

Roadmap of Transition toward SF₆ Alternative Technologies

- Initiatives by Switchgear Manufacturers in Japan -

September 11, 2023 (Rev.1)

Task force on SF₆ Alternative Technologies, SF₆ Gas WG
The Japan Electrical Manufacturers' Association

Back Ground and Motivation

- Worldwide efforts towards “Carbon Neutrality by 2050”
- Introduction of environmental regulations in EU and the US on SF₆ gas usage of T&D equipment
- Acceleration in development of SF₆ alternative technologies



- Japanese manufacturers have to steadily proceed development of SF₆ free equipment to completely meet with the “7 requirements*” under a feasible roadmap in the view point of both contribution of reducing environmental load and enhancement of global business

(*“seven(7) requirements”: Application guidelines for SF₆ gas alternative technologies, proposed by “The SF₆ Alternative Gas Study Group” participated by Japanese academic organizations, electric power companies and switchgear manufacturers)

- Industry-level broad discussions are necessary on evaluation system to activities for environment and society issues
- Clarification of effective timing and process is necessary to advance “Carbon Neutrality of T&D systems”



The Japanese Seven switchgear manufacturers have jointly developed a roadmap toward SF₆ alternative technologies

Requirements from T&D Market on SF₆ Alternative Technologies

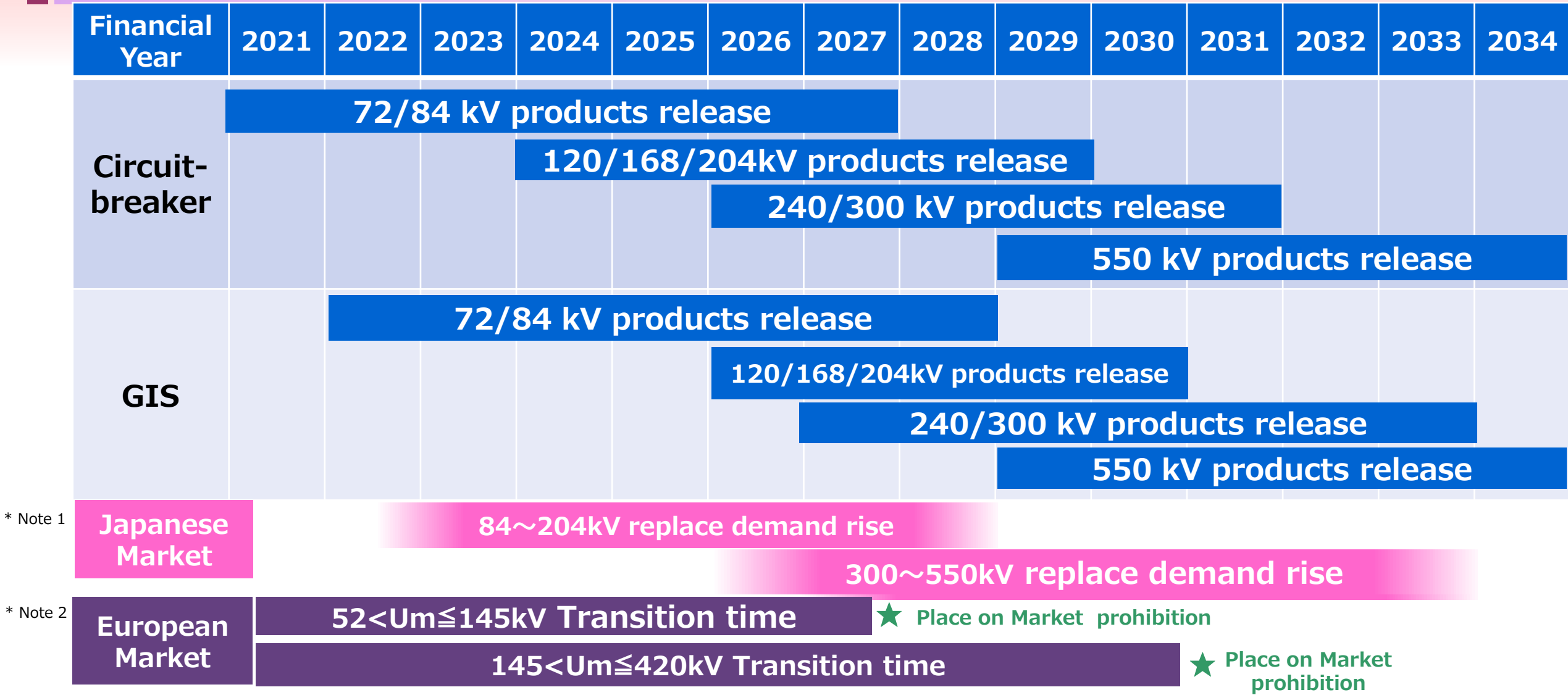
- Development has to meet the “7 requirements” proposed by The SF₆ Alternative Gas Study Group*

(*The SF₆ Alternative Gas Study Group was established in April 2016 to grasp various issues such as the impact of the introduction of SF₆ alternative gases in Japan collect and share experiences in the past development of SF₆ gas equipment, the latest international technical trends, and verification issues. Japanese 11 electric companies, 7 academic organizations and 7 switchgear manufacturers participate in the group.)

No.	Category	Requirement
1	EHS	Especially, toxicity of decomposition gas and decomposition
2	Service Condition	Normal use conditions specified in the standard
3	Stable Supply	Stable supply of alternative gases is possible in the future. It is desirable that gas can be supplied by multiple suppliers.
4	Gas Handling	Simple handling of SF ₆ alternative gas
5	Life Cycle Cost	Life cycle cost is equivalent or reasonable to SF ₆ gas equipment.
6	Footprint	Replacement in locations where installation space is limited
7	Voltage Coverage	Support up to the maximum operating voltage of 500kV–63kA

JEMA Roadmap of non-SF₆ Switchgear Development

※products release: Completion of type tests/start bidding(not include delivery time)



* Note 1 : S. Tsukao, "Trends and requirements for SF6 alternative technologies", Electrical Review, pp. 45-55, September 2020
K. Taketa et al., "Domestic situation and response based on trends in international SF6 gas alternative technology", IEE Japan Annual Meeting, S5-4, March 2021

* Note 2 : ENTSO-E and T&D Europe "Transition Times from SF₆ to alternative technologies for HV and EHV applications", October 2021
Proposal for Repealing Regulation (EU) No 517/2014 , April 5, 2022

JEMA Roadmap of non-SF6 Switchgear Development

< Basic concept and conditions >

1. Both circuit-breakers and GISs are separately considered.
(Japanese electric companies practice to manage/technically examine separately circuit-breaker to GIS.)
2. “Products release” means completion type tests/start bidding, not including delivery time.
3. Categorized into 4 voltage classes according to JEC-2300:2020; namely, “72/84 kV”, “120/168/204 kV”, “240/300 kV” and “550 kV”.
4. Clarify estimated rising of replace demand in Japan and prohibition schedule of SF₆ equipment in EU.
5. Although coverage up to 550 kV should be a big technical challenge, the Japanese manufacturers aim to complete it in adequate and satisfactory period.

(Reference) Global Warming Potential of SF₆

- SF₆ was listed as one of the global warming gases in the 3rd Conference of Parties of UNFCCC in Kyoto (COP3) on December 1997.
- Global warming potential (GWP) of SF₆ is specified as 25,200. (1kg of SF₆ = 25.2 CO₂e ton)

GWP of global warming gases (IPCC #6 report, 2021)

Gasses	Chemical formula	Atmospheric lifetime (years)	Radiative efficiency (W m-2 ppb-1)	GWP*
Carbon dioxide	CO2	(**)	1.37E-05	1
Methane	CH4	12.4	3.63E-04	28
Nitrous oxide	N2O	121	3.00E-03	264
Hydrofluorocarbons (eg. HFC-134a)	CH2FCF3	13.4	0.16	1,300
Perfluorinated carbons (eg. PFC-14)	CF4	50,000	0.09	6,630
Sulphur hexafluoride	SF6	3,200	0.57	25,200

* GWP for time horizon of 100 years

** The CO2 response function is used. See the reference for details.

Radiative efficiency

Time-dependent decay in abundance

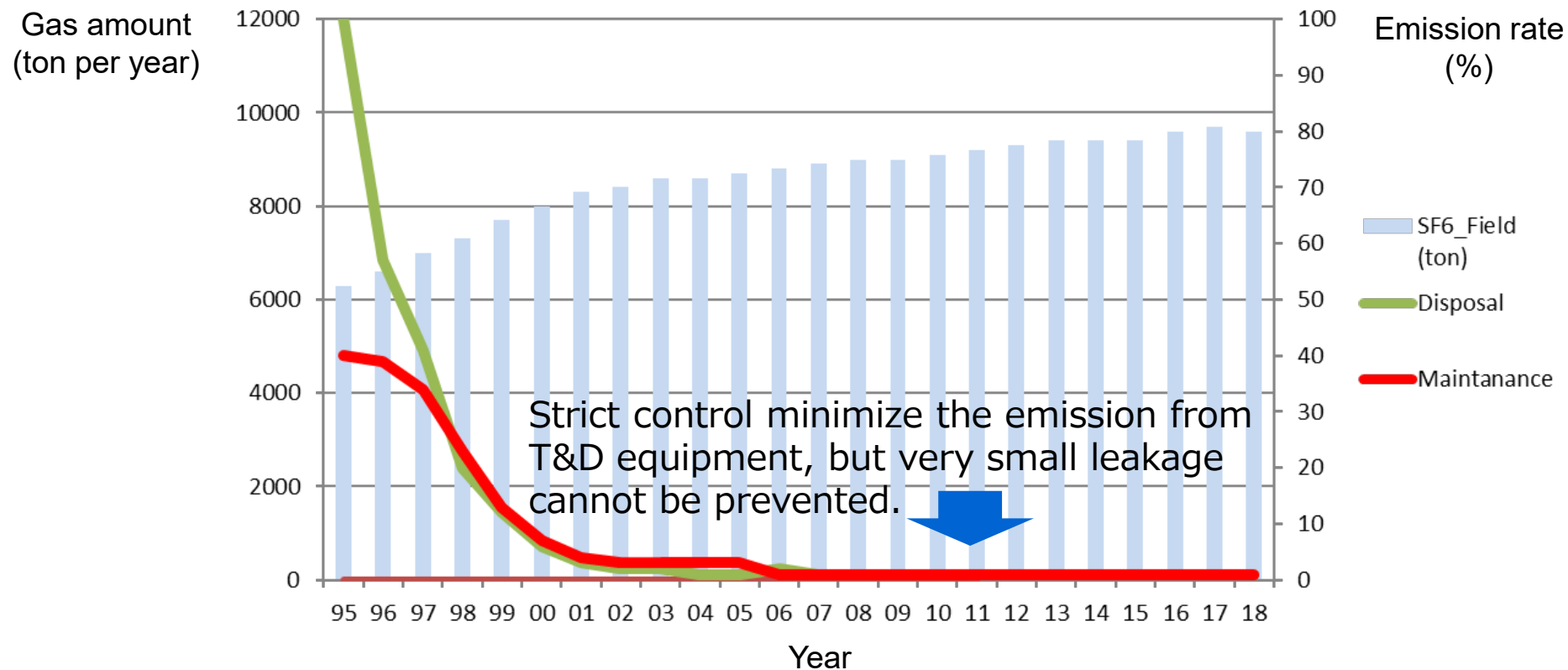
$$GWP_{SF6} = \frac{\int_0^{100yrs} (a_{SF6} \times x(t)) \cdot dt}{\int_0^{100yrs} (a_{CO2} \times r(t)) \cdot dt} = 25,200$$

CO₂ value as a unit

(Reference) Efforts to reduce SF₆ Emissions of Electrical Industries in Japan

- Emission control targets* have been achieved since 2005 by industry-level voluntary actions based on “Closed Cycle Concept”.
(* Emission control targets: <3% in manufacturing, <3% in maintenance, <1% in disposal)
- On the other hand, Japan possess a large amount of SF₆ gas corresponding to approx. 20% in the world.

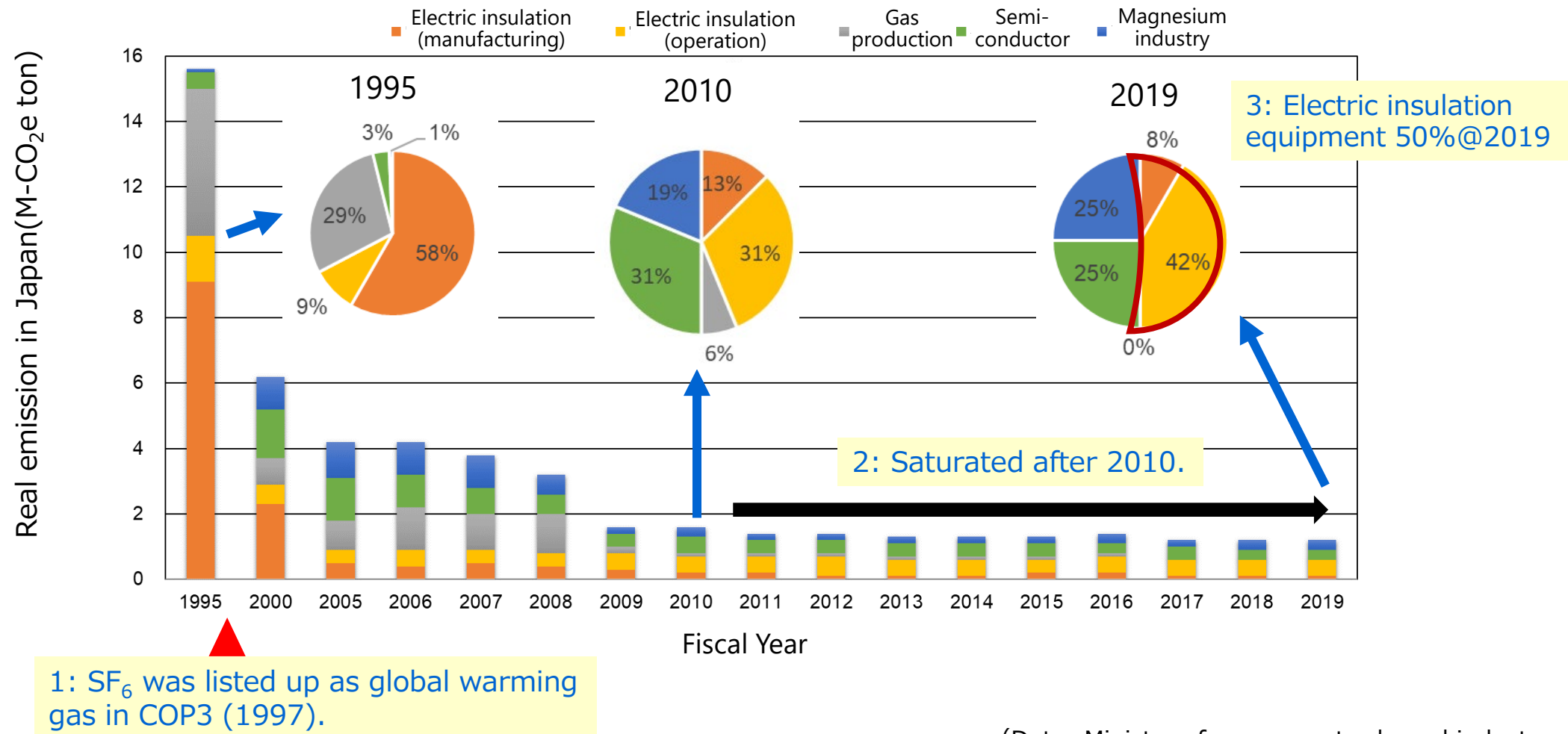
Usage and actual emissions of SF₆ gas in Electrical industries in Japan



(Data: Ministry of economy, trade and industry of Japan)

(Reference) Breakdown of SF₆ Emission into Industries in Japan

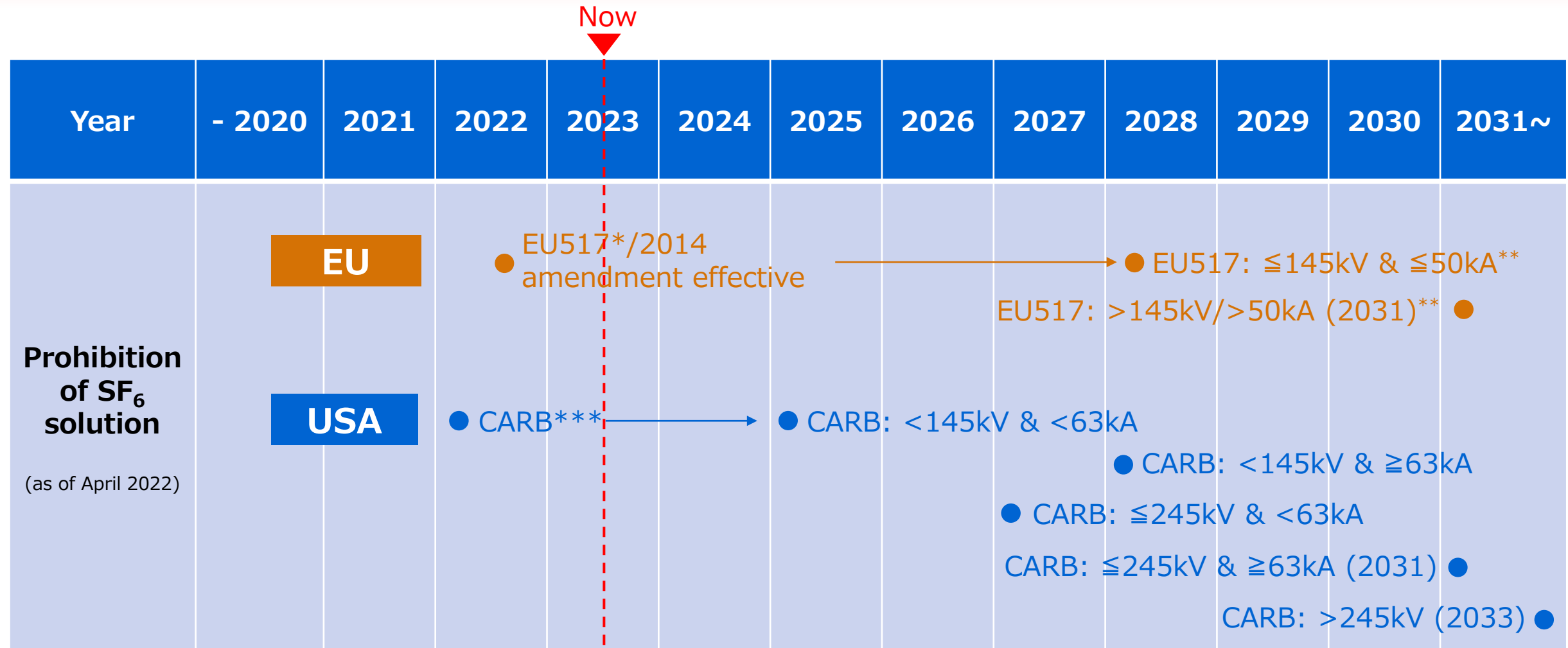
- SF₆ real emission in whole industries was drastically reduced in '00s and is has been saturated in '10s.
- Electric insulation equipment(manufacturing and usage) shares 44% in 2010 and 50% in 2019 of whole SF₆ emission in Japan.



(Data: Ministry of economy, trade and industry of Japan)

(Reference) Phase-out of SF₆ Electric Equipment in EU and the U.S.A.

- Japanese manufacturers have to consider important events in these markets.



*EU517 : Regulation (EU) No 517/2014 on fluorinated greenhouse gases

**Proposal document for amendment published on April 4, 2022

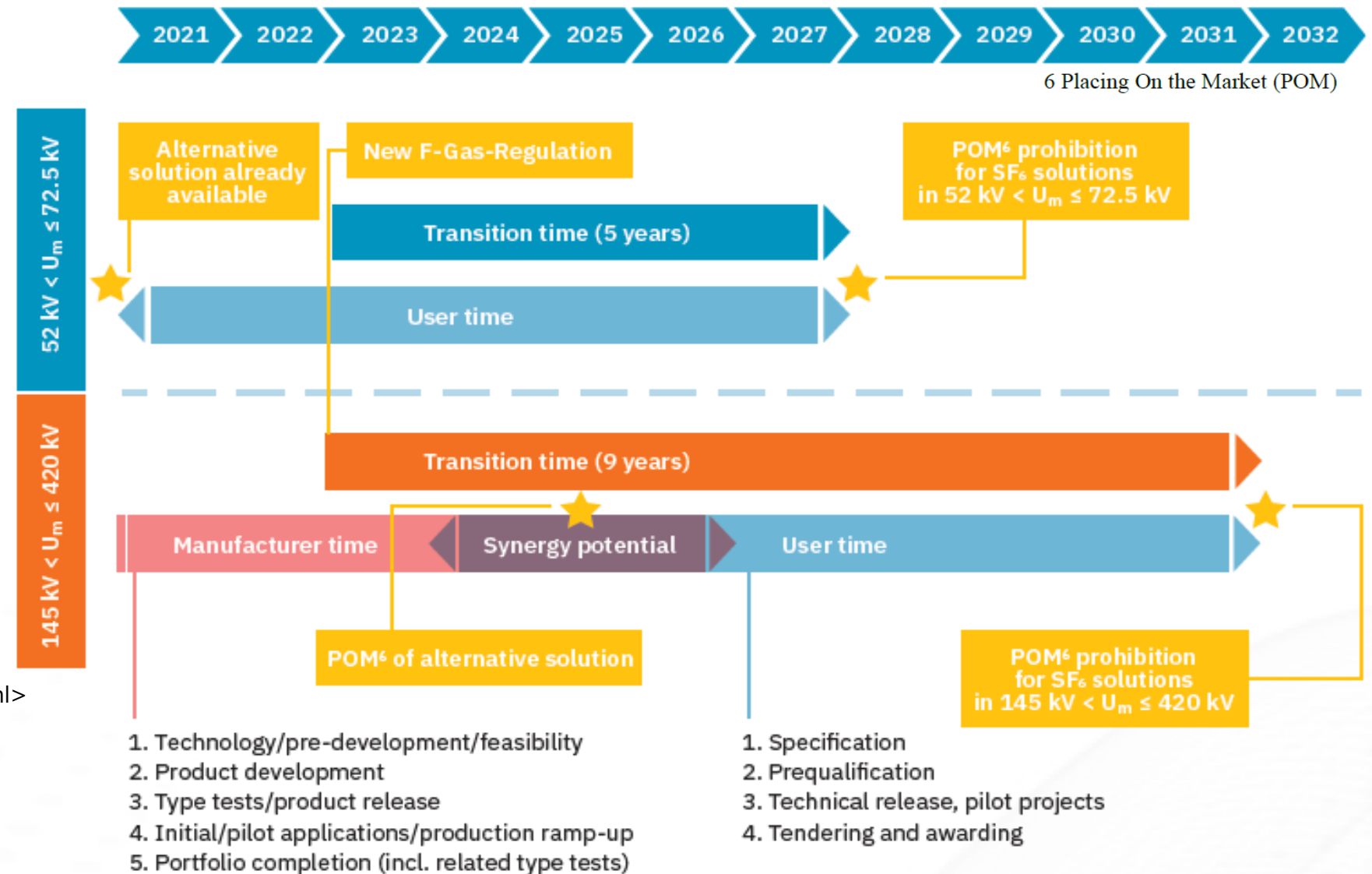
***CARB: California Code of Regulations (CCR), sections 95350-95359.1 lead by CARB(California Air Resources Board) are effective on January 1, 2022

(Reference) Roadmap by European Electricity Industry (October 2021)

- Electricity Industries jointly clarified controllable roadmap for phase-out
- “Transition time” are set before complete prohibition of SF₆ solutions



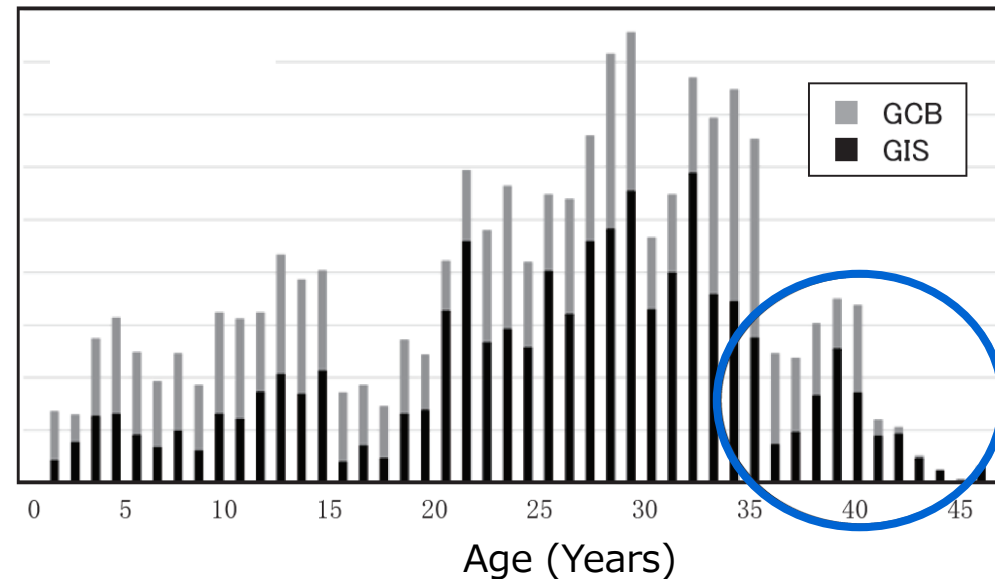
<<https://www.tdeurope.eu/publicationss/position-papers.html>>



(Reference) Prospected Replace Demand in Japan

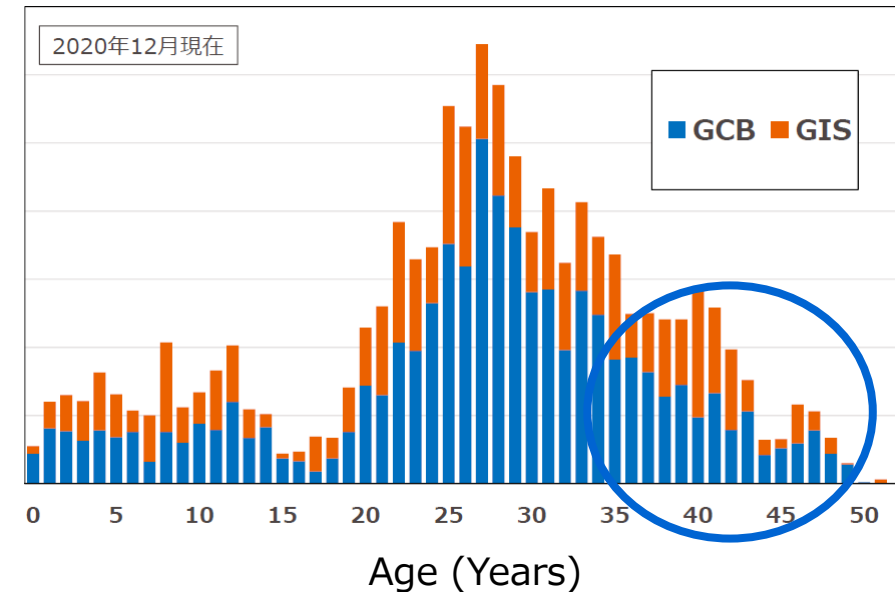
- Effective reduction of SF₆ usage can be realized by promptly development of equipment to meet rising of replace demand
- Prospected start of replace demand (* JEMA's survey assuming product life time of 40 years)
 - 72 kV, 168 kV : 2023 to 2027
 - 300 kV, 550 kV : 2026 to 2035

Population switchgear age
In Tokyo EPCO as of 2020



Reference : S. Tsukao: "Trends and requirements for SF₆ alternative technologies", Electrical Review, pp.45-55, September 2020

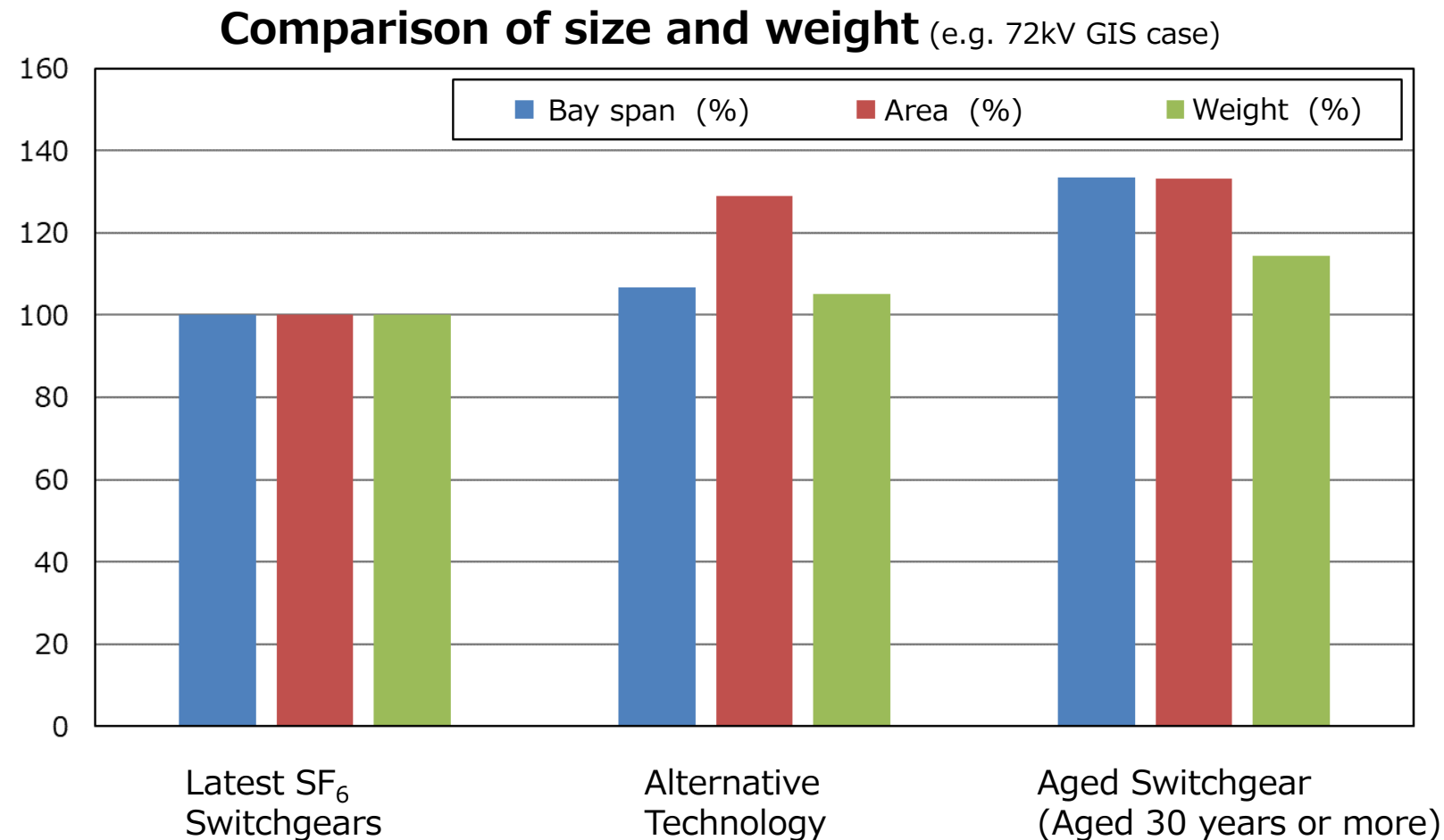
Population of switchgear age
In Kansai EPCO as of 2020



Reference : K. Taketa et al., "Domestic situation and response based on trends in international SF₆ gas alternative technology", IEE Japan Annual Meeting, S5-4, March 2021

(Reference) Applicability to Replacement of Existing SF₆ GISs

- Footprints of switchgears using alternative technologies are estimated generally 1.2 to 1.5 times larger than the latest SF₆ ones due to less insulation and interruption performance.
- They are applicable for near-term replacement needs for existing switchgears installed 40 or more years ago.
- Consecutive efforts for compactness are necessary in design technique, new technology application, high pressurize of insulating medium, and so on.



(Reference) Applicability to Replacement of Existing SF₆ Circuit-breakers

- Footprint of circuit breakers using alternative technologies is almost same because same air insulation distances are needed.

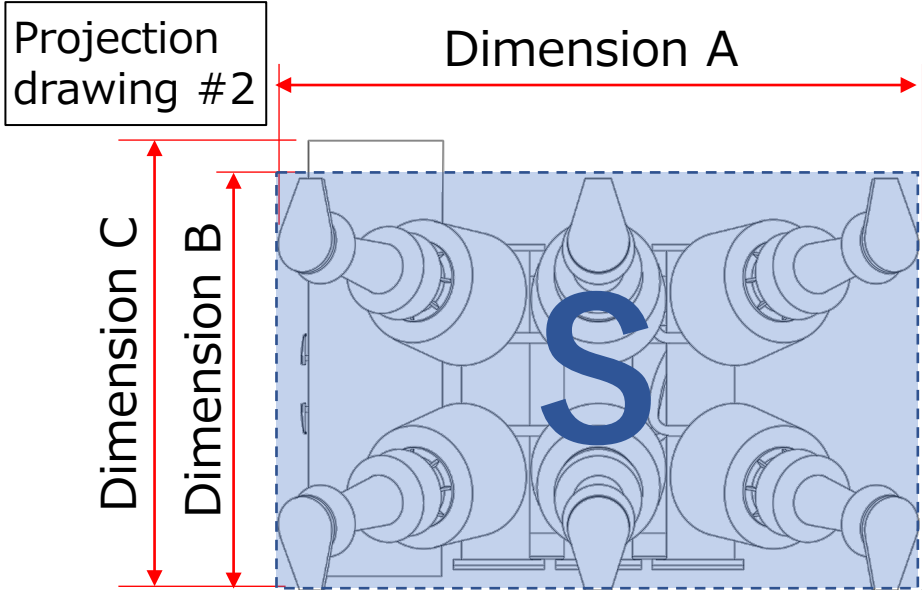
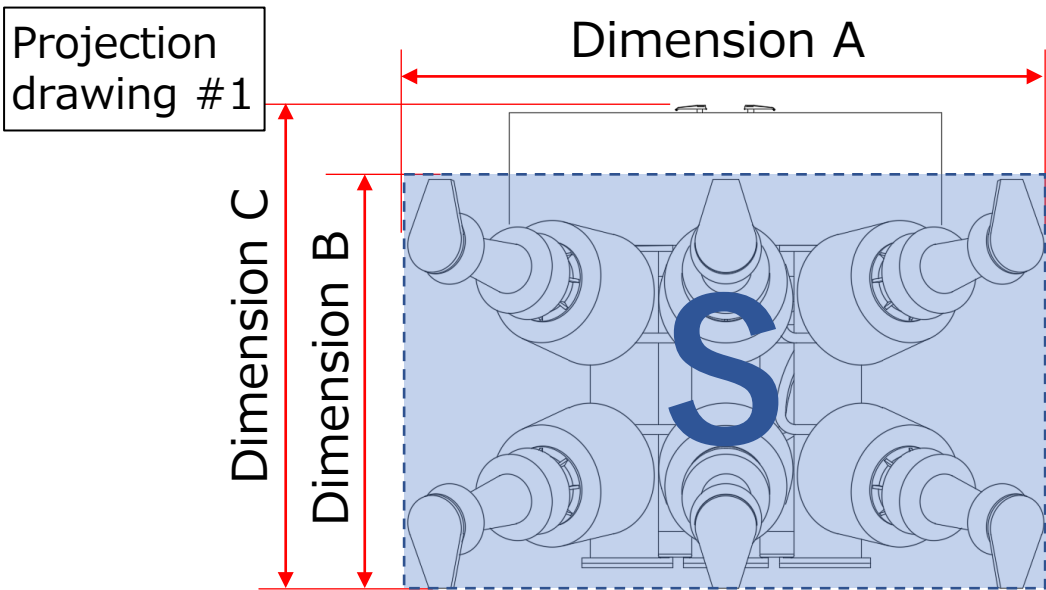
Air insulation distance



SF₆ Alternative
Circuit Breaker

Comparison in 72kV rating (for low pollution area)

	Projection drawing	Dimension A	Dimension B	Dimension C	Area S
SF ₆ alternative	# 1	2600	1630	2130	4.2 m ² (100%)
SF ₆ (manufacture A)	# 2	2410	1570	1770	3.8 m ² (89%)
SF ₆ (manufacture B)	# 2	2480	1530	<1530	3.8 m ² (90%)



Revision history

First edition published on May 31, 2022
Revision 1 published on September 11, 2023