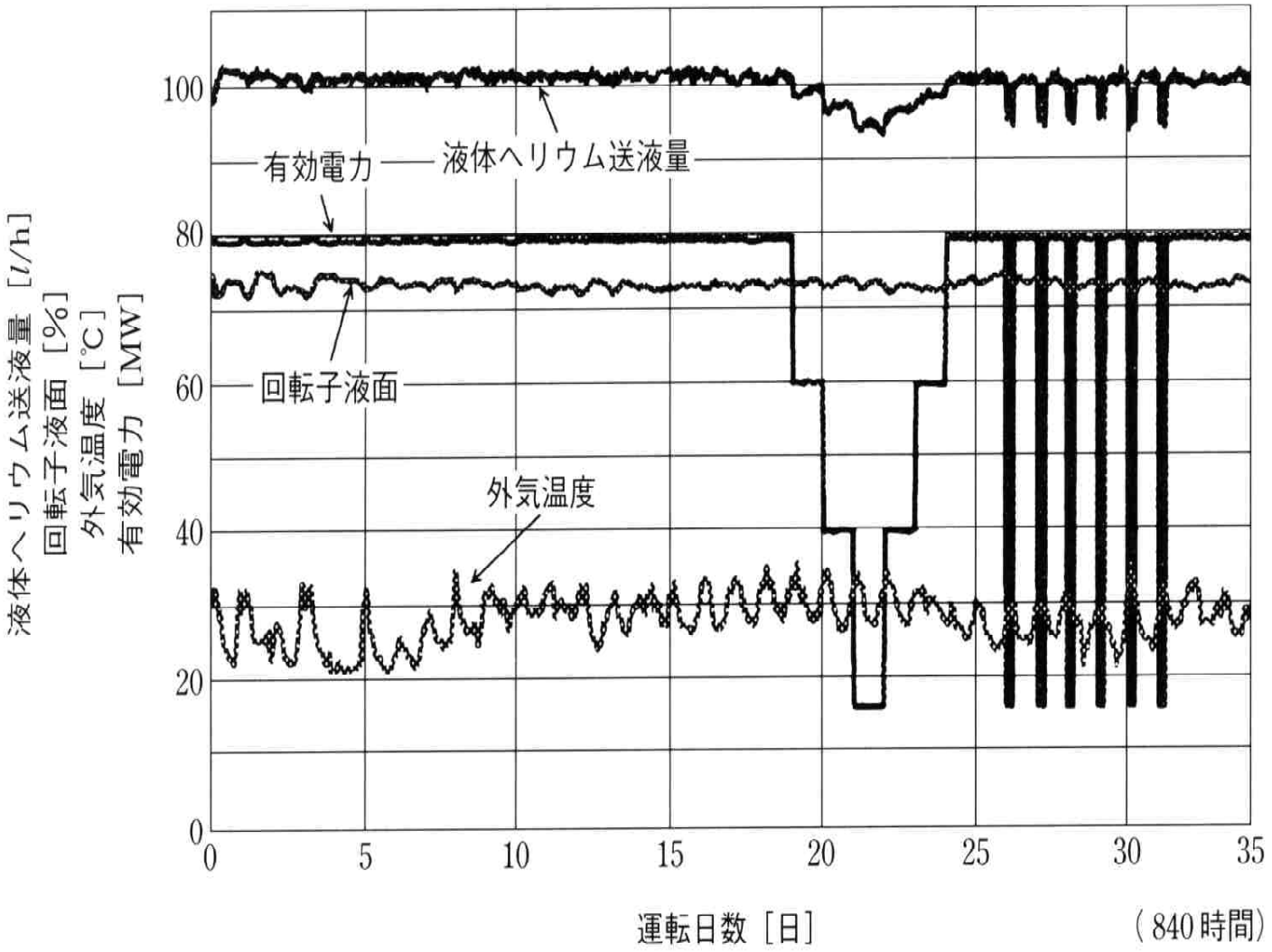


Grid connected test



(Since there was no prime mover to drive the superconducting generator, active power was supplied to the superconducting generator from the synchronous generator for the load. For this reason, the load fluctuation test was performed only with reactive power.)

Long-term continuous test



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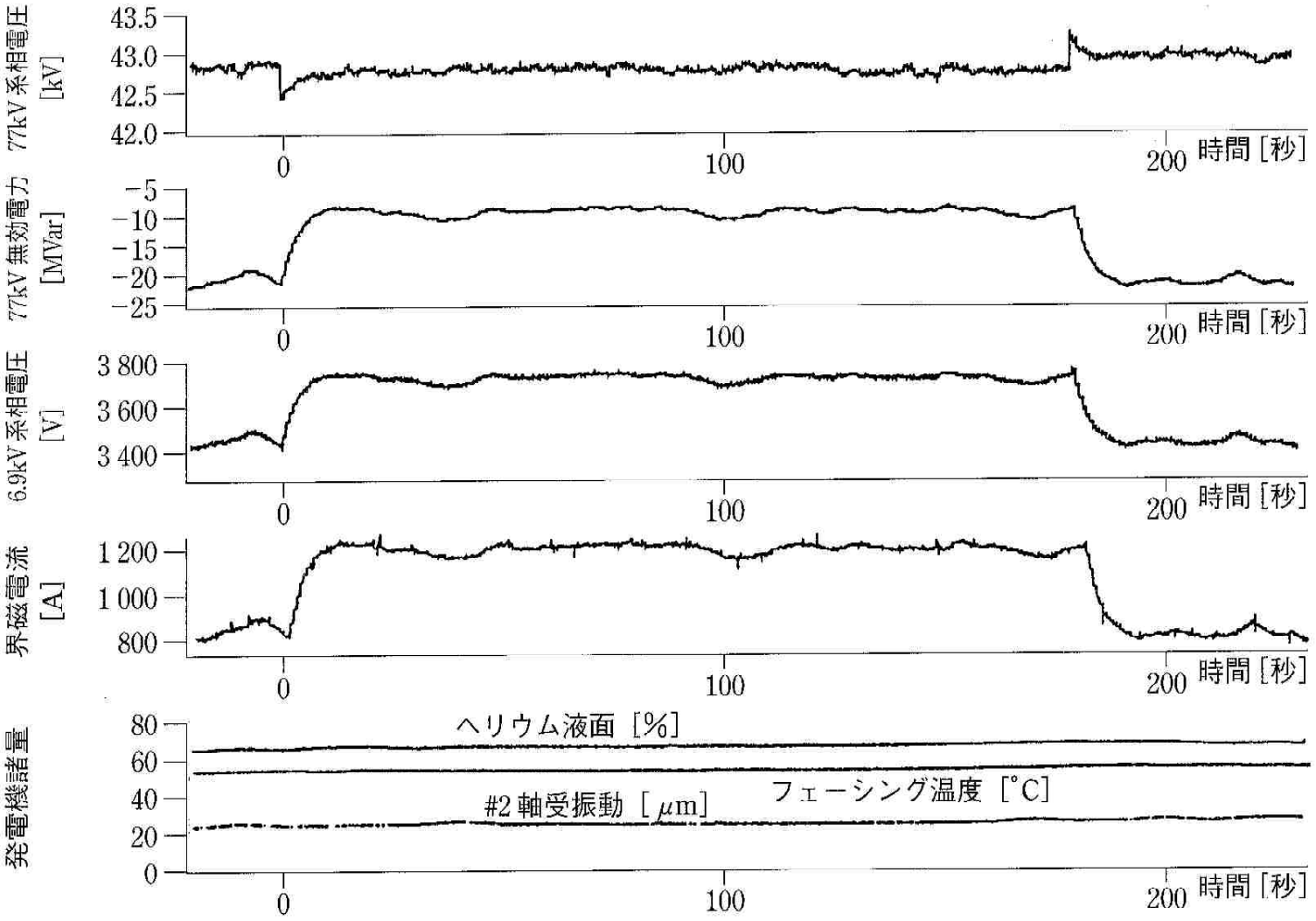
Reactive Load Fluctuation Test



Technical Challenge to HTS Generator

(At the end of the Super-GM project, FY1999)

■ Technology Perspectives

- **Increasing the current** of **wires** and **conductors**.

(Super-GM carried HTS wire development, including **IBAD**)

- **Large critical currents** in high magnetic fields.
- Compatibility of **Electrical insulation and cooling**.

■ Motivation & Environment

- Necessity of strong development and marketability.
- Development Support System.

The Future of the Electricity Business in Japan

80% Reduction in Society by 2050

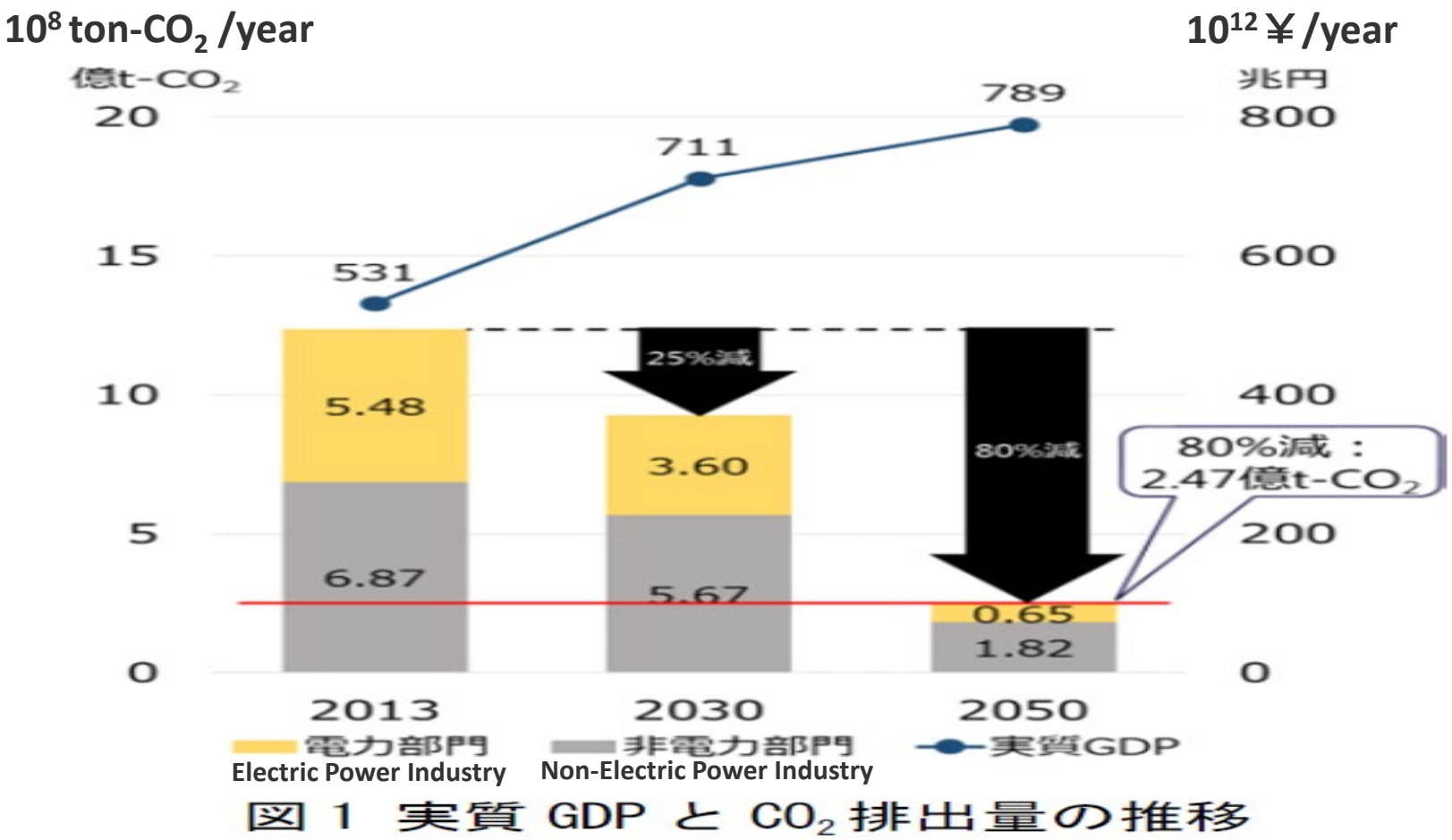


図 1 実質 GDP と CO_2 排出量の推移

Central Research Institute of Electric Power Industry Report No. Y19501 (April 2019)

⇒ 88% reduction in electricity sector emissions

80% Reduction in Power Supply in 2050

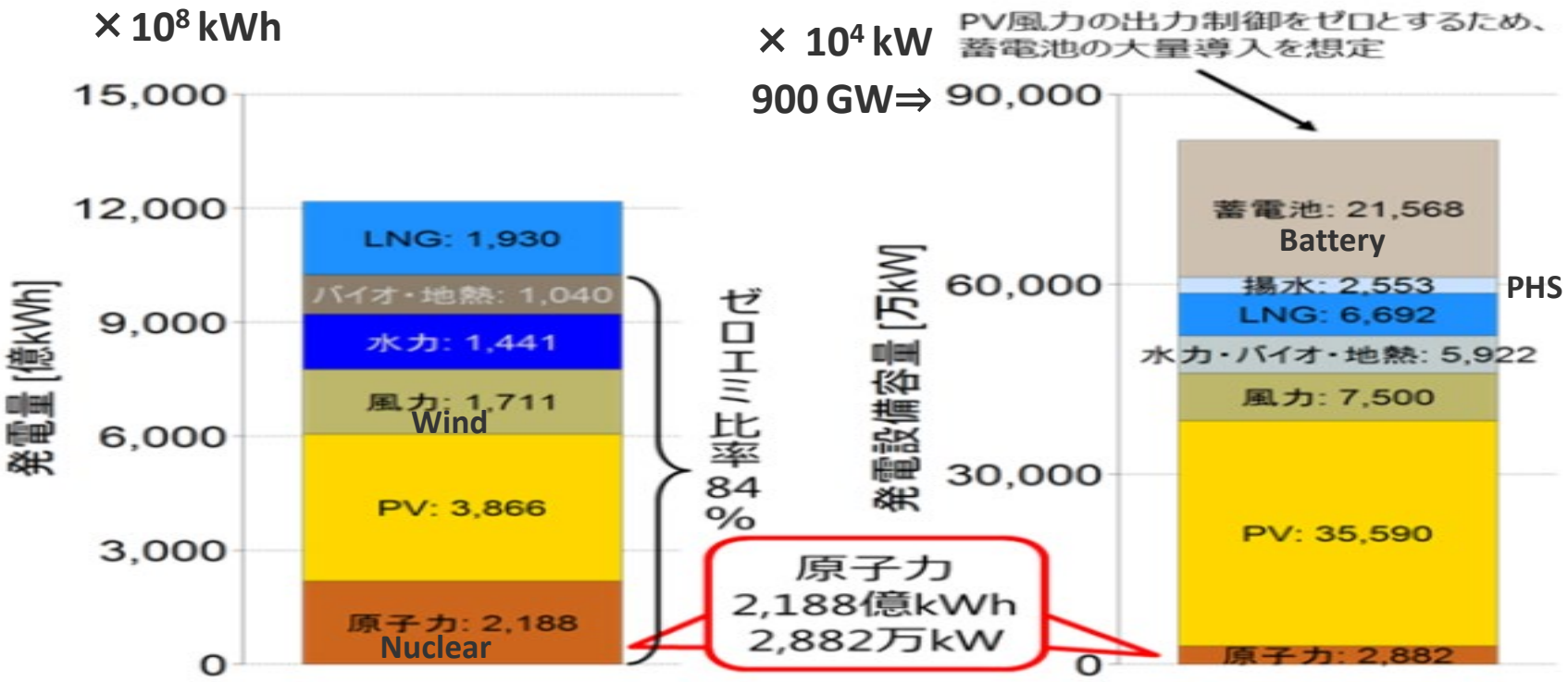
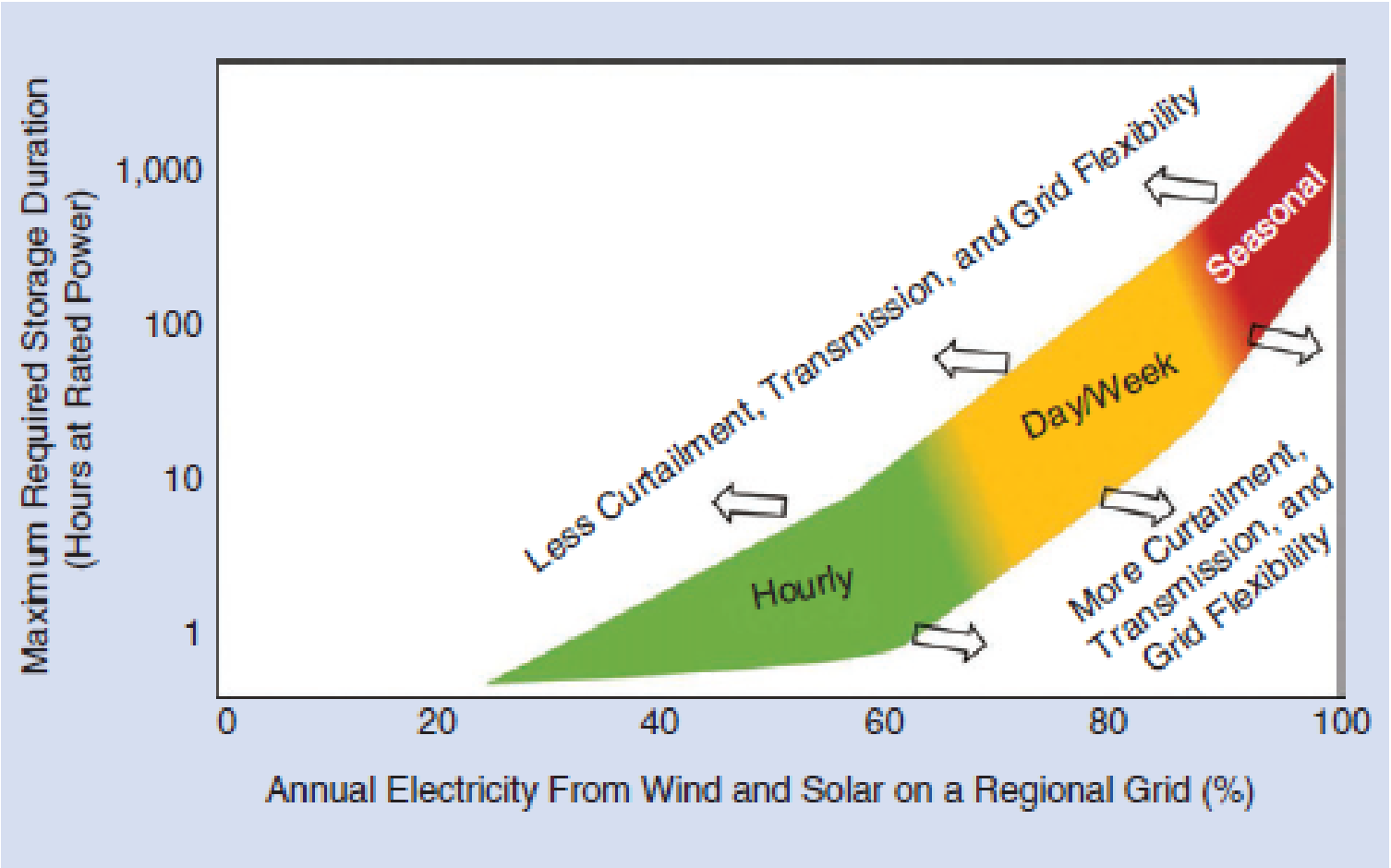


図 2 $CO_2$80%減を達成する際の 2050 年の電源構成

Central Research Institute of Electric Power Industry Report No. Y19501 (April 2019)

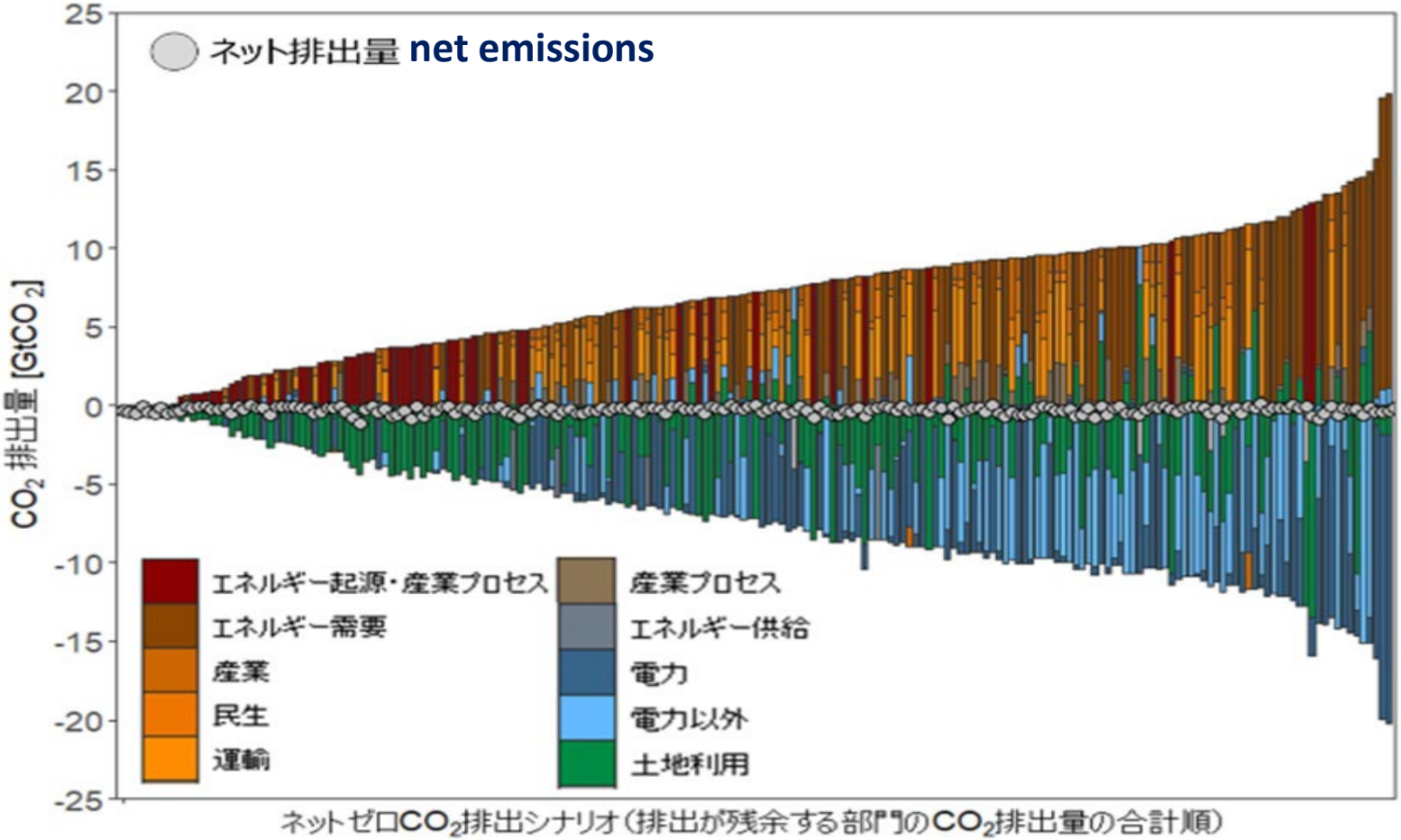
⇒ How to transmit the unevenly distributed renewable energy to the demand area has not been examined.

Electricity Storage Needed Large-scale Introduction of Wind and Solar



IEEE Electrification Magazine DECEMBER 2021 p. 6

CO_2 Emissions When Net Zero Emissions are Achieved in IPCC/SR15



Central Research Institute of Electric Power Industry Report Y20001（October 2020）

Research and Development in Electricity Business in the Future for low carbonization

- **Nuclear** power: long-term operation exceeding 60 years
- **Renewable** energy: Solar, wind, and geothermal
- Thermal power with **CCUS**: Carbon recycling and storage technology
- Direct **Air capture**: technically meaningful efficiency
- **Hydrogen** utilization technology: Utilization technology as secondary energy and carbon recycling material

⇒Engaging in all low-carbon technology development is needed including Superconducting.

Expectations for Superconducting Technology & Liquid hydrogen in Carbon Neutral Society

水素基本戦略

令和５年６月６日

再生可能エネルギー・水素等関係閣僚会議

Basic Hydrogen Strategy by Japanese Government

June 6, 2023

Refers to the vision for year 2050 and action plan until 2030 to accomplish the goal of realizing a hydrogen society ahead of the rest of the world by making hydrogen a new energy option amongst other renewable energy sources.

図 1　神戸液化水素荷役実証基地の完成イメージ

Fig. 1　Rendering image of liquefied hydrogen loading/unloading demonstration terminal in Kobe

川崎重工技報･182号　2020年9月

Liquid hydrogen Tank
2500 m^3

図 3　液化水素タンク
Fig. 3　Liquefied hydrogen storage tank

川崎重工技報･182号　2020年9月

「2023年度推進テーマ中間報告案（要約）」

『水素・超電導コンプレックス』

Hydrogen-Superconductivity Complex

Proposal by COCN

2024（令和6）年2月

推進テーマリーダー　来栖　努

（東芝エネルギーシステムズ株式会社

パワーシステム事業部・シニアフェロー）

COCN （Council on Competitiveness-Nippon:産業競争力懇談会）

IEEE CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 58, Feb. 2025.
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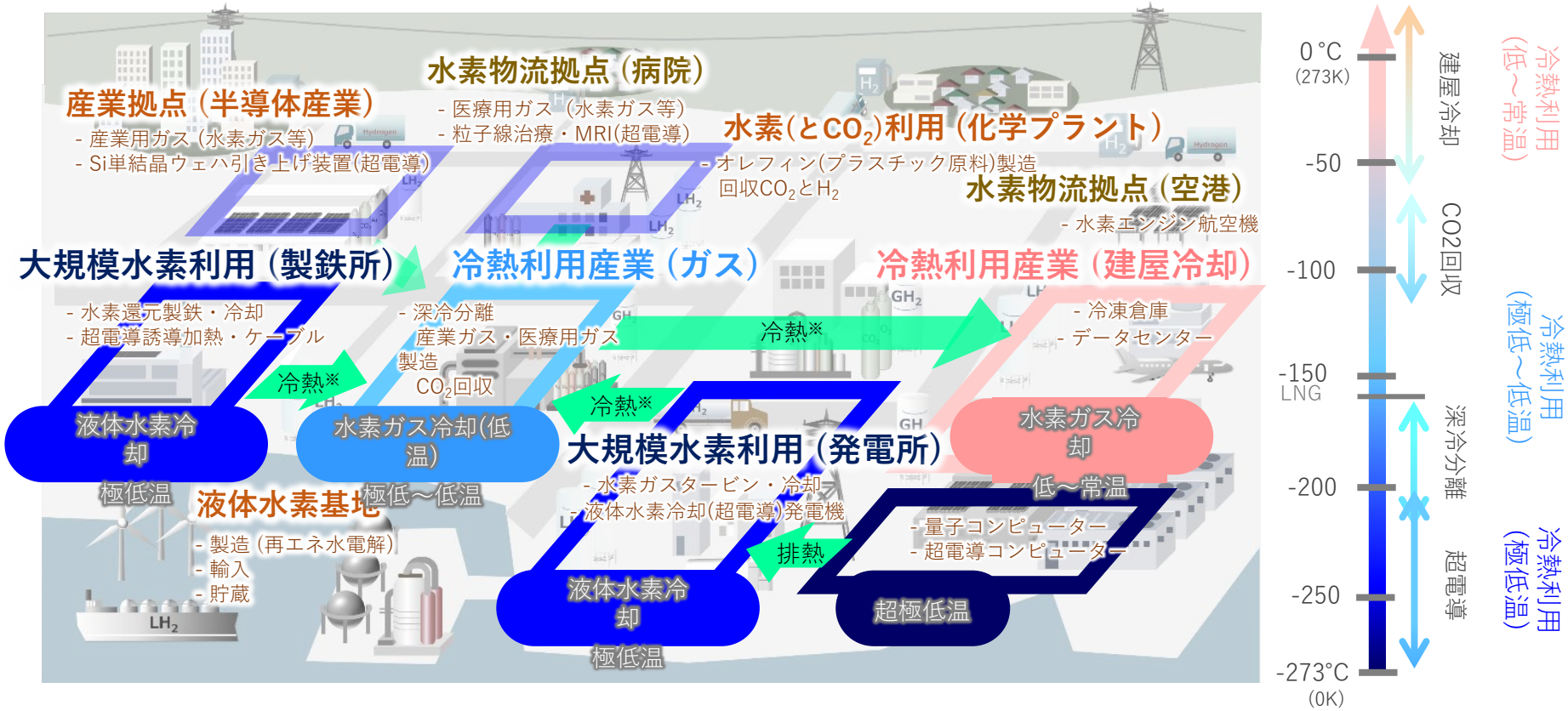
Wide Area Connection of RE

(広域再エネ連系構想)

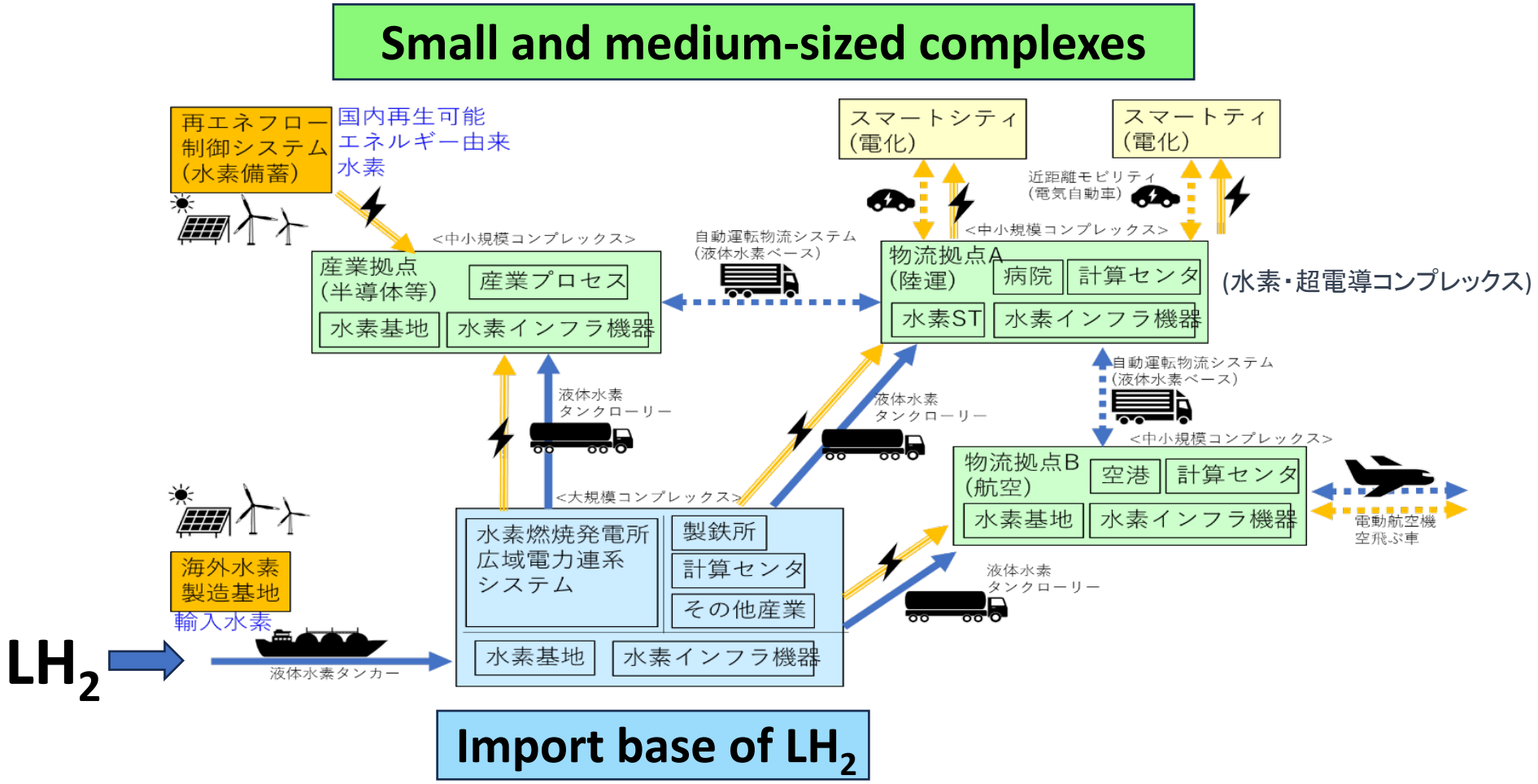
By connecting renewable energy power sources over a wide area with a superconducting generator and a hydrogen gas turbine that uses the cold heat of liquid hydrogen, the power system centered on renewable energy is stabilized. (It is expected to significantly reduce the cost of strengthening the power transmission infrastructure and become a low-cost CN measure.)

A social system that utilizes liquid hydrogen and heat without waste - Cascade use of cold

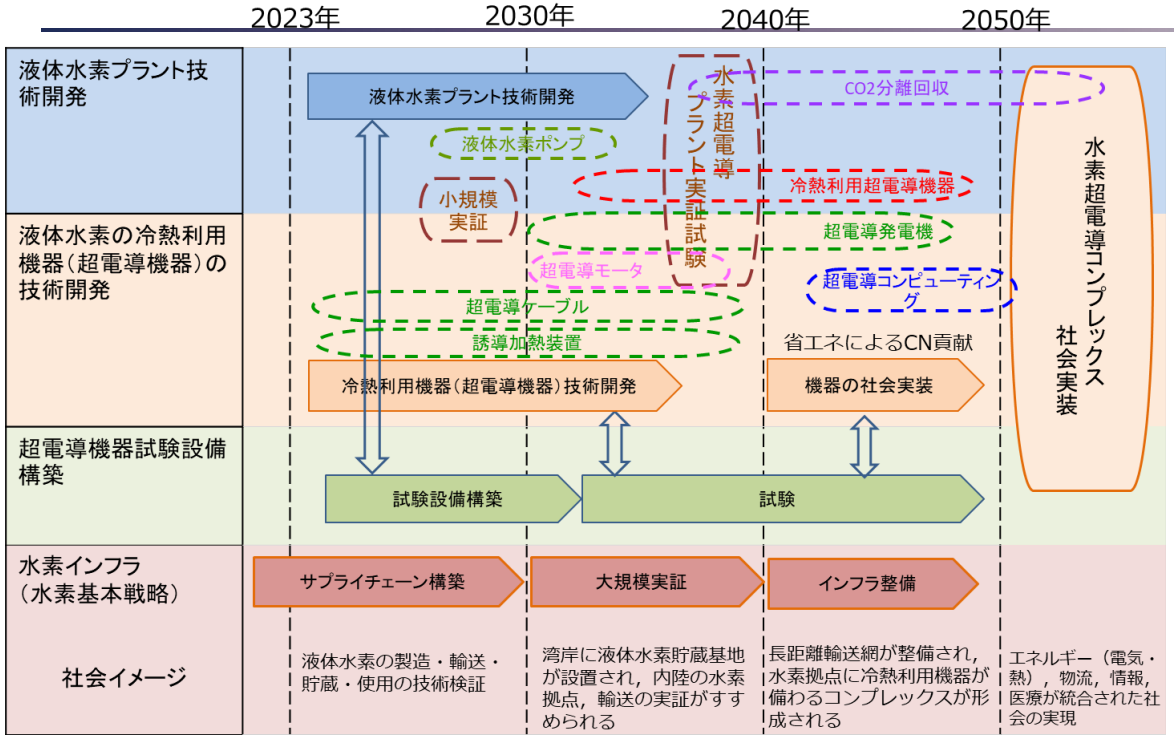


*1 The arrows indicating the movement of heat are in the opposite direction. Since the discussion is mainly about "cold and heat", we drew an arrow from low temperature to high temperature.

Hydrogen and SC Complex



R & D Scenario



開発推進者（案）

開発項目	推進者
液体水素プラント技術開発	冷凍機器メーカー 重工メーカー 大学，研究所 水素団体（コンソーシアム）
液体水素の冷熱利用機器（超電導機器）の技術開発	冷凍機器メーカー 超電導線材メーカー コイルメーカー 大学，研究所
水素冷却超電導機器試験設備	大学，研究所
水素・超電導プラント実証試験	冷凍機器メーカー コイルメーカー 大学，研究所 自治体，電力会社

Key points of the development scenario

・Focusing on "development of liquid hydrogen plant technology" and "technology development of liquid hydrogen cooling equipment (superconducting equipment)", small-scale demonstrations will be carried out, and after plant demonstrations, social implementation will be carried out.

・In order to accelerate development, we will utilize national professionals in priority focus areas and develop a test environment that can be used jointly by national research institutes.

LH_2 Cooled Generator by NEDO Project (FY2022-FY2023)

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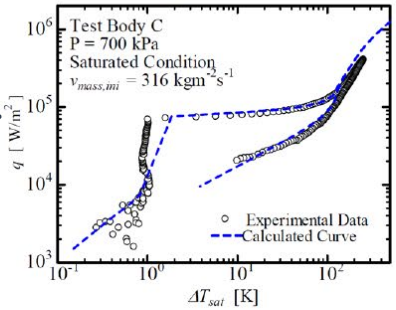
Basic technology development

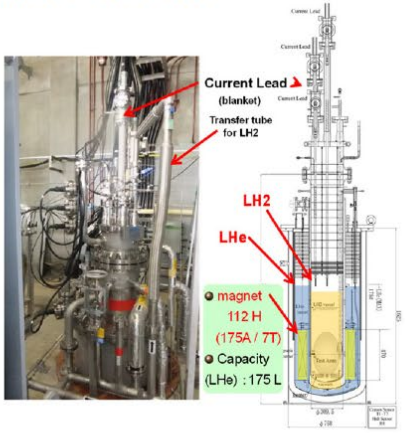
Noshiro Rocket Testing Center

①Boiling heat transfer test

8 W/cm²⇒



②Excitation test of HTS wires & coils



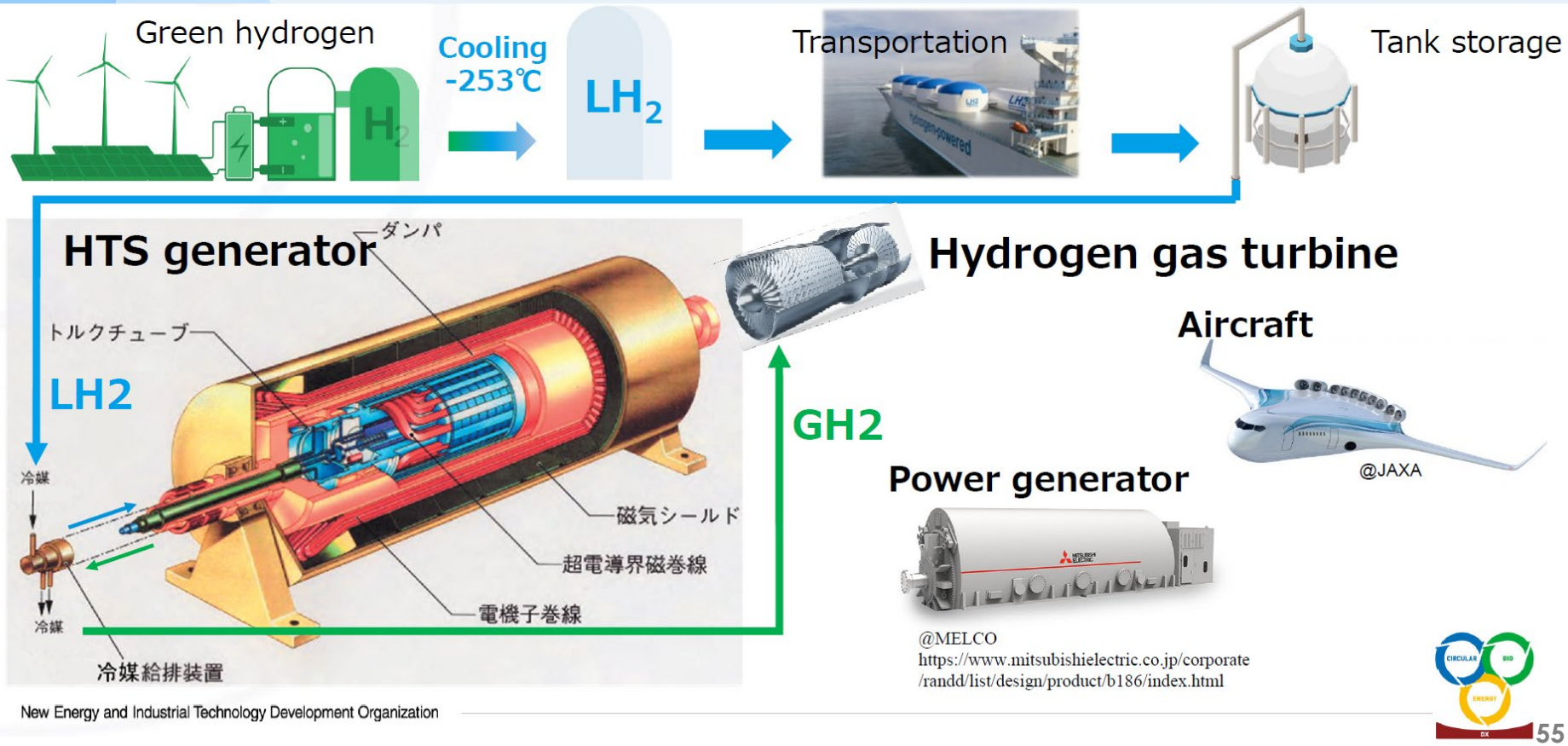
LH2 immersion cooling energization test apparatus

③LH2 supply test for rotating cryo.

New Energy and Industrial Technology Development Organization

Future image

NEDO



New Energy and Industrial Technology Development Organization

55

Implementation system

Generator design
Road map & scenarios
(Power Grid)

NEDO

MITSUBISHI ELECTRIC

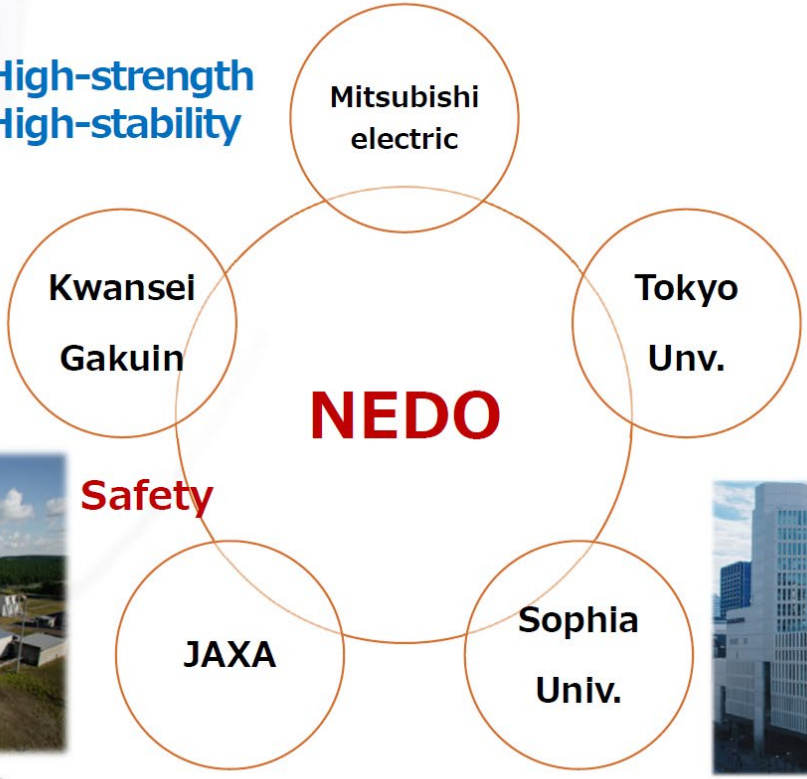
High-strength
High-stability

HTS bearing
Road map & scenarios
(Aircraft)

Heat balance
Road map & scenarios
(Aircraft)

Safety

Power grid analysis



New Energy and Industrial Technology Development Organization

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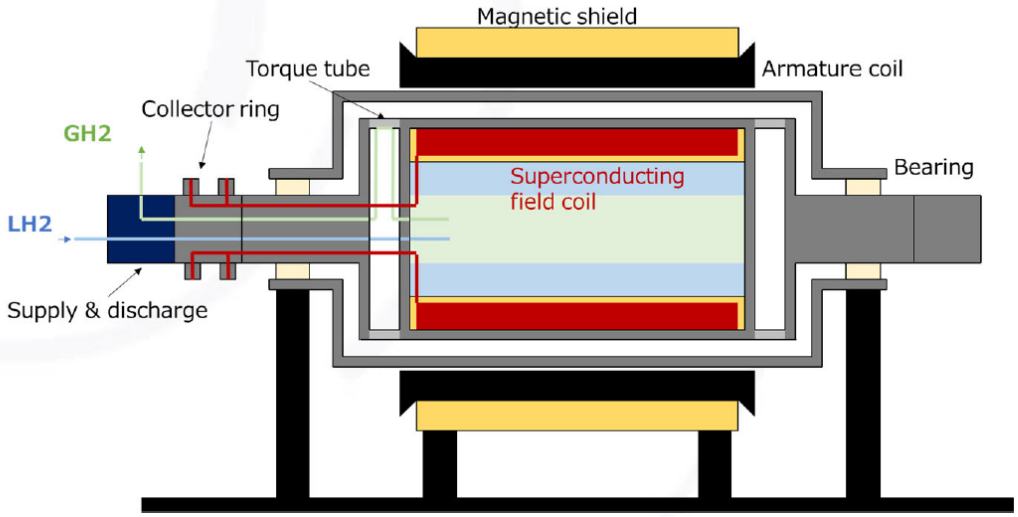
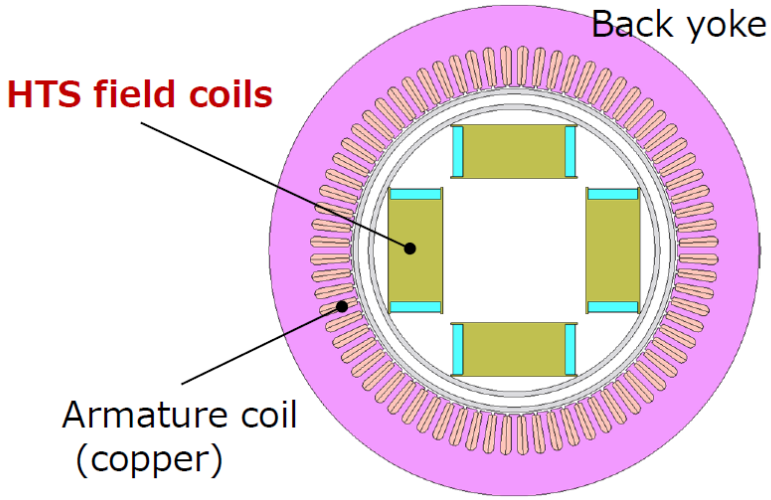
Plenary presentation given at ISS 2024, Kanazawa, Japan, Dec. 4, 2024.

10 kW demonstrator





Items	Values
Output power	10 kW
Rotation speed	1,800 rpm
Number of poles	4
Field coil	REBCO (LH2 cooling)

New Energy and Industrial Technology Development Organization

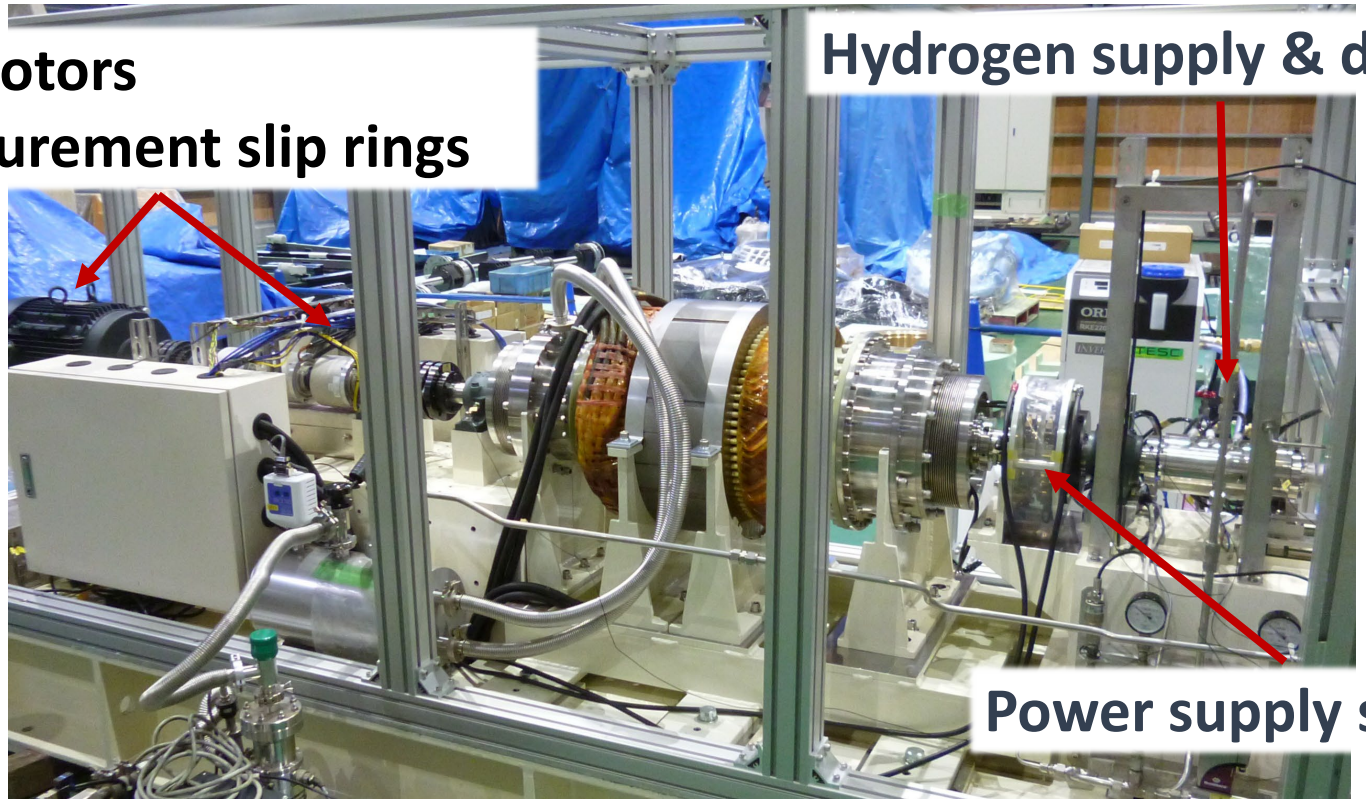
Verification of a **10 kW-class HTS generator** with the superconducting field coil is scheduled in 2024.

- **LH2 cooling (20 K)**
- 1,800 rpm rotation

10 kW demonstrator

NEDO

HTS generator: HTS rotor (4 poles) + Normal armature



Summary

*Liquid hydrogen is the key for Carbon Neutral Society and Superconducting Application.

*We should consider how we can apply already developed superconducting technology to carbon neutral society.

*Both of superconducting technology and liquid hydrogen should be used for power application.

Thank you
for your attention !