iGDP
绿色创新发展研究院
Institute for Global Decarbonization Progress

Policy Brief Series

F-Gases Reduction Efforts and Perspectives in China

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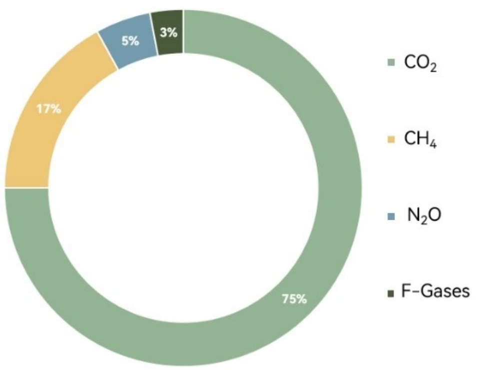
1. Fluorinated Greenhouse Gases as "Super Greenhouse Gases"

According to the World Meteorological Organization (WMO), 2023 was the warmest year on record, with global near-surface average temperatures about 1.45 (±0.12) °C above pre-industrial levels—dangerously close to the Paris Agreement's 1.5 °C limit.[1] As climate change worsens, more ambition is urgently needed.

Fluorinated greenhouse gases (F-Gases) regulated by the Kyoto Protocol include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).[2] Despite making up only 3% of total emissions,[3] these gases have a much higher Global Warming Potential (GWP) (Fig. 1). For instance, SF_6 has a greenhouse effect up to 25,200 times stronger than CO_2 over a 100-year period, making it one of the most powerful greenhouse gases (GHGs) (Table 1). According to the IPCC Synthesis Report, F-Gases have contributed around 0.1 °C to historical global warming, while carbon dioxide, the main GHG, has accounted for a 0.8 °C rise in temperatures.[4]

Figure 1 Global share of GHGs emissions (2023)



Source: UNEP, Emissions Gap Report 2024

Table 1 GWP values for F-Gases (CO_2 GWP100 = 1)

Gas	Life Cycle (Years)	GWP100
HFC-23	228	14600
HFC-32	5.4	771
HFC-125	30	3740
HFC-134a	14	1530
PFC-14	50000	7380
PFC-116	10000	12400
SF_6	3200	25200
NF_3	569	17400

Source: IPCC, AR6 Report

[1] World Meteorological Association. (2024). State of the global climate 2023.
[2] Nitrogen trifluoride (NF_3) was not covered by the Kyoto Protocol adopted in 1997; however, the Kyoto Protocol <Doha Amendment>, which came into effect on December 31, 2020, brought NF_3 under control. China's most recent national GHG inventory is for 2018 data and has not yet included NF_3.
[3] United Nations Environment Programme. (2024). Emissions Gap Report 2024.
[4] Intergovernmental Panel on Climate Change. (2023). Climate Change 2023: Synthesis Report.

2. F-Gases Emissions Status and Trends

2.1 Global Emissions of F-Gases

The emissions of HFCs, PFCs, SF_6, and NF_3 primarily stem from human activities such as leaks and venting during their production, storage, transportation, and use. These emissions are associated with various industries, including refrigeration, electronics, electric power, metallurgy, and chemicals (Table 2).[5]

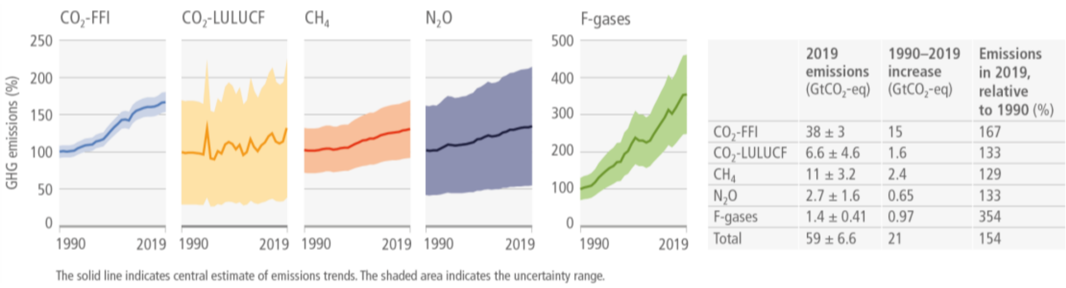
Table 2 Main Sources of F-Gases Emissions

HFCs	Leakage during production, storage, transportation and use of refrigerants, blowing agents, fire extinguishing agents, medical aerosols, etc.
PFCs	Aluminum production, semiconductor manufacturing, photovoltaic manufacturing, etc.
SF_6	Power industry, magnesium smelting, electronics industry, etc.
NF_3	Semiconductor manufacturing, electronics industry, photovoltaic manufacturing, etc.

Source: Summary by iGDP

In 2023, global GHGs emissions totaled 57.1 billion tons of CO_2 equivalent (CO_2e), with F-Gases making up approximately 1.7 billion tons, or 3%.[6] Although they represent a small fraction of the total emissions, their growth rate is the highest among all GHGs. From 1990 to 2019, F-Gases emissions increased by 254%,[7] nearly four times the growth rate of CO_2 during the same period. In 2023, while global GHGs emissions grew by 1.3%, F-Gases emissions surged by 4.2%.[8]

Figure 2 Global Trends in Anthropogenic Non-CO_2 emissions (1990-2019)



Source: IPCC, AR6 Report

2.2 F-Gases Emissions in China

In 2018, China emitted 284 million tons of CO_2e from F-Gases (excluding NF_3), which represented about a quarter of global F-Gases emissions and 2.2% of the country's total

[5] Research Group on Technology Development for Non-CO_2 Greenhouse Gas Emission Reduction. (2022). Assessment and Outlook for Non-CO_2 Greenhouse Gas Emission Reduction Technology Development.
[6] United Nations Environment Programme. (2024). Emissions Gap Report 2024.
7 Intergovernmental Panel on Climate Change. (2023). Climate Change 2023: Synthesis Report.
[8] Ibid.

GHGs emissions.[9] HFCs made up more than 66% of this total, equaling 189 million tons of CO_2e, while PFCs and SF_6 contributed 0.22 million and 0.73 million tons of CO_2e, respectively.[10]

The high emissions of HFCs in China are closely tied to the country's large refrigeration industry. China produces over 80% of the world's household air conditioners and more than 60% of the refrigerators,[11] with a total of 540 million air conditioning units in use, placing the country at the forefront globally.[12] Currently, the most commonly used refrigerants in the market are HFCs, the third-generation refrigerant. According to China's Ministry of Ecology and Environment, China's production of 11 types of HFCs accounts for over 80% of the global HFCs.[13] The main source of PFCs emissions in China is electrolytic aluminum production, while SF_6 emissions are primarily linked to the power industry, with studies indicating that over 95% of China's SF_6 emissions originate from this sector.[14]

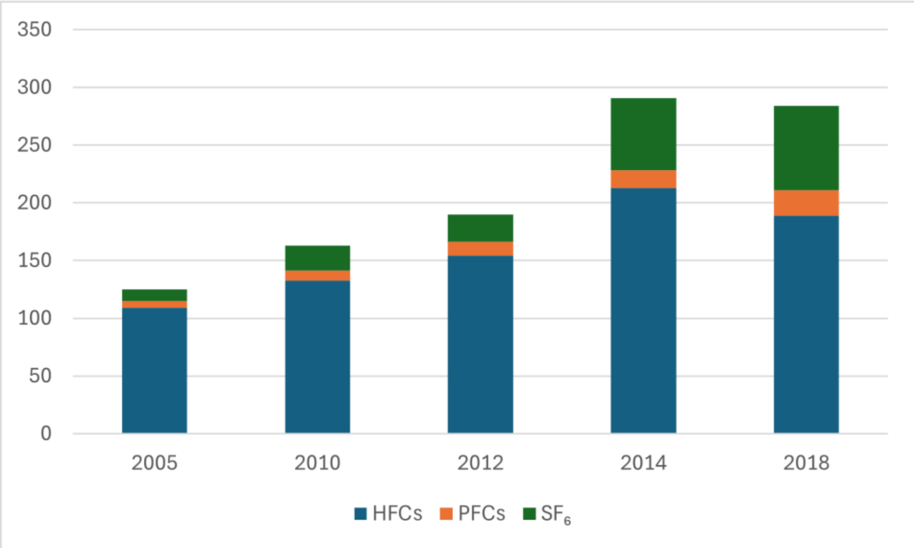
China's F-Gases emissions have seen significant increases in recent years. Between 2005 and 2018, F-Gases emissions grew by 127.2% (Figure 3). Studies show that, despite *the Kigali Amendment to the Montreal Protocol* calling to limit HFCs production and consumption, China's HFCs emissions will continue to rise rapidly for some time due to time-lagged emission effects. Projections suggest emissions could peak at more than 600 million tons of CO_2e in the 2030s, before decreasing to below 400 million tons by 2050.[15,16,17] Additionally, with limited emission control mechanisms in place, emissions of SF_6 and PFCs still have potential to increase and might even surpass HFCs emissions, complicating efforts to reduce overall F-Gases emissions. [18,19, 20]

The studies above show that while reducing HFCs production and consumption as per *the Kigali Amendment*, if other F-Gases emission reduction policies can be coordinated, it will

[9] Ministry of Ecology and Environment, People's Republic of China. (2023). People's Republic of China Third Biennial Update Report on Climate Change.
[10] Ibid.
[11] National Development and Reform Commission of the People's Republic of China. (2019). Green and High-Efficiency Cooling Action Plan.
[12] Shi, F. (2021). China has a total of 540 million air conditioning units. Beijing Business Daily. https://www.bbtnews.com.cn/2021/0827/409021.shtml.
[13] Ministry of Ecology and Environment of the People's Republic of China. (2024). Notice on Strict Control of the Second Batch of Hydrofluorocarbon Chemical Production and Construction Projects (Draft for Comments).
[14] Zhou, S., Teng, F., & Tong, Q. (2018). Mitigating sulfur hexafluoride (SF_6) emission from electrical equipment in China. Sustainability, 10(7), 2402.
[15] Bai, F., An, M., Wu, J., Fang, X., Jiang, P., Yao, B., ... & Hu, J. (2023). Pathway and Cost-Benefit Analysis to Achieve China's Zero Hydrofluorocarbon Emissions. Environmental Science & Technology, 57(16), 6474-6484.
[16] Teng, F., Su, X., & Wang, X. (2019). Can China peak its non-CO_2 GHG emissions before 2030 by implementing its nationally determined contribution? Environmental Science & Technology, 53(21), 12168-12176.
[17] Institute of Climate Change and Sustainable Development, Tsinghua University. (2020). Comprehensive Report on China's Long-term Low-Carbon Development Strategy and Pathway.
[18] iGDP. (2024). Energy Policy Simulator. https://energypolicy.solutions/home/china-igdp/en.
[19] Song, R. (2019). Opportunities to advance mitigation ambition in China: Non-CO_2 greenhouse gas emissions. In World Resources Institute Washington, DC Working Paper.
[20] Guo, L., Yang, Y., Fraser, P. J., Velders, G. J., Liu, Z., Cui, D., ... & Fang, X. (2023). Projected increases in emissions of high global warming potential fluorinated gases in China. Communications Earth & Environment, 4(1), 205.

be conducive to achieving near-zero emissions of F-Gases and support China's carbon neutrality goal.

Figure 3 Historical trend of F-Gases emissions (Mt CO_2e) in China



Source: China's Third Biennial Update Report on Climate Change

3. Actions to Reduce F-Gases Emissions

3.1 Global F-Gases Emission Reduction Actions

Around the world, many countries and regions are actively working to reduce F-Gases emissions. So far, 160 countries have ratified *the Kigali Amendment*.[21] The European Union and Japan have implemented relatively stringent policies and management measures to control F-Gases emissions.

Table 3 EU and Japan F-Gases Emission Control Policies

	Policy Content	Source
European Union	• **Market bans:** Set the timetable of banning products from the market based on usage or GWP and achieve a complete phase-out of HFCs consumption by 2050. • **Quota system:** Only importers and producers that have experience in trading activities of chemicals for three consecutive years prior to the quota allocation period shall be allowed to receive a quota allocation. • **Extended Producer Responsibility scheme:** By the end of 2027, F-Gases producers will finance the recovery, recycling, reclamation and destruction of F-Gases in products subject to Directive 2012/19/EU.	*Regulation 2024/573 of the European Parliament and of the Council*[22]

[21] United Nations. (2016). Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer.
[22] European Union. (2024). Regulation (EU) 2024/573 of the European Parliament and of the Council.

	• In addition, the regulation strengthens controls in areas including import and export, data reporting, and leakage.	
	• PFCs emissions from aluminium production are included in the European Union Emissions Trading System (EU ETS).[23]	*EU ETS*
Japan	(**Life cycle management** of production, consumption, recycling, reclamation/destruction of F-Gases) • **Major responsibilities of stakeholders:** 1) Producers shall reduce the production of F-Gases and promote the use of low-GWP substances. 2) Users shall regularly check for leakages; When recharging/recovering gases, entrust the registered enterprises to conduct relevant operations; Pay for recovery, transportation, recycling, and destruction. 3) Refrigerant recycling/reclamation/destruction enterprises must be registered with the government. • **Reporting system:** F-Gases producers or importers shall report shipments for each fiscal year; Users shall report leakages; Refrigerant recycling/destruction companies shall issue recycling/recharge/destruction certificates to record the data. (This system provides clear monitoring and statistics of domestic refrigerant information in Japan.)	• *Home Appliance Recycling Law* • *Act on Recycling of End-of-Life Automobiles* • *Act on Rational Use and Proper Management of Fluorocarbons*[24,25]

3.2 China's F-Gases Emission Reduction Actions

China has also implemented several emission reduction policies targeting F-Gases, with a particular focus on controlling HFCs emissions due to their significant share in total F-Gases emissions.

Table 4: China's Major Policy Actions to Promote F-Gases Emission Reduction gas emissions

Strategic Planning for F-Gases Emission Reduction		
Gases	Policy Content	Source
Non-CO_2/ F-Gases	• Controls over methane and other non-CO_2 GHGs will also be strengthened. • Continue to push for HFC-23 destruction, study and formulate nitrous oxide emission reduction plans for key industries, promote low-warming-potential power facilities, and strengthen the emission control of HFC, nitrous oxide, and sulfur hexafluoride. • Step up the control of key non-CO_2 GHGs emissions. China will research and implement an action plan to control non-CO_2 GHGs emissions; continue to improve the technical system for monitoring, reporting and evaluation of non-CO_2 GHG emissions; and gradually establish a sound statistical accounting system, policy system and management system for non-CO_2 GHGs emissions.	• *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy* • *China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy* • *The Outline of the 14th Five-Year Plan for Economic and Social Development and Long-range Objectives through the Year 2035 of the People's Republic of China* • *Opinions of the Central Committee of the Communist Party of China and the State Council on Further Promoting the Nationwide Battle to Prevent and Control Pollution*

[23] European Commission. Scope of the EU ETS.
[24] Ministry of the Environment, Japan. Act on Rational Use and Proper Management of Fluorocarbons.
[25] PAN X., HU J., LI C. & LIN J. (2022). Enlightenment and reference of Japanese refrigerant recovery management modes.

	• Incorporate greenhouse gas controls into environmental impact assessment management. • Strengthen the control of non-CO_2 GHGs, and study and formulate greenhouse gas emission standards for key industries.	• *Implementation Guide on Promoting the Synergistic Efficiency of Reducing Pollution and Carbon*
HFCs	• To freeze the production and use of HFCs at baseline levels in 2024. The production and use of HFCs will not exceed 90% of the baseline starting from 2029, 70% from 2035, 50% from 2040 and 20% from 2045.	• *The Kigali Amendment to the Montreal Protocol*
	• Implement the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, and strictly require all difluoro-chloromethane production enterprises to harmlessly dispose of their by-product trifluoro methane. Increase the research and development of low-carbon and environmentally friendly alternative technologies. Actively adopt low global warming potential alternative technologies in the process of replacing HCFCs to reduce emission; promote the recovery, reuse and harmless treatment of controlled substances, and support relevant production companies to create green factories and strictly control leakage and discharge of controlled substances during production. Priority should be given to the implementation of alternative and emission reduction HFC actions in industries where alternative technologies are relatively mature.	• *China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy*
	• Strengthen the management of ozone-depleting substances and hydrofluorocarbons (HFCs), accelerate the retrofitting of production lines using hydrochlorofluorocarbons (HCFCs), and phase out the use of HCFCs.	• *Implementation Guide on Promoting the Synergistic Efficiency of Reducing Pollution and Carbon*

Policies for F-Gases Emission Reduction

Gases	Policy description	Policy source
HFCs	(18 HFCs are incorporated under control) • Gradual reduction and eventual phase-out of Ozone Depleting Substances (ODS) used as refrigerants, blowing agents, fire extinguishing agents, solvents, cleaning agents, processing aids, pesticides, aerosols, expanding agents and other uses. • Implement total amount control and quota management for the production, use, import and export of ODS. • Encourage and support scientific research, technology development, promotion and application of substitutes and substitution technologies for ozone-depleting substances.	• *Regulations on Administration of Ozone Depleting Substances* • *List of Controlled Ozone Depleting Substances* • *Administrative Measures for the Import and Export of Ozone Depleting Substances* • *List of Ozone Depleting Substances subject to Import and Export Control*
	• No new construction or expansion of chemical production facilities for controlled use of HFCs shall be permitted. • Chemical production facilities for controlled use of HFCs that have been built and need to be reconstructed or constructed off-	• *Circular on Strictly Controlling HFC Chemical Production Construction Projects*

	site shall not increase HFCs production capacity, nor the types of HFCs products for controlled use.	
	• By-product HFC-23 from the production of HCFC-22 or HFCs shall not be directly emitted. • By-product HFC-23 should be eliminated to the extent possible using destruction technologies approved by the Conference of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, except for feedstock and controlled uses.	• *Notice on Control of By-product Trifluoro methane Emissions*
	• Baseline value of HFCs production is 1,853 million tons of CO_2e, and the baseline value of use is 905 million tons CO_2e (including imports of 0.05 million tons)	• 2024 Hydrofluorocarbon (HFC) Quota Setting and Allocation Plan
	• Accelerate the phase-out of HCFCs refrigerants, limit and control the use of HFCs, strictly control the leakage and emission of refrigerants in the production process, and carry out recovery, recycling and harmless disposal.	• *Green and High-Efficiency Cooling Action Plan* • *Implementation Guide for the Upgrading and Recycling of Refrigeration Equipment* • *The 14th Five-Year Plan for Cold Chain Logistics Development*
SF_6	• Starting from 2023, 110 and 220 kV GIS busbars and disconnectors of new stations will be fully promoted with mixed gas equipment, and companies will strive to realize "zero growth" in the total use of SF_6 gas in 2028. • Raise annual SF_6 leakage rate standard to 0.1%.	• *(Plan from State Grid Corporation of China) Notice on the Promotion and Application of Mixed Gas GIS Equipment*[26]

Source: Summary by iGDP

4. Opportunities and Challenges for F-Gases Emission Reduction in China

Reducing F-Gases emissions, particularly HFCs, will support China in achieving its dual carbon targets. This effort presents both opportunities and challenges at various stages of the F-Gases life cycle, from developing alternatives and improving production processes to enhancing post-use recycling and disposal.

4.1 Opportunities and Challenges for HFCs Emission Reduction

The primary focus for reducing HFCs emissions lies in the refrigeration industry. Developing environmentally friendly alternatives and advancing refrigerant recycling technologies are crucial for lowering emissions before refrigerants reach the end of their life cycle.

[26] This is a corporate-issued plan rather than a national policy. State Grid Corporation of China is one of the major consumers of SF_6 in China. According to the China Industry News, as of 2020, the total amount of SF_6 used by State Grid for 10-1000kV distribution switchgear and substation switchgear equipment was approximately 31,786 tons.

R&D and adoption of environmentally friendly refrigerants: Developing and adopting low-GWP alternatives to HFCs is a key strategy for reducing emissions at the source. In the refrigerant industry, alternatives like hydrofluoroolefin refrigerants (HFO, such as HFO-1234yf), hydrocarbon refrigerants (HC, like HC-290), and certain natural refrigerants (like R744, i.e. CO_2), are promising options. However, these alternatives often encounter challenges related to safety, cost, or energy efficiency. For example, R1234yf and R290 are flammable, creating safety risks during use.[27] Additionally, R744 requires operation under high pressure, which not only demands specialized pressure-resistant equipment but also raises costs and safety concerns.[28]

China is still in the process of transitioning from second-generation refrigerants (HCFCs), which deplete the ozone layer, to third-generation refrigerants (HFCs). If companies can leapfrog directly to fourth-generation refrigerants, it could alleviate some pressure to reduce HFCs emissions. However, this presents a significant challenge, as China faces serious intellectual property barriers in HFO research and development, making it increasingly difficult to identify new, single working substances in the future. Currently, there are over 1,600 HFO patents, but Chinese companies hold only 14% of the total and just 1.7% of the core patents.[29]

Column-Domestic Practices: Most of China's domestic HFOs production capacity is controlled by foreign OEMs or Sino-foreign joint ventures. For example, Zhejiang Juhua Co., Ltd. produces 4 types of HFO for Honeywell, while Sinochem-Honeywell Joint Venture manufactures HFO-1233zd.[30] Although some domestic enterprises have developed HFO production technologies with independent intellectual property rights, the overall production capacity remains limited. For example, Huanxin fluorine materials Co., Ltd produces HFO-1234fy by using trifluoroethylene as raw material, with an industrial facility capable of producing 3,000 tons annually. Additionally, the industry is working to overcome patent barriers through developing compound working substances. For example, Zhejiang Research Institute of Chemical Industry has developed a composition of HFO-1234ze(E)/HFE-143a/HFC-32, while Zhejiang University developed HFO-1234fy/HFC-152a/HFC-134a, etc.[31]

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[27] Eiji Hihara. Research Project on Risk Assessment of Mildly Flammable Refrigerants.
[28] Zhang, X., Wang, F., Fan, X. W., Wei, X. L., & Wang, F. K. (2013). Determination of the optimum heat rejection pressure in transcritical cycles working with R744/R290 mixture. Applied thermal engineering, 54(1), 176-184.
[29] ZHANG, J. R&D progress of low-GWP refrigerants in China.
[30] SinoLink Securities Research Institute. The progress of existing production capacity of the fourth generation-refrigerant and the projects under construction.
[31] ditto

Refrigerant recycling technology: After recovering the refrigerant, reclamation technology – such as simple and distillation reclamation technology – can be selected based on its purity, whether it is a single or compound working substance, and other relevant characteristics.[32] In general, refrigerant recycling helps reduce emissions, eases the burden of quota reductions under the Montreal Protocol, and lowers environmental safety risks. However, China's refrigerant recycling and reuse is still in its early stages, with relatively outdated technology. According to statistics, only 40% and 14% of the refrigerant in every air conditioner and refrigerator, respectively, can be recovered during the recycling process in China.[33] This recovery rate is significantly lower compared to the advanced technologies in Europe, the U.S., and other developed countries. Additionally, the recycling cost can reach 40,000 to 100,000 RMB per ton, which is quite high.

Column-Domestic Practices: Tianjin Aohong Environmental Protection Materials Co., Ltd. is the largest refrigerant recycling enterprise in China, with its key technical performance indicators meeting the international advanced standards and offering cost advantages. In 2020, the company recycled 815 tons of refrigerant, which contributed to a reduction of about 1.6 million tons of CO_2e emissions. In 2021, over 1,200 tons of refrigerant were recycled, leading to a reduction of about 2.4 million tons of CO_2e emissions.

4.2 Opportunities and Challenges for HFC-23 Emission Reduction

HFC-23 is a by-product of the HCFC-22 production process and is designated for destruction under *the Montreal Protocol*. The Protocol has approved eight technologies for HFC-23 destruction, with incineration being the most common. However, incineration is energy-intensive and results in the loss of fluorine resources. As a result, China is encouraging companies to explore solutions, such as reducing the by-product rate and improving resource utilization.[34]

Improving the production process: The by-product rate of HFC-23 can be reduced by extending the catalyst service life, optimizing the reaction pressure, temperature, catalyst concentration, adjusting the raw material supply ratio and feeding method. Currently, the

[32] Han, X., Ye, G. Refrigerant recovery and reuse. https://cms.myhuiyi.com/Annex/20230423140002731.pdf.
[33] Solid Waste and Chemical Management Technology Center, Ministry of Ecology and Environment. (2022). Refrigerant Recovery and Reuse Management of Controlled Substances Under Montreal Protocol.
[34] Ministry of Ecology and Environment of the People's Republic of China. (2021). Notice on the control of by-product trifluoromethane emissions.

by-product rate of HFC-23 in most enterprises in China remains around 2-3%, but it has the potential to be reduced to less than 1% through the production process optimization.[35]

Resource utilization: The most economically and socially beneficial method for utilizing HFC-23 is to react with chloroform ($CHCl_3$) and convert it back to HCFC-22. This conversion process is efficient, safe, and can achieve near-zero emissions of HFC-23. Additionally, the technology can be integrated into the existing HCFC-22 production process, making the investment cost relatively low.[36,37]

Column-Domestic Practices: Zhejiang Research Institute of Chemical Industry and Zhonghao Chenguang Research Institute have developed HFC-23 conversion technology that is fully integrated with an HCFC-22 production unit. This technology officially began operation in December 2023. With an annual conversion capacity of 15,000 tons of HFC-23, this technology is expected to reduce CO_2e emissions by 220 million tons per year.[38]

[35] Solid Waste and Chemical Management Technology Center, Ministry of Ecology and Environment. (2022). Refrigerant Recovery and Reuse Management of Controlled Substances Under Montreal Protocol.
[36] Ibid.
[37] Green and low-carbon innovation conference. (2024). 2023 Top 10 scientific and technological innovations for China's carbon peak and carbon neutrality.
[38] China Haohua Chemical Group. (2024). Progress in the first set of by-product HFC-23 utilization project in China.

4.3 Opportunities and Challenges for SF_6 Emission Reduction

Reducing SF_6 emissions in the power industry can also be achieved through using alternative gases and promoting recycling.

R&D and adoption of alternatives in power equipment: Emissions can be reduced by either using a mixture of SF_6 with other gases or completely substituting SF_6 with alternative gases. Studies have shown that when using SF_6 gas mixtures, if SF_6 accounts for 30% in SF_6/N_2 mixture at an air pressure of 0.7MPa, the GWP can be reduced by approximately 50%. In terms of complete substitution, perfluoroisobutyronitrile (C_4F_7N) has demonstrated relatively strong performance.[39,40]

Column-Domestic Practices: Since 2017, China State Grid Corporation has launched pilot projects of SF_6/N_2 busbar and Disconnecting Ground Switch in provinces such as Hebei, Shandong, Anhui. Starting in 2023, the promotion and application of SF_6/N_2 mixed gas GIS equipment has been underway. From the second half of 2023, the State Grid Corporation has decided to stop purchasing Electrical switchgear containing SF_6.[41]

In addition, fluorine-free GIS equipment is also being promoted in China. More than 100 Siemens Blue GIS devices have been put into operation.[42] In 2020, Pinggao Electric Co., ltd. and Xi'an Jiaotong University designed China's first 126kV fluorine-free insulated metal enclosed switchgear with application value.[43]

SF_6 recycle technology: The comprehensive purification technology included in the 2015 "Catalog of National Key Promoted Low-carbon Technologies" can achieve a recovery rate of over 95%. And since the cost of SF_6 purification is lower than the cost of purchasing new gas, this abatement measure can even bring a considerable economic benefit.

Column-Domestic Practices: China State Grid Corporation has developed a complete set of technology and equipment for SF_6 gas recycling and built 26 provincial-level SF_6 recycling centers. By the end of 2020, the SF_6 recycling rate from State Grid exceeded

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[39] Yan, X., Gao, K., Zheng, Y., Li, Z., Wang, G., He, J., & Liu, Y. (2018). Research progress on SF_6 gas mixtures and alternative gases. Power System Technology, 42(6), 1837-1844.
[40] Zhou, W., Zheng, Y., Yang, S., Qin, Z., & Wang, B. (2016). Research progress and trend of environmentally friendly insulating gas as an alternative to SF_6. High Voltage Electrical Apparatus, 52(12), 8-14.
[41] YU, N. (2024). Strict control of sulfur hexafluoride! Accelerate fluorine-free substitution of power equipment.
[42] Ibid.
[43] The Paper. (2020). China's first 126kV fluorine-free environmentally friendly gas-insulated metal-enclosed switchgear was successfully developed.

96.5%, with a total of 732.3 tons of SF_6 gas being recycled, equivalent to a reduction of 17.502 million tons of CO_2e.[44]

4.4 Opportunities and Challenges for PFCs Emission Reduction

The primary focus for reducing PFCs emissions is the electrolytic aluminum sector, with an emphasis on minimizing the anode effect that generates PFCs through improved equipment and production processes.

Electrolytic aluminum anode effect reduction technology: The anode effect in the aluminum production process is the main source of PFCs emissions. To address this, technology such as "nano-ceramic-based anti-oxidation anode coating",[45] or the low anodic effect design can effectively reduce PFCs emissions.[46] Both technologies can bring additional economic benefits.

Column-Domestic practices: Nearly ten large-scale electrolytic aluminum enterprises including Shandong Weiqiao Venture Co., Ltd., Huanghe Xinye Co., Ltd., and Guangxi Hualei New Materials Co., Ltd. have applied "nano-ceramic-based anti-oxidation anode coating" technology, with a cumulative electrolytic aluminum production capacity of 1.7 million tons. And the low anodic effect design has been applied to 712 sets of 300kA electrolyzers in Shanxi Huasheng Aluminum Co., Ltd., Yunnan Aluminum Co., Ltd., etc., covering 3% of China's aluminum output.[47]

4.5 Opportunities and Challenges for Harmless Treatment of F-Gases

F-Gases at the end of their life cycle need to be destroyed.

Plasma technology: The use of plasma that produces high temperatures to break down F-Gases molecules is more energy-efficient, achieves a high removal rate, and has lower operating costs compared to incineration.[48]

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[44] National Energy Administration. (2021). Replies to Recommendation No. 6052 of the Fourth Session of the 13th National People's Congress.
[45] Ministry of Ecology and Environment of the People's Republic of China. (2022). Technical introduction to the catalogue of low-carbon technologies promoted by the state (the fourth batch).
[46] Research Group on Technology Development for Non-CO_2 Greenhouse Gas Emission Reduction. (2022). Assessment and Outlook for Non-CO_2 Greenhouse Gas Emission Reduction Technology Development.
[47] Wuhan Energy Conservation Association. (2021). Technologies for reducing perfluorocarbons (PFCs) emissions in aluminum electrolysis production.
[48] Research Group on Technology Development for Non-CO_2 Greenhouse Gas Emission Reduction. (2022). Assessment and Outlook for Non-CO_2 Greenhouse Gas Emission Reduction Technology Development.

Column-Domestic practices: In 2021, 62.3% of the refrigerants destroyed in China were processed using plasma technology.[49] A "low-temperature plasma degradation SF_6 device" developed by Guizhou Electric Power Research Institute has been put into use in Guizhou, Hubei, Chongqing, Anhui, etc. This technology has achieved an SF_6 degradation rate of 96%, successfully degrading SF_6 emissions over 770,000 tons of CO_2e.[50]

5. F-Gases Emission Reduction Outlook in China

In light of the Paris Agreement's objective to limit global warming to 2°C above pre-industrial levels, and to strive for a limit of 1.5°C, increased international bilateral and multilateral cooperation can be essential for reducing GHGs emissions.

In November 2023, China and the United States released the *Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis*, in which they stated, "the two countries intend to work together under *the Kigali Amendment* to phase down HFCs and commit to ensure application of ambitious minimum efficiency standards for all cooling equipment manufactured". This reflects both countries' proactive commitment towards *the Kigali Amendment* and their higher aspirations for the future development of their refrigeration industries.

The Global Cooling Pledge, introduced at the 2023 United Nations Climate Change Conference (COP28), presents a valuable opportunity to enhance HFCs emissions reduction and promote sustainable cooling. The pledge aims to "reduce cooling-related emissions by 68% from today by 2050, significantly increase access to sustainable cooling by 2030, and increase the global average efficiency of new air conditioners by 50%". At COP28, 63 countries committed to the pledge, and that number has now increased to 71.[51]

In addition to the declarations and commitments mentioned above, the *Nationally Determined Contributions* (NDCs) also play a key role in guiding the emission reduction actions of Paris Agreement Parties. As of 2022, 53% of countries included HFCs emissions reduction in their NDCs overall targets, while 36% addressed PFCs and SF_6, 26% included NF_3.[52] 13 countries listed measures that would have the benefit of reducing HFCs emissions in their NDCs.[53] However, when it comes to quantified targets, Japan is currently the only country to have announced a specific plan: to cut F-Gases emissions by 17.3 Mt CO_2e by 2030 from 2013 levels, which includes 17.6 Mt CO_2e for HFCs and 1.1 Mt CO_2e for NF_3,

[49] Solid Waste and Chemical Management Technology Center, Ministry of Ecology and Environment. (2022). Refrigerant Recovery and Reuse Management of Controlled Substances Under Montreal Protocol.
[50] China Energy Net. (2023). Guizhou Power Grid put into use a new sulfur hexafluoride degradation device.
[51] Climate & Clean Coalition. Global Cooling Pledge. https://coolcoalition.org/global-cooling-pledge/.
[52] UNFCCC Secretariat. (2022). Nationally Determined Contributions Under the Paris Agreement.
[53] Climate & Clean Air Coalition. (2024). Leveraging the Benefits of non-CO_2 Pollutants and Air Quality in NDC 3.0.

although emissions of PFCs and SF_6 are expected to rise. According to Japan's Ministry of the Environment, F-Gases emissions saw their first decline in 2022 since 2009.[54]

Under *the Paris Agreement*, countries will soon submit NDCs for 2035. In this round of updates, more countries are expected to include targets and measures for reducing F-Gases or HFCs emissions. This is in line with the upcoming reduction timetable set by *the Kigali Amendment* and the increasingly widespread climate actions: by 2024, Kigali non-Article 5 parties (e.g. the United States, Japan, and the EU) will need to cut HFCs production and consumption by 40% from baseline levels, while Article 5 Group 1 parties (such as China, Thailand, and Brazil) will enter the compliance process.

The upcoming NDCs update also presents a significant opportunity for China to enhance its efforts in reducing F-Gases. At the 2024 UN Climate Change Conference (COP29), during the World Leaders Climate Action Summit, China announced that it would submit its 2035 NDCs that are economy-wide and cover all greenhouse gases,[55] signaling a positive step towards non-CO_2 GHGs reduction. Moreover, the series of actions China has already taken to reduce HFCs can serve as a solid policy foundation for updating its NDCs. With the pioneering implementation of HFCs emission reduction policies, along with the groundwork taken at the corporate levels to address SF_6 and PFCs emissions, China may consider further enhancing the regulatory framework and emission reduction strategies for SF_6 and PFCs in the future.

[54] Ministry of the Environment, Japan. (2024). Japan's Progress on Climate Change Measures and International Cooperation.
[55] Xinhua. (2024). Address by Chinese Vice Premier Ding Xuexiang at World Leaders Climate Action Summit.

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