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EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Ninety-first Meeting
Montreal, 5-9 December 2022
Item 7(b) of the provisional agenda[1]

Addendum

REPORTS ON PROJECTS WITH SPECIFIC REPORTING REQUIREMENTS

1. The present addendum includes reports on projects with specific reporting requirements pertaining to China that are due at the 91st meeting.

2. The document is divided into the following three sections:

Section	Report title	Paragraphs
I	Report on progress in the implementation of activities listed in decision 83/41(e)	3 to 6
II	Study to determine the regulatory, enforcement, policy or market circumstances that might have led to the illegal production and use of CFC-11 and CFC-12 (decision 83/41(d))	7 and 8
III	Updated report on the production of CTC and its feedstock uses in China (decision 84/41(b) and (c))	9 to 34

[1] UNEP/OzL.Pro/ExCom/91/1

I. Report on progress in the implementation of activities listed in decision 83/41(e)

Introduction

3. At its 83rd meeting, the Executive Committee considered the following two documents:

(a) Review of current monitoring, reporting, verification and enforcement (MRVE) systems in accordance with HCFC consumption and production phase-out management plan Agreements between the Government of China and the Executive Committee, submitted by UNDP on behalf of the Government of China, in line with decisions 82/65 and 82/71(a); and

(b) Desk study on the current system of monitoring consumption of foam-blowing agents at enterprises assisted under stage I of the HCFC phase-out management plan and verification methodology submitted by the World Bank on behalf of the Government of China in line with decision 82/67(c).

4. In its deliberations, the Committee *inter alia* welcomed a number of regulatory and enforcement actions to be undertaken by the Government; noted with appreciation that the Government will undertake additional actions in support of its enforcement actions; and further noted with appreciation that the Government will consider a set of suggestions to supplement and augment its regulatory and enforcement actions. The Executive Committee also noted that the Government of China would submit a report at the 84th meeting, and again to the 86th meeting, on its progress in implementing the activities described in sub-paragraphs (a) to (d) of decision 83/41.

5. At its 84th meeting, the Executive Committee considered the progress report submitted by the Government of China in line with decision 83/41(e).[2] Subsequent to a discussion, the Executive Committee took note of the information provided by the representative of the Government of China regarding implementation of the activities listed in decision 83/41.

6. The Government of China had submitted to the 86th meeting a progress report pursuant to decision 83/41. The Executive Committee deferred consideration of the progress report to the 87th, 88th, and 90th meetings in accordance with the agreed procedures for conducting those meetings. At the 90th meeting, the Executive Committee agreed to further defer consideration of the report to the following in-person meeting on account of the online participation of key representatives of one member's delegation. The progress report is attached in its entirety to the present document without editing or further review.

II. Study to determine the regulatory, enforcement, policy or market circumstances that might have led to the illegal production and use of CFC-11 and CFC-12 (decision 83/41(d))

Introduction

7. In the context of its discussions on China's monitoring, reporting, verification and enforcement systems at its 83rd meeting, the Executive Committee *inter alia* decided to note that the Government of China will consider engaging a non-governmental consultant to undertake a study (including quantitative data, where available, and qualitative market information) to determine the regulatory, enforcement, policy or market circumstances that might have led to the illegal production and use of CFC-11 and CFC-12 (decision 83/41(d)).

[2] UNEP/OzL.Pro/ExCom/84/22/Add.1.

8. Pursuant to decision 83/41(d), the Government of China had submitted to the 86th meeting the Study on the Supervision, Law Enforcement, Policy and Market Situation of Ozone Depleting Substances in China that was prepared by a non-governmental consultant. The Executive Committee deferred consideration of the study to the 87th, 88th, and 90th meetings in accordance with the agreed procedures for conducting those meetings. At the 90th meeting, the Executive Committee agreed to further defer consideration of the study to the following in-person meeting, on account of the online participation of key representatives of one member's delegation. The study is attached in its entirety to the present document without editing or further review.

III. Updated report on the production of CTC and its feedstock uses in China (decision 84/41(b) and (c))

Introduction

9. At its 84th meeting, the Executive Committee considered the report on the production of carbon tetrachloride (CTC) and its feedstock uses in China (decision 75/18(b)(iii)) contained in documents UNEP/OzL.Pro/ExCom/84/22/Add.2 and Add.3 and, subsequent to a discussion, decided *inter alia* to invite the Government of China, through the World Bank, to submit, to the 88th meeting, an updated report on the production of CTC and its feedstock uses in the country, taking into consideration the information contained in documents UNEP/OzL.Pro/ExCom/84/22/Add.2 and Add.3, and including: (i) an update on the progress in monitoring perchloroethylene (PCE) plants that used the alkane chlorination process; (ii) any additional information relevant to the difference in emissions described in the report, and the estimated CTC emissions from China included in section 1.2.3 of the Scientific Assessment of Ozone Depletion: 2018;[3] and to note that the Government of China was considering monitoring the PCE that used the alkane chlorination process, and to invite the Government to include in the updated report any actions taken on that matter (decision 84/41).

10. The Government of China, through the World Bank, submitted the updated report on the production of CTC and its feedstock uses in China[4] on 20 September 2020. Given the limited time available before the 88th meeting, and in line with decision 84/41, the Secretariat undertook a preliminary review of the updated report, contained in section IV of document UNEP/OzL.Pro/ExCom/88/18/Add.1. The Secretariat undertook a detailed review of the updated report for the 90th meeting, contained in section III of document UNEP/OzL.Pro/ExCom/90/9/Add.1; the Executive Committee agreed to defer consideration of the updated report to the following in-person meeting on account of the online participation of key representatives of one member's delegation. The present document contains the Secretariat's review of the updated report as presented to the 90th meeting.

Updated report

Chloromethane (CM) and CTC production

11. CM[5] and CTC production steadily increased between 2015 and 2019. In 2019, there were 16 CM production enterprises with total production capacity of 2,730,000 tonnes per annum. The production levels of CM and CTC are given in table 1.

[3] Page 1.24 of https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf.
[4] The updated report contains information considered confidential by the Government of China and is available by request to Executive Committee members on the understanding that the information contained therein is not disclosed to a third party.
[5] CM encompasses methyl chloride (CH_3Cl), dimethyl chloride (CH_2Cl_2), chloroform ($CHCl_3$) and CTC. CM is produced by reaction methyl chloride with Cl_2.

Table 1. Production of CM and CTC in China (mt)

Particulars	**2015**	**2016**	**2017**	**2018**	**2019**
CM production	2,055,221	2,264,813	2,586,052	2,647,676	2,927,110*
CTC production	97,161	105,675	122,759	140,095	155,669
Percentage of CTC production	4.73%	4.67%	4.75%	5.29%	5.32%

* Production was above the nameplate capacity for 2019.

12. During the period 2015 to 2019, the stock level for CTC grew from 1,435.9 mt at the beginning of 2015 to 12,588.2 mt by December 2019.

Conversion of CTC to non-ODS chemicals at CM producers

13. Most (68-71 per cent) of the CTC produced in 2018-2019 was used internally by CM producers for conversion to non-ODS chemicals (PCE, methyl chloride, and chloroform[6]). The remaining CTC was sold to 25 registered feedstock users; minor quantities (less than 0.3 per cent of CTC production) was used for laboratory and analytical uses and as a process agent.

Feedstock use of CTC

14. CTC is used as a feedstock for the manufacture of 15 non-ODS chemicals, including four chemicals[7] that had not been manufactured in 2017. The number of feedstock users[8] in 2018-2019 grew to 25 from the 21 users that were active in 2017. The quantity of CTC used as a feedstock increased from 29,199 mt in 2015 to 50,337 mt in 2019, principally due to the increased manufacture of HFC-245fa, HCC-240fa, and PCE. The manufacture of three of the new chemicals in 2018-2019 accounted for less than 1 per cent of CTC used as feedstock, while the manufacture of the fourth chemical (HCC-240fa) became the largest feedstock use in 2019, accounting for approximately 40 per cent of the CTC used as feedstock in 2019. HCC-240fa is principally used as a feedstock for the manufacture of HFOs and HFC-245fa.

Production of PCE

15. There are two PCE production processes in China: the acetylene chlorination process and the C1-C3 alkane chlorination process. The former, which is the main production pathway of PCE in China due to the low price and the availability of acetylene in China, does not result in the production of CTC by-product, while CTC by-product is produced in the latter process. The updated report confirmed that there was only one PCE plant that uses the alkane chlorination process. All CTC by-product at that enterprise is recycled directly to the reactor, along with other reactants, after product distillation. CTC is partially separated in the quench tower, and in the purification units; the streams from these two processes containing a mixture of CTC, PCE, and other components are fed to a storage tank, which are not suitable for sale without purification. As there is no CTC purification unit at the enterprise, CTC from the enterprise cannot be sold; the contents of the storage tank, including the by-produced CTC, is recycled to the reactor. Production at the enterprise is supervised by the local ecology and environment bureau (EEB), which undertakes routine environmental supervision and monitoring, and irregular inspections to ensure that no CTC leaves the production line.

[6] In 2019, the CM producers also manufactured a small quantity of hydrochloric acid.
[7] Triphenylmethanol, glufosinate-ammonium, 3-(2,2-dichlorovinyl)-2,2-dimethyl cyclopropanecarbonyl chloride (DVDC), and 1,1,1,3,3-pentachloropropane (HCC-240fa).
[8] Those feedstock users do not include the CM producers that have their own internal conversion of CTC, except for the one CM producer that also buys CTC to augment its internal production.

Estimated CTC emissions

16. The updated report provided estimated emissions of CTC for 2018-2019 based on the model described in the report on the 2015-2017 production of carbon tetrachloride and its feedstock uses in China,[9] and the 2018-2019 CTC production and use data. CTC emissions are estimated from three sources: from the CTC production by CM producers, from the conversion of CTC to non-ODS chemicals by CM producers, and from CTC feedstock users.

17. CTC emissions from CM production was assumed to be very low given advanced process technology and onsite management and controls at CM production facilities; the enterprises have installed cryogenic condensers in tank outlets to reduce volatile emission from the tail gas of CTC tanks; CTC incinerators are operational in most of the enterprises; closed systems with advanced cargo-tank and product-tank connections for avoiding any CTC emissions in the loading/unloading process and onsite management; and process controls and advanced equipment used to minimize emissions of CTC during maintenance. In 2017, emissions of CTC were estimated at 25.6 mt, with an additional 365.6 mt of potential emissions,[10] resulting in maximum CTC emissions of 391.2 mt (0.3 per cent of CTC production); emissions in 2018 and 2019 increased to 29.6 mt and 30.3 mt, with an additional 432.2 mt and 543.7 mt of potential emissions, resulting in maximum CTC emissions from the production of CM of 461.8 mt and 574 mt (0.3 and 0.4 per cent of CTC production), respectively.

18. CTC emissions from the conversion of CTC to non-ODS chemicals by CM producers was assumed to be very low, in line with the advanced CTC conversion technology and process management for the large scale, continuous and highly automatic production process. All the CM production enterprises converting CTC are designed specifically for converting their CTC by-product; strict measures similar to that used in the CM production process are used to lower CTC emissions. In 2017, emission of CTC from CM producers during the conversion to non-ODS chemicals were 17.9 mt, with additional potential emissions of 84.3 mt, resulting in maximum emissions of 102.2 mt. Emissions in 2018 and 2019 decreased to 13.1 mt and 14.2 mt, with potential emissions of 86.9 mt and 75.0 mt, resulting in maximum emission of 100.0 mt and 89.2 mt, respectively. Emissions decreased notwithstanding the increased quantity of CTC converted to non-ODS chemicals due to change in relative proportion of non-ODS produced and the different emissions associated with each process; in particular, the highest emissions in 2017 were from the production of chloroform, which decreased in 2018 and 2019. In contrast, production of methyl chloride, which does not result in emissions of CTC, increased, as did production of PCE, which has relatively low emissions of CTC.

19. CTC emissions from feedstock use are assumed to be low given a high utilization rate of CTC that is ensured by adjusting the reaction conditions, recycling CTC in the production process, and advanced production technology and management of CTC. Emissions of CTC from feedstock use in 2017 were 39.4 mt, with additional potential emissions of 138.6 mt, resulting in maximum emissions of 177.9 mt. Emissions in 2018 and 2019 increased to 54.3 mt and 75.2 mt, while additional potential emissions decreased to 74.4 mt and 93.8 mt, resulting in maximum emissions of 128.7 mt and 169.0 mt, respectively.

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[9] Paragraphs 8 to 10 of document UNEP/OzL.Pro/ExCom/84/22/Add.2.

[10] Potential emissions were derived based on a technical assessment of possible emissions of CTC from various waste streams and were estimated based on product disposal methods; unlike actual emissions, which were based on direct estimates of CTC in emission streams, potential emissions are based on usage of products or disposal methods for the CTC streams that could have different CTC levels, before discharge to the atmosphere. The report indicated that those potential emissions are unlikely considering the advanced process technology and management level in the CM production enterprises and the restrict supervision of volatile organic compounds (VOCs) and chemical oxygen demand (COD) by ecology and environmental protection bodies in China.

20. Table 2 summarizes the estimated CTC emissions for 2017-2019.

Table 2. Estimated 2017-2019 CTC emissions in China (mt)

Year	**2017**			**2018**			**2019**		
Item	Actual emission	Potential emission	Maximum emission	Actual emission	Potential emission	Maximum emission	Actual emission	Potential emission	Maximum emission
CM production	25.6	365.6	391.2	29.6	432.2	461.8	30.3	543.7	574.0
Conversion at CM producers	17.9	84.3	102.2	13.1	86.9	100.0	14.2	75.0	89.2
Feedstock uses	39.4	138.6	177.9	54.3	74.4	128.7	75.2	93.8	169.0
Total	**82.9**	**588.4**	**671.3**	**97.0**	**593.5**	**690.5**	**119.7**	**712.5**	**832.2**

Secretariat's comments

<u>CTC production, stock levels, and controls</u>

21. The percentage of CTC production as a function of CM production increased to satisfy increased market demand for CTC as a feedstock. In particular, CM producers can adjust their production process and the amount of CTC by-product depending on the demand for CTC for feedstock uses. The national CTC by-production monitoring platform started operation in 2019; the platform allows for the daily monitoring of production at CM producers.

22. The increase in CTC stock levels in 2019 was principally due to an operational problem with the destruction device at one CM producer that year; subsequently, the CM producer commissioned another CM producer to assist in the disposal of the stock, which was monitored by the local EEB. The World Bank emphasized that the Ministry of Ecology and Environment pay close attention to CM producers' CTC stockpiles and urges them to complete any required disposal in a timely manner.

23. At the 84th meeting, the World Bank had indicated that further research was needed on whether technology upgrades at CM producers could further reduce the concentration of CTC in chloroform, a potential source of CTC emissions. The World Bank informed that since then, CM producers had not considered such technology upgrades.

24. At the 84th meeting, the Secretariat had noted that for all feedstock users included in the 2015-2017 report, material conversion ratios varied for individual enterprises on a year-to-year basis and across enterprises for the same feedstock use; moreover, some reported material conversion ratios appeared to vary by year within the same enterprise, which would make comprehensive monitoring of CTC difficult. The Government considered the existing system adequate.

<u>PCE production through the C1-C3 alkane chlorination process</u>

25. At the 84th meeting, the Secretariat had requested clarification on monitoring of CTC at PCE producers that use the C1-C3 alkane chlorination process. The updated report indicates that the only PCE producer that uses the alkane chlorination process does not have a CTC purification unit to separate CTC from the process streams that include a mixture of CTC, PCE, and other components. Accordingly, the Government considered the risk of diversion of CTC is low and therefore has not taken any additional actions to monitor the PCE plant. The World Bank confirmed that the PCE producer would need to submit an environmental impact assessment in order to substantially modify its production process, including by installing a CTC purification unit.

CTC emissions

26. At the 88th meeting, the Secretariat noted that the updated report did not include information or analysis to address the difference in emissions reflected in the 2018 Scientific Assessment of Ozone Depletion and those in documents UNEP/OzL.Pro/ExCom/84/22/Add.2 and Add.3. In particular, the updated report includes estimated emissions of CTC that are orders of magnitude less than those in the 2018 Scientific Assessment Report, as well as in the scientific journal article by Lunt et al. (2018),[11] which was published too late to be considered in the 2018 report.

27. Lunt et al. (2018) used two methods to estimate emissions of CTC from China of 17 (11-24)[12] or 13 (7-19) Gg/year for the period 2009 to 2016. Those emission estimates are based on long-term, high-frequency observations of CTC at the Gosan measurement station on Jeju Island, Republic of Korea.[13] The authors also assessed emissions from China using data from the Korea-U.S. Air Quality (KORUS-AQ) flight campaign in May-June 2016, and found that emissions from China were 16 (13–21) Gg/year, consistent with the authors' Gosan-derived estimated emissions for 2016 of 15 (11–20) Gg/year. While the report on the 2015-2017 production of carbon tetrachloride and its feedstock uses in China[14] only provided estimated emissions for 2017, scaling the model based on 2016 CTC production, conversion by CM producers, and feedstock uses would result in CTC emissions that are two orders of magnitude below those estimated by Lunt et al. (2018); the maximum CTC emissions estimated by the model would be one order of magnitude below those estimated by Lunt et al. (2018).

28. Further to a request for clarification at the 88th meeting[15] regarding the difference in emissions, the Government of China, through the World Bank, noted the relevance of the CTC emission discrepancy and that there have been substantial differences in top-down and bottom-up estimates of CTC emissions data for years. The Government considered that discrepancy to be a global issue that involves not only China but also other countries in other regions. The Government further noted that the Scientific Assessment Panel has examined this issue for over ten years, and while the discrepancy of CTC emission between top-down and bottom-up estimates has been significantly reduced in the 2018 Scientific Assessment Report, differences still exist and remain to be explained. The 2018 Scientific Assessment Report pointed to the need for improved understanding on factors such as the concentration of air samples and meteorological conditions that affect the assessment. The Government of China expressed its interest to follow up relevant research in this regard.

29. The Government of China further noted that based on the updated report and the regulations on CTC management and monitoring, the estimated CTC emissions in the 2018 Scientific Assessment Report could not be fully explained, no information on additional CTC emission sources was found, and emphasized that:

(a) The CM production lines are a highly automated and closed system with seamless connection among equipment and incineration units, thus CTC emissions are virtually negligible;

[11] Lunt, M. F., Park, S., Li, S., Henne, S., Manning, A. J., Ganesan, A. L., et al. (2018). Continued emissions of the ozone-depleting substance carbon tetrachloride from eastern Asia. Geophysical Research Letters, 45. https://doi.org/10.1029/2018GL079500.

[12] Estimated emissions are provided as an average with the 95 per cent confidence level indicated in brackets; 1 Gg = 1,000 mt.

[13] https://agage.mit.edu/stations/gosan-jeju-island

[14] Documents UNEP/OzL.Pro/ExCom/84/22/Add.2 and UNEP/OzL.Pro/ExCom/84/22/Add.3.

[15] Paragraphs 18 and 19 of document UNEP/OzL.Pro/ExCom/88/18/Add.1.

(b) Enterprises that use CTC as a feedstock make best efforts to handle CTC in a cost-effective manner to reduce their production costs, so there is no motive for enterprises to deliberately emit CTC; and

(c) The Government had implemented strict inspections and law enforcement for environmental protection in recent years, in particular for those chemical plants. The supervision on VOCs and chemical oxygen demand was greatly strengthened by various level ecology and environmental protection bodies. In this regard, the CTC emissions by these enterprises are unlikely to be those suggested in the 2018 Scientific Assessment Report or the article by Lunt et al. (2018).

30. The Secretariat notes that subsequent to the article by Lunt et al. (2018), Park et al. (2021)[16] reported a decline in emissions of CFC-11 and related chemicals, including CTC, from eastern China. In particular, Park et al. (2021) found that CTC emissions from eastern China were higher than expected after 2013 and then declined one to two years before 2019 when a reduction in CFC-11 emissions was observed: emissions from eastern China grew from 6.0 ± 1.4 Gg/yr for 2011-2012 to 10.9 ± 2.0 Gg/yr for 2014-2017, and subsequently declined to 6.2 ± 1.4 Gg/yr in 2018-2019. Notwithstanding those decreases, the CTC emissions estimated by Park et al. (2021) for 2018-2019 are two and one order of magnitude higher than the estimated CTC emissions and maximum CTC emissions, respectively, in the updated report. Furthermore, while Park et al. (2021) reported a substantial (by over 40 per cent) decrease in CTC emissions in 2018-2019, the model used to estimate CTC emissions in the reports on the 2015-2019 production of CTC and its feedstock uses in China suggests gradually increasing emissions of CTC in 2015-2019, consistent with increased CTC production, conversion by CM producers, and feedstock use, suggesting that the model may not be capturing some sources of CTC emissions that were controlled in the latter part of 2015-2019.

31. The Secretariat enquired whether the Government had further views on the difference between the estimated CTC emissions in the updated report and those by Park et al. (2021), noting that those emissions were specific to China and not global emissions. Moreover, as noted by Lunt et al. (2018), in contrast to global emissions estimation, regional inverse modeling studies can help to address the geographical source of the discrepancy in top-down and bottom-up emissions on a global scale because such regional studies are relatively insensitive to uncertainty in the CTC lifetime. The Government was of the view that the model used in the 2015-2019 reports considered all relevant production process that may generate CTC emission, and the CTC emission discrepancy was a global issue that needed further research.

32. The Secretariat further noted that an analysis of high-quality observations of CTC atmospheric abundances in China could be helpful in understanding the reasons for the differences in emissions reported in the scientific literature and those in the reports on the 2015-2019 production of CTC and its feedstock uses submitted by China. However, while a preliminary analysis of local data[17] suggested emissions of CTC in 2009-2010 that are comparable to those reported by Lunt et al. (2018) and Park et al. (2021) for those years, it appears that an analysis based on more recent data has not yet been undertaken notwithstanding that at least one atmospheric monitoring site in China[18] included observations of atmospheric abundances of CTC.

[16] Park, S, Western, L.M, Park, S., Western, L. M., Saito, T., Redington, A. L., et al. (2021). A decline in emissions of CFC-11 and related chemicals from eastern China. Nature. https://doi.org/10.1038/s41586-021-03277-w

[17] The preliminary analysis was not published in the peer-reviewed scientific literature but is available here: https://www.sparc-climate.org/fileadmin/customer/5_Meetings/2015_PDF/13_Bo_Yao_Long-term_observation_of_CCl4_at_CMA_network_in_China.pdf.

[18] The Global Atmospheric Watch (GAW) at Shangdianzi. A figure showing the timeseries of averaged atmospheric abundances of CTC at the station is available here: https://yhp-website.oss-cn-beijing.aliyuncs.com/upload/2019%E4%B8%AD%E5%9B%BD%E6%B8%A9%E5%AE%A4%E6%B0%94%E4%BD%93%E5%85%AC%E6%8A%A5_1634010133088.pdf.

33. Regarding the atmospheric monitoring network the Government of China intended to establish in line with decision 83/41(b)(i), the World Bank informed that the Government was conducting the construction of the monitoring stations as planned, and that atmospheric monitoring of controlled substances would begin in 2022.

Recommendation

34. The Executive Committee may wish to consider the information contained in the updated report on the production of carbon tetrachloride and its feedstock uses in China (decision 84/41(b) and (c)) contained in document UNEP/OzL.Pro/ExCom/91/18/Add.1.

Progress Report Pursuant to Decision 83/41 of the 83rd Meeting of the Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol

I. Background

According to Decision 83/41 of the 83rd Meeting of the Executive Committee (ExCom) of the Multilateral Fund, the Government of China will report to the ExCom, at the 86th meeting, on its latest progress in implementing the activities related to China's ODS monitoring and law enforcement.

II. Progress of monitoring and law enforcement activities

The Government of China attaches great importance to the unexpected emission increase of trichlorofluoromethane (CFC-11) in the atmosphere. On the one hand, control of CTC supply is strengthened to prevent diversion of CTC to illegal ODS production. On the other hand, China is constantly strengthening monitoring and law enforcement of ODS to prevent illegal sales and use of ODS. Since the beginning of 2020, although the COVID-19 pandemic has posed adverse impacts on monitoring and law enforcement in implementing the Montreal Protocol, the Government of China is still striving to overcome difficulties and take active actions to improve law and regulation system, conduct law enforcement actions, intensify CTC supervision and management, build capacity for implementing the Montreal Protocol, strengthen cooperation with the industry, and establish monitoring network, etc. The progress of relevant work from October 2019 to July 2020 is as follows (see Annex 1):

(I) Improve law and regulation system

In August 2019, the Ministry of Ecology and Environment (MEE) launched the revision of *the Regulation on the Administration of Ozone Depleting Substances* (hereinafter referred to as the Regulation), conducted an assessment of the implementation of the Regulation, and formulated *the Regulation on the Administration of Ozone Depleting Substances and Hydrofluorocarbons (Draft for Soliciting Opinions*) based on the assessment and new requirements for implementing the Montreal Protocol. The revision mainly includes: 1) Considering the future compliance requirements of the Kigali Amendment, hydrofluorocarbons (HFCs) are incorporated into the scope of control; 2) To further clarify definition and classification of uses, it is stipulated that co-production and by-production are classified as production activities, pre-blended polyols are included in the monitoring scope as mixtures, and pre-blended polyols manufacturing enterprises are strictly supervised as consumption enterprises with controlled use. At the same time, targeted monitoring measures are formulated for supervising controlled use and feedstock use; 3) Work related to monitoring and evaluation is included, a national monitoring network of controlled substances under the Montreal Protocol will be established, and the monitoring and evaluation work will be organized accordingly; 4) The legal responsibilities of both market entities and supervisors are further elaborated, and the punishment measures on various violations are further reinforced, 5) Supporting policy measures will be improved and the R&D and application of testing and monitoring methods of controlled substances will be encouraged and supported.

As of the end of June 2020, public opinion solicitation has been completed. At present, it is being revised based on opinions and feedback. The Regulation (Revised Draft for Approval) will be submitted to the State Council for review within 2020, and will be issued upon the approval by the State Council in accordance with relevant procedures.

(II) Carry out law enforcement actions

1. Cracking down on illegal use of CFC-11

From June to August 2019, MEE dispatched law enforcement officers to form joint enforcement groups with local law enforcement personnel to 11 key provinces/municipalities including Shandong, Hebei, Henan, Jiangsu, Zhejiang, and Guangdong to conduct special inspections. In this action, 656 system houses and polyurethane foam enterprises were inspected. Testing through portable instant detectors found that samples from 37 enterprises, including 6 system houses and 31 foam manufacturers, contained CFC-11. After the laboratory retesting, it's confirmed that 16 enterprises have been engaged in illegal use of CFC-11. None of these 16 enterprises received funds from the Multilateral Fund or was registered with the China Plastic Processing Industry Association (CPPIA). The local ecology and environment bureaus (EEBs) have handled these cases in accordance with the law. Through laboratory testing, samples from the 21 enterprises were found to contain no or only trace of CFC-11. Hence, these 21 enterprises could not be confirmed using CFC-11.

Among these cases, one enterprise's legal representative was sentenced to 10 months of imprisonment for the crime of environmental pollution by the local court. The specific circumstance is: Through the sudden unannounced inspection in Huzhou Deqing Minghe Insulation Materials Co., Ltd. (hereinafter referred to as Minghe Company), Zhejiang working group found clues of the company's illegal practice which pointed out the criminal facts of Minghe Company's three-year illegal purchase and use of 849.5 tons of CFC-11 in the production of pre-blended polyols. The sentence of the case was pronounced by the People's Court in Deqing County in March 2020: Minghe Company was fined 700,000 RMB yuan for environmental pollution caused by its illegal production of pre-blended polyols using CFC-11, and illegal gains of more than 1.4 million RMB yuan was recovered; its legal representative Qi was sentenced to 10 months of imprisonment for the crime of environmental pollution and was fined 50,000 RMB yuan. Among the 4 suppliers (all dealers) of CFC-11 raw materials in this case, 2 were held criminally responsible for the crime of environmental pollution (one was sentenced to 8 months of imprisonment, the other was sentenced to 9 months of imprisonment), and the other 2 people are still under investigation. It is the first case that was sentenced to substantial punishment for the illegal use of ODS in the domestic polyurethane foam sector to date, which fully reflects China's firm zero-tolerance attitude towards illegal activities related to ODS. MEE issued a public report with the theme of *China's First Case of Illegal Use of ODS Sentenced to Criminal Punishment*.

Among the other 15 enterprises which involved violations, including 4 system houses and 11 polyurethane foam enterprises, about 9.4 tons of CFC-11 raw materials, 4.35 tons of pre-blended polyols and 2.2 tons of polyurethane foam products were seized and soundly disposed of, a fine of 2,816,900 RMB yuan was imposed (including the confiscation of illegal gains). Facilities and equipment of one enterprise were dismantled, violation of one enterprise has been transferred to the public security bureau (the case is still under investigation), and another enterprise was shut down.

2. Additional law enforcement equipment for local EEBs

As of the end of December 2019, a total of 50 portable ODS instant detectors have been distributed to EEBs of 30 provinces (autonomous regions and municipalities) and law enforcement officers from some key cities and counties, so as to help them conduct on-site inspection.

3. Strengthen supervision and law enforcement

In December 2019, MEE formulated *the Guideline on Supervision of Ozone Depleting Substances (Trial)*, including specific requirements for methods and contents of law enforcement inspection and handling of illegal behaviors. The Guideline has been issued and distributed to local EEBs.

MEE has formulated and issued *the 2020 Work Plan for Law Enforcement Inspection on Ozone Depleting Substances* in July 2020 and launched a new round of special ODS law enforcement inspection nationwide at the end of July 2020 mainly targeting at HCFC-141b and HCFC-22 production enterprises and illegal production and use of CFC-11. Outcome of this special law enforcement inspection will be reported to MEE from local EEBs by the end of this year.

In 2021, through the national CTC online monitoring platform and industrial rewards for reporting platform, MEE will further intensify source control, crack down on illegal ODS production, and improve the identifying mechanism, investigation mechanism and disclosure mechanism of illegal ODS production cases in steps.

(III) Intensify source control

1. Establishment of CTC monitoring platform

MEE has imposed stricter control measures on the chloromethane producers generating CTC as by-product since 2019, requiring every enterprise to install a verifiable and quantitative CTC online production monitoring system. At present, all chloromethane producers have completed the installation of the online monitoring systems. Meanwhile, MEE is working on establishing a national CTC monitoring platform, which is currently in the stage of system design and development. The online trial operation is expected to be completed by the end of 2020 to realize online monitoring of CTC by-production in all chloromethane enterprises.

With regard to perchloroethylene (PCE) production enterprises, according to the current available information, there is only one enterprise that uses the alkane chlorination process during the PCE production in China. On September 5th 2019, MEE conducted an on-site survey on this enterprise with local EEBs. In light of the survey, during the PCE production process of this enterprise, CTC is only generated as an intermediate conversion product and reactor diluent, which is not separated or purified as by-products in the system. Since CTC does not flow out of the system and the production facility has no outlet pipes for CTC, there is no need to take daily supervision measures targeting at CTC on this enterprise as applied to chloromethane enterprises.

2. On-site supervision

From June 2019 to January 2020, MEE dispatched supervisory working groups to 16 chloromethane enterprises with CTC by-production to carry out the on-site inspection on CTC crude output, purification, residue, storage, conversion and sales, and other key processes to ensure legal production and use. By January 2020, 14 rounds of on-site supervision with attendance reaching 577 had been conducted. Each round lasted for two weeks (including holidays), achieving continuous daily on-site supervision. Since February 2020, the on-site inspection of CTC by-production enterprises has been suspended due to the COVID-19 pandemic, however, MEE still requires chloromethane production enterprises to report CTC related data weekly, and local EEBs have taken measures to conduct on-site inspections as needed.

(IV) Building Capacity for implementing the Montreal Protocol

1. Construction of testing laboratories and development of testing standards

For construction of testing laboratories, by the end of 2019, MEE had completed the construction of 8 ODS testing laboratories for industrial products, and all of them have obtained the expansion of CMA (China Inspection Body and Laboratory Mandatory Approval) certificate to ensure testing reports with legal effect could be provided.

For the formulation of laboratory testing method standards for ODS in industrial products, in October 2019, MEE approved and issued two national environmental protection standards, *Determination of ozone-depleting substances including HCFC-22, CFC-11, and HCFC-141b in pre-blended polyols —Headspace/gas chromatography-mass spectrometry (HJ 1057-2019*) and *Determination of ozone-depleting substances including CFC-12, HCFC-22, CFC-11 and HCFC-141b in rigid polyurethane foam and pre-blended polyols—Portable headspace/gas chromatography-mass* *spectrometry (HJ 1058-2019)*, to standardize testing of controlled substances under the Montreal Protocol. At present, testing standards for ODS in liquid refrigerants and solvents are being developed and is progressing on schedule, and it is expected to be officially released by the end of 2020.

2. Hold Supervision and law enforcement training

In December 2019, MEE held a training workshop on ODS phase-out management, which trained about 120 officers and technical support personnel from the atmospheric environmental management division of local EEBs. In December 2019 and July 2020, MEE held two training workshops for law enforcement personnel, training a total of 400 environmental law enforcement officers at the provincial, city and county levels.

In order to further enhance the capacity of grassroots environmental protection personnel below the provincial level, some provinces and municipalities have also held ODS phase-out management training workshops within their provinces or municipalities. In October and November 2019, Henan, Jiangxi and Shanxi carried out training workshops respectively, a total of 1,130 personnel of atmospheric environmental management departments from provincial, city and county levels received training.

MEE and the General Administration of Customs will continue to jointly organize the training workshop on ODS import and export management for a total of 70 customs officers in this October.

3. Optimize ODS information management system

Since October 2019, MEE has launched the construction of the ODS data information management system, which will be comprehensively updated based on the existing HCFCs online information system to realize the online data reporting of enterprises. The online test of the system modules will be completed before the end of 2020.

(V) Enhance cooperation with industries

1. Enhance communication with industries

Industrial associations have been providing technical support for supervision and management, policy formulation, and law enforcement of the government over the long term. Some technical experts recommended by industrial associations directly participate in special law enforcement operation and on-site inspection, providing technical support for supervision and law enforcement from a professional perspective. During the revision of the Regulation, communications have been conducted actively with industrial associations, experts, scientific research institutions and others, and their suggestions have been fully incorporated during the revision process.

2. Market analysis of the PU foam sector

China Plastic Processing Industry Association (CPPIA) cooperated with industry experts to analyze the situation of the polyurethane foam market in 2018 and consumption of various blowing agents by using mass balance analysis. See Annex 2 for details.

3. Market analysis of refrigeration and air-conditioning sector

MEE has communicated with industrial associations and experts to discuss the feasibility and methodology of mass balance analysis in the refrigeration and air-conditioning market. The feasibility research on the mass balance analysis of the industrial and commercial refrigeration and air-conditioning (ICR) sector and room air-conditioning (RAC) sector has been completed.

Studies have shown that for the RAC sector, the use of HCFC-22 in the RAC manufacturing sector could be analyzed and calculated by collecting data on the annual output of various product types, charging quantity of various product types, and the proportion of using HCFC-22 as the refrigerant (See Annex 3 for details). However, scattered maintenance of room air-conditioners brings great difficulties on data collection, therefore it is impossible to conduct a mass balance analysis on the HCFC-22 consumption in the servicing sector.

The ICR sector has a wide range of equipment products and applications. The size of various products varies greatly and there are numerous models, which makes it difficult to obtain statistics on product data. A number of equipment in the ICR sector are non-standard or customized products. Considering factors include application occasions, customer needs, technologies and energy efficiency levels, even for similar products with the same cooling capacity, the refrigerant charge amount would vary greatly when different refrigerants are applied. In addition, various products' sales are affected by the domestic and international economic situation, policy changes, and weather, making it difficult to collect data on refrigerant consumption. Therefore, it is impossible to carry out mass balance analysis on refrigerant consumption in the ICR sector.

(VI) Establishment of monitoring and alerting capacity

In 2019, the Government of China officially launched the planning of the ODS atmospheric monitoring network to strengthen compliance monitoring and early warning capability and performance evaluation capability. According to the regional characteristics of the distribution of ODS production and consumption in China, through the scientific assessment of the existing atmospheric pollutant monitoring background stations, 6 stations which are suitable for monitoring ODS have been selected preliminarily. The monitoring capability will be progressively improved. National atmospheric ODS monitoring network will be established in phases and steps, and a unified technical system of monitoring technology and comprehensive evaluation method, quality management, data sharing and information release will be built. At present, the National ODS Monitoring Expert Committee has been established and a joint expert team has been formed. At the same time, MEE is organizing relevant domestic research institutions to develop high-sensitivity ODS atmospheric monitoring equipment. MEE will start construction of ODS monitoring stations in 2021 and conduct ODS monitoring in 2022.

(VII) Non-governmental study

In accordance with the decision of the 83rd Meeting of the ExCom, MEE selected an independent non-governmental consulting agency (ESD China Limited) through public bidding to conduct a study to evaluate the ODS phase-out regulations, policies, law enforcement and market circumstances and risks in China. At present, the study report has been completed and will be submitted to the ExCom.

In general, since the unexpected increase in global emissions of CFC-11, the Government of China has promptly taken a series of actions to comprehensively strengthen the capacity of compliance management and supervision and law enforcement, to further provide guarantees to ensure sustainable compliance.

In terms of improving the laws and regulations, the Government of China has organized the revision of the Regulation to further clarify management measures and law enforcement basis for all aspects of ODS. For management scope, the life-cycle supervision of production, sales, use, import and export, recycle, reuse and destruction of ODS are to be achieved. For management system, the full process supervision on ODS monitoring and evaluation, directory management, technology research and development, quota approval, supervision and inspection, and violation punishment are to be realized. At the same time, the legal force and deterrence have been further enhanced by reinforcing the intensity of penalties for various cases of violations.

In terms of source control, all chloromethane production enterprises have installed a verifiable and quantitative CTC online production monitoring system, realizing real-time monitoring of the entire process of CTC from production to disposal. For the management of the production and consumption of ODS raw materials, through measures including the revision of the Regulation and establishment of the ODS data information management system, targeted supervision and reporting measures have been formulated for implementation. By adopting these measures, the Government of China has carried out more systematic and strict control over ODS from the source of supply to prevent the illegal outflow of ODS.

In terms of supervision and law enforcement, through a combination of national special law enforcement and daily supervision and inspection in all provinces and cities, the Chinese government has been severely cracking down on illegal ODS behavior and holding the offenders accountable, continuously imposing high pressure and deterrence against illegal ODS behavior, which has fully demonstrated China’s firm attitude of “zero tolerance” towards illegal ODS behavior. In response to the issue such as inadequate inspection capabilities of ODS law enforcement and testing methods, MEE has established 8 laboratories for testing ODS in industrial products and issued relevant testing standards, so as to provide timely and effective technical support for law enforcement inspections. By issuing *the Guideline on the Supervision of Ozone Depleting Substances (Trial)* and providing law enforcement detectors for local EEBs and organizing training for law enforcement officers from provincial, municipal and county levels, China has been continuously strengthening ODS supervision and law enforcement capabilities of local law enforcement officers, resulting in systematic and regular ODS supervision and law enforcement.

In terms of ODS atmospheric monitoring and evaluation, in response to the lack of scientific monitoring capabilities and the lack of effective compliance evaluation mechanisms, the Chinese government has initiated the planning and construction of an ODS atmospheric monitoring network. Through establishment of a unified technical system of monitoring technology and comprehensive evaluation methods, quality management, data sharing and information release, monitoring and evaluation work will be organized to timely collect, analyze and evaluate the background and trend of ODS in the atmosphere, strengthen compliance monitoring and early warning capabilities and performance evaluation capabilities, so as to provide technical support for compliance management.

On the basis of summarizing previous experience in compliance practice, the Chinese government has made further improvement in compliance supervision and management by adopting the above measures in terms of scientific monitoring, law and regulation system, supervision and law enforcement, capacity building etc., so as to comprehensively enhance the implementation of the Montreal Protocol. At the same time, public participation and industry collaboration have been further consolidated to form a sound system of ODS supervision and management. The system will continue to operate effectively in the future to provide a strong guarantee for ensuring effectiveness of compliance.

Appendix I: Progress of Decision 83/41 and all relevant work

No.	Activities	Decision 83/41	Progress
1	Improve Law and Regulation System	a)i) Increase and extension of penalties for enterprises' non-compliance with the controlled substance regulations C)d) Extension of penalties and prohibitions to consumers of controlled substances or products containing controlled substances, where appropriate;	● The implementation of the Regulation has been assessed and *the Regulation on the Administration of Ozone Depleting Substances and Hydrofluorocarbons (Draft for Soliciting Opinions*) has been formulated based on the assessment opinions and new requirements for implementing the Protocol. The revision reinforces the punishment measures on various cases of violations, and incorporate HFCs into scope of control; • As of the end of June 2020, MEE has completed the public opinion solicitation. At present, it is being revised based on the opinions and feedback; • The Regulation (Revised Draft for Approval) will be submitted to the State Council for review in 2020.
2	Carry out law enforcement actions	a)ii) Intensification of inspections of enterprises currently or formerly using controlled substances a)iii) Implementation of controlled-substance inspection plans for ecology and environment bureaus (EEBs); a)iv) Increased provision of support and enforcement tools to EEBs; c)ii) Increased direction on enforcement at the provincial	• During the 2019 special ODS law enforcement inspection organized by MEE, it is confirmed that 16 enterprises have been engaged in illegal use of CFC-11, the local EEBs have handled these cases in accordance with the law. In one case, the enterprise's legal representative was sentenced to 10 months of imprisonment for the crime of environmental pollution by

		level from the national government; c)vi) Random testing of products that might contain controlled substances; c)viii) Reporting on the details of enforcement activities, including the capacity of the reactor, amount of controlled substance on site, relevant records on feedstock purchases and sales, any penalties resulting from the enforcement action	the local court.; • As of December 2019, 50 portable ODS instant detectors have been distributed to local EEBs; • MEE launched a new round of special ODS law enforcement inspection nationwide at the end of July 2020. The inspection is mainly targeted at HCFC-141b and HCFC-22 production enterprises and illegal production and use of CFC-11; • *The Guideline on the Supervision of Ozone Depleting Substances (Trial)* was issued and distributed to local EEBs in December 2019; • In 2020, another joint special law enforcement action will be organized with participation by both central and local law enforcement officers. • In 2021, through the national CTC online monitoring platform and industrial rewards for reporting platform, MEE will further intensify source control, crack down on illegal ODS production, and improve the identifying mechanism, investigation mechanism and disclosure mechanism of illegal ODS production cases in steps .
3	Intensify Source Control	b)iii) Real-time flow monitoring of CTC at chloromethane production enterprises	• All 16 chloromethane enterprises with CTC by-production have completed the installation of the CTC online production monitoring systems. MEE compiled

			the CTC Monitoring Platform Construction Plan; the platform is currently in the stage of system design and development; • From June 2019 to January 2020, MEE has dispatched supervisory working groups to 16 CTC by-production enterprises to carry out the on-site inspection which achieved continuous daily on-site supervision. A total of 14 rounds of on-site supervision with attendance reaching 577 had been conducted.. During the COVID-19 outbreak, the enterprises were required to report CTC related data weekly, and local EEBs have taken measures to conduct on-site inspections as needed. • The online trial operation of the national CTC monitoring platform is expected to be completed by the end of 2020 to realize the online monitoring of CTC as by-product in all chloromethane enterprises.
4	Build capacity for implementing the Protocol	a)v) Development of an online registration and tracking system for controlled-substance users; a)vi) Increased training for customs officers; b)ii) Establishment of an additional six testing laboratories for controlled substances in products; c)iii) Development of performance indicators for enforcement activities, such as the number of customs	• MEE had completed the construction of 8 ODS testing laboratories for industrial products, and all of them have obtained the expansion of CMA certificate for these laboratories to ensure testing results with legal effect could be provided; • In October 2019, MEE has approved and issued two national environmental protection standards for the

		officers trained or inspections undertaken	determination of ODS in polyurethane foam and pre-blended polyols. • In December 2019, MEE held a training workshop on ODS phase-out management, which trained about 120 officers and technical support personnel from the atmospheric environmental division of local EEBs. In December 2019 and July 2020, MEE held two training workshops for law enforcement personnel, the two workshops trained a total of 400 environmental law enforcement officers at the provincial, city and county level; • Trainings have been conducted by key local EEBs: In October and November 2019, Henan, Jiangxi and Shanxi carried out training workshops respectively, a total of 1,130 personnel from provincial, city and county level atmospheric environmental management departments received training; • MEE and the General Administration of Customs will continue to jointly organize the training workshops on ODS import and export management for a total of 70 customs officers in this October. • Since October 2019, MEE has launched the construction of the ODS data information management system, which will be comprehensively updated based on

			the existing HCFCs online information system to realize the online data reporting of enterprises. The online test of the system module will be completed before the end of 2020.
5	Enhance Cooperation with Industries	a)vii) Conduct an annual mass balance analysis of foam blowing components to determine the market size of the foam sector; a)viii) Publicizing the outcome of investigations and increased communication with industry; c)v) Regular and frequent consultations with industry and enterprises to ascertain market conditions; c)vii) Conduct annual mass balance analysis of refrigeration and air-conditioning market to determine market size and verify reported HCFC consumption;	• Industrial associations have been providing technical support for supervision and management, policy formulation and law enforcement, and some technical experts directly participate in special law enforcement operation and on-site inspection supervision etc. During the revision of the Regulation, communications are conducted actively with industrial associations, experts, scientific research institutions and others, and their suggestions are fully incorporated during the revision process; • China Plastic Processing Industry Association (CPPIA) cooperated with industry experts to analyze the situation of the polyurethane foam market in 2018 and consumption of various blowing agents by using mass balance analysis; • MEE has communicated with industrial associations and experts to discuss the feasibility and methodology of mass balance analysis in the refrigeration and air-conditioning market. The feasibility research on the mass balance analysis of the ICR sector and RAC sector

			has been completed. The analysis found that mass balance analysis was applicable to the use of HCFC-22 in the room air-conditioning manufacturing sector, but not to the industrial and commercial refrigeration sector.
6	Establishment of measuring and alerting capability	b)i) Establishment of a national controlled atmospheric monitoring network for controlled substances; c)i) Fast-track atmospheric monitoring through movement or modification of existing equipment and/or flask sampling	• The National ODS Monitoring Expert Committee has been established and a joint expert team has been formed. • MEE is organizing relevant domestic research institutions to develop high-sensitivity ODS atmospheric monitoring equipment. • MEE will start the construction of ODS monitoring stations in 2021 and conduct ODS monitoring in 2022 as planned.
7	Non-governmental study	d) To note that the Government of China will consider engaging a non-governmental consultant to undertake a study (including quantitative data, where available, and qualitative market information) to determine the regulatory, enforcement, policy or market circumstances that might have led to the illegal production and use of CFC-11 and CFC-12	• Through public bidding, MEE selected an independent non-governmental consulting agency (ESD China Limited) to conduct a study to evaluate the ODS phase-out regulations, policies, law enforcement and market circumstances and risks in China. At present, the study report has been completed and will be submitted to the 86th meeting of the ExCom.

Appendix 2: Mass balance analysis of the PU foam sector in 2018

1. Background

Polyurethane (PU) foam can be divided into flexible foam (sponge), rigid foam and integral skin foam. Flexible PU foam is highly resilient and is widely used in sectors such as furniture manufacturing. The integral skin PU foam has high-resilience inner core and good strength skin, and is mainly used in sectors including automobiles and furniture in the manufacturing of auto seat, steering wheels, armrests, etc. Rigid PU foam mainly serves as thermal insulation materials, and as the material with the best thermal insulation performance known so far, it has been widely used in various sectors of the national economy. The main subsectors using PU rigid foam currently include household appliances (insulation), solar water heaters (water tanks), building materials (insulation materials), cold storage, refrigerated transportation (reefer containers, refrigerated vehicles, and square cabin, etc.), petrochemicals (pipelines), automobiles (integral skin foam for steering wheels, seat, ceilings, etc.), aerospace, furniture manufacturing, etc., and a small amount is used for non-insulation purposes such as shoemaking, floating body, etc.

The blowing agents of PU foam products are grouped into two categories, namely chemical blowing agents and physical blowing agents. Up to now, the main chemical blowing agent is water. PU physical blowing agents include the phased-out CFC-11, HCFC-141b in the phase-out process, as well as cyclopentane, hydrofluorocarbons (HFCs), hydrofluoroolefins (HFO) and methyl formate etc.. Due to the differences in molecular weights, different physical blowing agents require different amount of blowing agents to achieve the same foaming effect. Ratio of various blowing agents in PU foam pre-blended polyols is shown in Table 1.

Table 1 Ratio of various blowing agents in pre-blended polyols

Blowing agent	Ratio in pre-blended polyols	HCFC-141b equivalent coefficient
CFC-11	24-28%，maximum distribution 25%	0.80
HCFC-141b	18-25%, maximum distribution 20%	1
Water	2.5-5%, maximum distribution 2.5%	8
Hydrocarbon (cyclopentane etc.)	10-12.5%, maximum distribution 12%	1.67
HFC-245fa/365mfc	10-12.5% (compared with CFC/HCFC system, more water is needed), maximum distribution 12%	1.67

HFO	Around 20% (more water is needed)	1

Note: HCFC-141b equivalent coefficient is the ratio of the blowing effect by an amount of other blowing agents to that of HCFC-141b of the same amount with HCFC-141b as the baseline blowing agent. For example, the equivalent coefficient HCFC-141b of the hydrocarbon blowing agent is 20%/12%=1.67, indicating that, for the same amount of hydrocarbon and HCFC-141b blowing agent, hydrocarbon can produce 167% foam produced by HCFC-141b. The coefficient is used to simplify the calculation of the amount of various raw materials when a foam product uses multiple blowing agents. The HCFC-141b equivalent coefficient is not completely related to the molecular weight of the blowing agent because considering different costs of different blowing agents, water is usually added to the higher-cost blowing agents when needed.

2. Calculation and data sources of blowing agent consumption in the PU foam sector

There are two main raw materials for PU foam: isocyanates (polymeric MDIs) and pre-blended polyols, into which the blowing agents are usually pre-blended. For foam products mainly using physical blowing agents (blowing agents other than water), the ratio of MDI to pre-blended polyols ranges from 1.05 to 1.1. When water is added to replace part or all of the physical blowing agents, MDI consumption will increase gradually and could bring the ratio up to 2. In addition, for foam products with high flame-retardant requirements or heat-resistant requirements (such as polyisocyanurate panels and pipes), the ratio can also reach 2.

In Chinese PU foam sector, the number of MDI suppliers is extremely limited, and they are all super large enterprises. Many organizations in the polyurethane sector have conducted continuous statistical analysis on the consumption data of the entire sector and its sub-sectors, and the data is highly credible. In contrast, pre-blended polyol suppliers are numerous and vary considerably. Statistics of the sector, especially its sub-sectors, is inaccurate. Therefore, MDI is used as the base data for analyzing blowing agent consumption in the PU foam sector: the amount of pre-blended polyols in different sub-sectors can be achieved by calculating the ratio of MDI to pre-blended polyols in various sub-sectors through the proportion of HCFC-141b conversion in each sub-sector and the distribution of the various blowing agent consumption in each sub-sector; consumption of various blowing agents can be calculated in different sub-sectors by using the estimated ratio of various blowing agents in each sub-sector, and the ratio of blowing agent in pre-blended polyols. In this way, the consumption of various blowing agents in each sub-sector could be reached, and the total amount of various blowing agents can be compared with the annual amount of various blowing agents obtained by our investigation.

2.1 MDI consumption

MDI consumption in the PU foam sector and its sub-sectors is provided by the consulting firm in collaboration with the China Plastics Processing Industry Association (CPPIA). During estimation of blowing agents consumption in the sub-sectors, MDI consumption in polyurethane products (such as adhesives, sealants, elastomers, etc.) that use no or few blowing agents is excluded.

Table 2 MDI consumption in the PU foam sector and its sub-sectors in 2018

Consumption sub-sectors	Consumption of isocyanates (polymeric MDIs), 10,000T
Refrigerators and freezers	48.67
Small household appliances such as electric water heaters	4.33
Solar water heaters	1.08
reefer container	3.47
Automotive foam	15.20
Pipeline	8.62
Spraying foam	5.20
Panels	6.24
Filling (security doors)	2.00
Total	94.81

2.2 Investigation of various blowing agents consumption in the PU foam sector

1. HCFC-141b consumption in the PU foam sector comes from annual data reporting by the government. In 2018, HCFC-141b consumption in the PU foam sector was 34,176.74 metric tons.

2. Consumption of HFCs/HFOs blowing agents and hydrocarbon blowing agents were obtained through investigation of suppliers by CPPIA. The categories of HFCs blowing agents used in Chinese PU foam sector include HFC-245fa/365mfc (HFC-365mfc may also be mixed with HFC-227ea), with a total consumption of about 8,300 metric tons in 2018. HFO-1233zd(E) is mainly used in refrigerator foam, with a consumption of about 1,800 metric tons in 2018. The main hydrocarbon blowing agents is cyclopentane, and two other categories, namely n-pentanes and isopentanes are also used. The total consumption in 2018 was about 43,000 metric tons.

3. No objective data source was found for consumption of water foaming agents, but we know water foaming applications in the Chinese PU foam market well. Water foaming is mainly used in automotive foam (seat, car parts of integral skin foam and ceilings, etc.), pipe insulation and filling foam sectors with low thermal insulation requirements.

4. In China, the PU foam sector also consumes other blowing agents such as methyl formate and liquid carbon dioxide, and their consumption in 2018 did not exceed 3,000 metric tons.

3. Calculation of various blowing agents consumption in the PU foam sector

3.1 Analysis of rationality of blowing agent consumption in terms of foaming efficiency of various blowing agent and the total sector scale

Table 3 Proportion of blowing agents in foam products in the PU foam sector

Blowing agent	Amount, MT	HCFC-141b equivalent coefficient	Equivalent amount of HCFC-141b, MT
HCFC-141b	34,177	1	34,177
hydrocarbon	43,000	1.67	71,810
HFCs	8,300	1.67	13,861
HFOs	1,800	1	1,800
Water	5,600	8	44,800
Total	92,877		166,448

PU foam production, 10,000 MT	174.58
The proportion of blowing agent in foam products based on HCFC-141b blowing agent	9.5%

According to the above calculations, the total consumption of blowing agents based on HCFC-141b accounts for about 9.5% of the total foam production. This is generally consistent with the practice of the PU foam raw materials, including HCFC-141b accounting for about 20% of pre-blended polyols and the ratio of MDI to pre-blended polyols being around 1.1. The above calculations are rational analysis, but it should be pointed out that there are other blowing agents such as methyl formate and liquid carbon dioxide in the Chinese PU foam market, and the total consumption should not exceed 3,000 tons.

3.2 Calculation of various blowing agents consumption in the PU foam sub-sectors (see

Table 4)

3.3 Analysis of differences

According to Table 3 and Table 4, the consumption of HCFC-141b and water is relatively consistent, but the total consumption of hydrocarbons and HFC/HFO calculated in Table 4 is about 4,700 metric tons more than that in Table 3. In our analysis, the main reason for the difference lies in our investigation focus on the cyclopentanes because there are a limited number of cyclopentane suppliers with whom we have established long-term information cooperation. However, n-pentane and isopentane, the two blowing agents with increased consumption in recent years and with broad applications, have received relatively little attention because we are not familiar with suppliers of n-pentane and isopentane. Another reason for the difference in blowing agent consumption is the fact that there are about 3,000 tons of other blowing agents in the PU foam sector, such as methyl formate, and liquid carbon dioxide.

4. Conclusion

The above analysis demonstrates that the consumption of MDI and various blowing agents obtained through various information channels is relatively consistent and reasonable.

The uncertainty of the analysis is mainly derived from the judgment on the ratio of water foaming. Due to lack of objective sources, making professional judgments based on our understanding of the sector is the only way. We believe that the sub-sectors of Chinese PU foam sector that use water foaming can support our judgment on water consumption in the PU foam sector.

Table 4 Proportion of blowing agents and consumption calculation in the PU foam sub-sectors in 2018 (Unit: 10,000 MT)

Consumption sectors	MDI	ratio of MDI to pre-blended polyols	pre-blended polyols	Foam production	Hydrocarbon+ HFC+HFO	Hydrocarbon+ HFC+HFO	Water foaming	Water consumption	The amount of HCFC-141b in pre-blended polyols	HCFC-141b consumption
Refrigerators and freezers	48.67	1.15	42.32	90.99	97%	4.93	0%	-	20%	0.25
Small household appliances such as electric water heaters	4.33	1.15	3.77	8.10	92%	0.42	0%	-	20%	0.06
Solar water heaters	1.08	1.08	1.00	2.08	10%	0.01	15%	0.006	20%	0.15
Reefer container	3.47	1.15	3.02	6.49	100%	0.36	0%	-	20%	-
Automotive foam	15.20	1.50	10.13	25.33	0%	-	95%	0.385	12%	0.06
Pipeline	8.62	1.25	6.90	15.52	3%	0.02	60%	0.166	20%	0.51
Spraying foam	5.20	1.05	4.95	10.15	0%	-	5%	0.010	25%	1.18
Panels	6.24	1.08	5.78	12.02	5%	0.03	0%	-	21%	1.15
Filling (security door)	2.00	1.05	1.90	3.90	0%	-	85%	0.065	20%	0.06
Total	94.81		79.77	174.58		5.78		0.641	1.78	3.42

Note: In China's PU foam industry, hydrocarbon blowing agents and HFC blowing agents are mainly used in refrigerators, freezers and reefer containers. They are usually mixed, and they have the same HCFC-141b equivalent coefficients, so they are calculated together. HFO's HCFC-141b equivalent coefficient is different from that of hydrocarbons, but it is also mainly used in refrigerators, freezers and reefer containers. Considering small amount of HFO, it is also calculated in combination with hydrocarbons and HFC.

Appendix 3: Mass balance analysis in room air-conditioning sector

1. Background

Based on the overall manufacturing and sales scale of the room air-conditioning (RAC) sector and the sales of room air-conditioners using HCFC-22 as refrigerant, China Household Electrical Appliance Association (CHEAA) conducted a mass balance analysis of HCFC-22 consumption in the RAC manufacturing sector for 2017 and 2018 to assess HCFC-22 consumption in the RAC sector and analyze HCFC-22 phase-out status in the sector in China.

2. Data sources

1) The total production of the RAC sector comes from statistical data of CHEAA;

2) Product mix and scale data of room air-conditioners for domestic sales are from Beijing All View Cloud Data Technology Co., Ltd.

3) Product mix and scale data of room air-conditioners for export come from the General Administration of Customs;

4) Sales of room air-conditioners using different refrigerants are from statistical and calculated data of CHEAA;

5) The HCFC-22 consumption per unit of room air-conditioners for various product types comes from investigation of refrigerant consumption in the RAC sector organized by CHEAA in 2011.

3. Calculation methodology

(1) At present, room air-conditioners using HCFC-22 refrigerant are mainly fixed-frequency products, which can be further subdivided into five categories: window air-conditioner, split air-conditioner with cooling and heating, stationary air-conditioner with cooling and heating, cooling only split air-conditioner and cooling only stationary air-conditioner.

(2) Since import of HCFC-22 air-conditioner products in non-A5 countries has been gradually banned around 2010, air-conditioners using HCFC-22 refrigerant for export are only sold to A5 countries.

(3) According to the calculation by CHEAA, the proportion of HCFC-22 refrigerant used in fixed-frequency room air-conditioners for domestic sale and export to A5 countries is about 70% at present;

(4) According to linear regression calculation results, marked HCFC-22 refrigerant charging quantity of a typical window air-conditioner (cooling capacity: 3 kW), split air-conditioner with cooling and heating (cooling capacity: 3 kW), a stationary air-conditioner with cooling and heating (cooling capacity: 5.5 kW), cooling only split air-conditioner (cooling capacity 3 kW), and cooling only stationary air-conditioner (cooling capacity: 5.5 kW) are respectively 0.89 kg, 0.89 kg, 1.66 kg, 0.84 kg, and 1.40 kg;

(5) According to sale scale of various product types, proportion of air-conditioners using

HCFC-22 refrigerant and charging quantity per unit, HCFC-22 consumption of various product types can be calculated separately, and the total HCFC-22 consumption of the RAC sector could be reached.

（6）Considering refrigerant leakage in the process of storage, transportation, charging, and repair, actual refrigerant charging quantity in the manufacturing process is often slightly larger than the quantity marked on the nameplate due to the manufacturer's consideration of product quality. Therefore, actual HCFC-22 consumption should be 10%~15% higher than the above calculation results.

4. Calculation results

According to the above methodology, HCFC-22 consumption in the RAC sector from 2017 to 2018 is estimated in the following table. HCFC-22 consumption in the RAC sector is about 53,600 metric tons in 2017, and about 51,500 metric tons in 2018, which are generally consistent with the annual sector consumption data reported to the Multilateral Fund Secretariat in 2017 and 2018.

Year	**2017**	**2018**
Sales of fixed frequency stationary air-conditioner with cooling and heating / 10,000	1161	1082
Sales of fixed frequency split air-conditioner with cooling and heating / 10,000	3800	3667
Sales of cooling only stationary air-conditioner / 10,0000	26	23
Sales of cooling only split air-conditioner / 10,000	254	306
Sales of window air-conditioner/ 10,000	1356	1445
Consumption of fixed frequency stationary air-conditioner with cooling and heating/ T	15273	13962
Consumption of fixed frequency split air-conditioner with cooling and heating consumption/ T	26743	25335
Consumption of cooling only stationary air-conditioner/ T	284	249
Consumption of cooling only split air-conditioner T	1691	1994
Consumption of Window air-conditioner consumption/ T	9568	10007

HCFC-22 consumption/ T	53559	51547

Study on the Supervision, Law Enforcement, Policy and Market Situation of Ozone Depleting Substances in China

Prepared by: ESD China Limited

August 2020

Abbreviations

AHF	Anhydrous Hydrofluoric Acid
APPL	The Law of Air Pollution Prevention of the People's Republic of China
CFC-11	Monofluorotrichloromethane
CFC-12	Difluorodichloromethane
CFCs	Chlorofluorocarbons
CMA	China Meteorological Administration
CTC	Carbon tetrachloride
EIA	Environmental impact assessment
FECO	Foreign Environmental Cooperation Center
GACC	General Administration of Customs
GWP	Global warming potential
HBFC	Bromofluorocarbon
HC	Hydrocarbon
HCFC-123	1,1,1-Trifluoro-2,2-Dichloroethane
HCFC-124	1,1,1,1-Tetrafluoro-2-chloroethane
HCFC-141b	1-fluoro-1,1-dichloroethane
HCFC-142b	1,1-Difluoro-1-chloroethane
HCFC-22	Difluorochloromethane
HCFCs	Hydrochlorofluorocarbon
HFC	Fluoroalkanes
HFC-134a	Tetrafluoroethane
HFC-245fa	Pentafluoropropane
HFC-365mfc	Pentafluorobutane
HFO	Fluoroolefin
I/E Office	National Management Office for the Import and Export of Ozone Depleting Substances
MARA	Ministry of Agriculture and Rural Affairs
MDI	Diphenylmethane diisocyanate
MDIs	Metered dose inhalers
MEE	Ministry of Ecology and Environment
MEM	Ministry of Emergency Management
MIIT	Ministry of Industry and Information Technology
MLF	Multilateral Fund
MOC	Ministry of Commerce
MOF	Ministry of Finance
MOFA	Ministry of Foreign Affairs
MOST	Ministry of Science and Technology
MOT	Ministry of Transport
MP	Montreal Protocol on Substances that Deplete the Ozone Layer
MYAs	Multiyear agreements
NDRC	National Development and Reform Commission
NLGPOL	National Leading Group for the Protection of the Ozone Layer

NOU	National Ozone Unit
NP	China's National Programme for the Phase-out of Substances that Deplete the Ozone Layer
ODP	Ozone depleting potential
ODS	Ozone depleting substances
PAG	Polyalkylene glycol
PCE	Perchloroethylene
PCIA	Petroleum and Chemical Industry Administration
PMO	Multilateral Fund Project Management Office of MEE
POE	Polyester
Polymeric MDI	the mixture of polymethylene, polyphenyl and polyisocyanate with different functions
PTFE	Polytetrafluoroethylene
PU	Polyurethane
R600a	Isobutane used as refrigerant
RAODS	Regulation on the Administration of Ozone Depleting Substances
SAMR	State Administration for Market Regulation
TCA	Methyl chloroform
TCM	Chloroform
TDI	toluene diisocyanate
TFE	Tetrafluoroethylene
TOR	Terms of reference
UNEP	United Nations Environment Programme
VCPOL	Vienna Convention for the Protection of the Ozone Layer

Executive Summary

I. Project Overview

According to Decision 83/41 of the 83rd Meeting of the Executive Committee of the Multilateral Fund (MLF) for the Implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer (MP), the Ministry of Ecology and Environment (MEE) of China engaged a non-governmental consultant to undertake a study (including quantitative data, where available, and qualitative market information) to determine the regulatory, enforcement, policy or market circumstances that might have led to the illegal production and use of CFC-11 and CFC-12. The evaluation study was scheduled to be completed in August 2020. Through public bidding, the MEE commissioned ESD China Limited to undertake the evaluation study.

The objectives of this study were consequently to evaluate the implementation effectiveness of China's ozone depleting substances (ODS) phase-out policies, regulations and enforcement through analysis of the existing policy and regulatory framework, ODS related production and consumption data, market information, and the special ODS enforcement campaign at national/local levels; to evaluate the effectiveness of control measures against illegal ODS production and consumption through correlation and mass balance analysis of production, demand and consumption data of relevant industries;and, to put forward recommendations on ODS management and improvement of the policy, regulatory and enforcement system for sustainable compliance with the MP.

The study focused its research mainly on CFC-11 and CFC-12. This report and the findings therein are the outputs of the study.

II. Research and Evaluation Principles and Methodology

The evaluation used as its point of entry China's MP implementation goals and achievements reflected in ODS phase-out sector plans in accordance with ODS phase-out obligations, entailed comprehensive analysis of relevant regulations, policies, law enforcement and market conditions for ODS phase-out, and focused on China's performance in CFC-11 and CFC-12 phase-out through analysis of available information and data.

According to the terms of reference (TOR), on-site visits were carried out to interview and collect information and data from government agencies, industry associations, implementation support agencies of the phase-out plans, and enterprises. Analysis and evaluation were conducted on China's ODS control legal and policy framework, including the supervision and management system. Quantitative and qualitative information through an ODS market survey was collected and analyzed to determine whether and the degree to which previously phased out substances, namely

Chlorofluorocarbons (CFCs), have been produced and consumed in China since elimination more than a decade ago.

Key to the research and evaluation was systematic review of CFC raw materials, production and use data, and inventories of CFC-11 and CFC-12 over time. In terms of raw materials, research concentrated on Carbon tetrachloride (CTC) consumption and in terms of production focus was turned towards current fluorochemical production at HCFC-22 production facilities, to verify whether there could be any diversion to CFC-11 or CFC-12 production. In terms of consumption, applications in which CFC-11 and CFC-12 were previously used, i.e., as foaming agent and refrigerant were examined. Finally, research was conducted on CFC inventories to assess the possibility of their illegal outflow.

Assessment of market conditions mainly employed the mass-balance method to analyze the relationship between market supply and demand for HCFCs, non-ODS foaming agents, isocyanate and polyether polyol systems so as to determine whether foam-related industries have or are using banned substances. The possibility of converting production facilities to CFC-11 or CFC-12 production was also evaluated, based on the analysis of HCFC-22 production facilities' capacity, output, raw material consumption and operation. In addition, the risk of illegal CTC outflow was assessed, based on the analysis of methane chloride plant production, by-product output, conversion volume and sales volume.

This study covers the starting year 2008, when CFCs were completely phased-out in China, to 2018, the most recent year with available statistics, as the evaluation period.

III. Key Findings

A.Laws, regulations and supervision and management

Since becoming a Party to the MP, China has established and implemented over a hundred laws, regulations and policies at both national and local levels in accordance with the MP. Requirements and management principles for ODS phase-out are laid out in the Law of Air Pollution Prevention of the People's Republic of China (APPL). The management and supervision of all aspects of the ODS lifecycle is detailed in the Regulation on the Administration of Ozone Depleting Substances (RAODS). Furthermore, the China's National Programme for the Phase-out of Substances that Deplete the Ozone Layer (NP) formulates the objectives, technical route to achieve objectives and the action plan for ODS phase-out in China and is reflective of the ODS phase-out plans / multiyear agreements (MYAs) agreed upon with the MLF Executive Committee for MP implementation.

Together, this law and regulations, policies and measures set forth specific and detailed requirements on new construction of ODS production and manufacturing facilities; ODS production, sales and use in various applications, import/export, recovery, reutilization, destruction, and substitute development;and,management and supervision of MP implementation. Through key policy measures including maintaining a controlled substances list and catalogue, rules on new and expansion of production and manufacturing facilities, a quota and licensing system,gradual industrial conversions, promotion of ODS substitutes, and, ODS bans, China has phased out the production and consumption of CFCs, Halons, CTC, Methyl chloroform (TCA) and MBr for controlled purposes, exceeded the HCFCs phase-out tasks for the first phase, completed the implementation goals required by the MP as scheduled, and gradually ceased essential use and critical use exemption. Till now, China has phased out some 280,000 tons of ODS, accounting for more than half of the ODS phased out by developing countries.

Similarly, China's ODS regulatory and policy framework has established and put a mechanism in place to continuously improve ODS supervision and management at both the national and local levels.Oversight, supervision and management rely on certain mandated institutions. The National Leading Group for the Protection of the Ozone Layer (NLGPOL) consists of the MEE, other national ministries and commissions, and contains specialized entities for ensuring MP compliance, including the Import/Export (I/E) Office, the Coordination Group for MP Compliance within MEE and its offices, and the Multilateral Fund Project Management Office of MEE (PMO). Institutions for ODS supervision and management at the local level are comprised of ecological and environment departments of provincial, municipal and county government. The Coordination Group Office takes charge of routine work related to MP compliance. In the top-down supervision and management system of China, the national level is primarily responsible for policy formulation, developing overall plans, and decision-making and conducting supervision and management over implementation of policies at local levels. The local level ecological and environmental departments of the provincial, municipal and county government execute national policies and plans, conduct on site supervision and inspection, and enforce the law. Supervision and management are carried out mainly on ODS-related project, licensing system for import and export, production and consumption quota system, ODS phase-out activities and data report.

The study found that the Chinese government, both at the national and local levels, has well incorporated supervision and management of ODS production and use into their conventional environmental supervision and law enforcement system; with routine environmental supervision according to law. Of note is the organization of special ODS supervision and law enforcement actions according to compliance progress determined by both national and local level authorities. The guiding principle of supervision and management is regular supervision of the market and industry in order to prevent and mitigate any nonconformance with rules and regulations.

It is because of an effective regulatory and policy framework and particularly through special campaigns and law enforcement that some illegal CFC-11 production and consumption has been identified and prosecuted over the period of study, namely in the rigid PU foam industry. This however can be characterized as small-in scale, of short duration and occurring in more remote areas where routine supervision and management capacity is weaker. Several cases that highlight these findings are included in the report.

Because of these select cases, the study finds room for further improvement of the ODS regulatory, policy and management framework, but more specifically related to the latter element entailing more comprehensive or consistent supervision throughout the country to prevent and detect breaches, and enforcement to discourage additional breaches from occurring. The study found that a sustainable compliance mechanism after initial phase-out goals have been achieved is needed along with better delineation of compliance responsibilities at different levels of government. Punitive penal policies require strengthening while incentive policies should be formulated to foster innovation in alternative technologies and processes, and rules detailed that promote substitute technologies. Increased information is central to preventing and detecting illegal actions and hence actions to prevent data gaps in the established national ODS phase-out and compliance information system are needed, particularly along the divide between MEE-EEB jurisdictions. Relatedly, capacity building of local government to build or enhance ODS monitoring capacity, including in strategically determined locations is needed.

B. Market Survey and Data Assessment

After CFC-11 was phased-out in 2007 in the PU foam sector, the industry had successfully adopted substitute technologies, primarily HCFC-141b, hydrocarbon (HC), HFCs, water and methyl formate. Using 2008-2018 data acquired through the market survey, the study carried out a mass-balance analysis of raw materials linked to rigid PU foam manufacturing. The results suggest that widespread production and consumption of CFC-11 during this period is unlikely. Based on the balance conditions between the market survey amounts of foaming agent and that derived from the market data of the mixture of polymethylene, polyphenyl and polyisocyanate with different functions (polymeric MDI), a foaming agent shortage might have occurred during 2008-2010 subsequent to the CFC-11 phase-out. As a consequence there could have been illegal CFC-11 use to fill the shortage but considering that the market often stockpiles upon an impending ban, the gap could have equally been met in full, or partially by CFC-11 stocks existing after 2007.

In the household refrigeration industry, the key to sustainable phase-out of the main refrigerant of CFC-12 was a commercially viable substitute for refrigerators and freezers. According to materials and data for the period 2008-2018acquired through market survey, the study carried out an economic analysis on alternative technologies and estimated consumption amounts of these various refrigerants. Results show the refrigerants available on the market could completely meet industrial requirements therefore reducing the possibility for illegal use of CFC-12.

In order to replace CFC-11 and CFC-12 refrigerant in the industrial and commercial refrigeration industry, the new equipment has to be specially designed to accommodate the substitute refrigerant. These changes to the production process and equipment are prohibitive for reconversion to CFCs, leaving a possible small amount of CFC-11/CFC-12 refrigerant needed for maintenance of old, installed units. This small amount alone would make it highly unlikely there is any significant demand for CFCs in this sector.

For mobile air conditioning, newly produced vehicles cannot be installed with units based on CFC-12 refrigerant due to the long-established industry standard around the world based on HFC-134a. The economic analysis of refrigerant technology in mobile air conditioning systems and analysis and calculation of the potential inventory CFC-12 indicate that the possibility of illegal use of CFC-12 in auto repair field is low. For medical aerosols, newly produced and inventoried medical-grade CFCs could meet this industrial demand. Moreover, the regulation of the pharmaceutical industry is strict, and virtually impossible to use CFCs illegally.

Theoretically speaking, HCFC-22 production can be converted to produce CFC-11 or CFC-12, but according to analysis and assessment of information and data including on the configuration of HCFC-22 production facilities, product capacity, raw material consumption, and the rate of operation during 2008-2018, the loss outweighs the gain for production line conversion. There is no economic driver for an enterprise to produce CFC-11 or CFC-12, nor subjective and objective conditions for production conversion.

CTC is the inevitable byproduct of methane chloride production. CTC generated may be sold legally as raw material, sold for exempted use purposes, used by methane chloride manufacturers directly as raw material, converted to a non-ozone depleting substance, or incinerated as residue product containing CTC. The study determined that over the period of review, CTC output has been largely balanced with its consumption as a raw material for non-ODS uses, for converting to a non-ODS, and with its sales volume as a legal raw material.

As CFCs were phased-out in 2007 and in order to meet immediate CFC demand of the pharmaceutical non-inhaled aerosol industry as well as the refrigeration servicing sector, China legally dedicated one CFC production line. It stored 500t CFC-11 and 3000t CFC-12. In total, this dedicated line produced 986.72t of CFC-11 and 2,887.5t of CFC-12, and was shut down completely by 2015. The data on CFC-11 and CFC-12 production, consumption and export from 2008 to 2018 largely reconciled. In 2018, a total 1.7t of CFC-11 and 642.3t of CFC-12 was left in stocks. As the account management system is scientific and rational for the inventory sales management, the risk of CFC illegal outflow is low.

C. Conclusions and Recommendations

Based on the review, analysis and evaluation of the laws and regulations, supervision and administrative system, and the qualitative and quantitative market information obtained from the market survey, the study concludes that widespread production and consumption of CFC-11 in the rigid PU foam sector during 2008-2018 was highly unlikely in China. This achievement is testament to the effectiveness of laws, regulations, systems and policies established and implemented. These include a supervision and management system that extends from the national level to the local level, the quota and licensing system, introduction of targeted policies and management measures, industrial conversions, and data reporting.

According to the mass-balance estimates using data acquired from the market survey, however, during a short time immediately after CFC-11 phase-out, there appears to have been a shortfall of CFC-alternatives for foam blowing. Therefore, one conclusion could be that CFC-11 use as a foaming agent might have existed to fill this shortage, which might be from illegal CFC-11 or stocks built by the private sector during the final years of CFC-11 consumption. More recently, isolated cases of limited illegal production and use of CFC-11 were found through the campaign led by MEE. The study examined circumstances that might have influenced this outcome and draws several conclusions and puts forward related recommendations as follow for reference:

- ***Complement and enhance legal provisions on sustainable compliance with the MP in the established ODS regulatory and policy framework and accelerate the revision of RAODS***. Over the years of implementation, it was found that there are some shortcomings relevant to the provisions of RAODS, including the challenges in dealing with already banned ODS. Specific regulatory or policy measures could help sustain bans. In addition, improved rules and policies that can ensure timely detection of illegal production, import/export, and consumption are necessary given that illegal actors fall outside the normal regulatory purview of authorities.

- ***Further clarify the roles and responsibilities of each relevant actor for sustainable compliance with the MP, strengthen the efforts and frequency of routine ODS law enforcement at the local levels, and increase the penalties for violations of the law***.

  The study found there is a lack of coordinated and consistent revisions to RAODS and implementing rules when other relevant laws are revised. This includes not comparing the similarities and differences between ODS emissions and the discharge of other common environmental pollutants which would facilitate and streamline the work of local officials during site inspections. Most notably the study revealed that penalties for violations are not always consistent with the costs of violations, and not enough to deter illegal action and potential economic gains.

- ***Improve incentives for innovation and development of alternative technologies and substitutes.***

There should be practical and specific incentive policies for each sector to further encourage and support the research, development and application of substitutes through market mechanisms as this may address the perception in the market that alternatives are higher in price or lead to poor product quality. These policies could include technical standards and economic instruments. In many cases, although the cost of developing, promoting and applying new technologies and products is fairly high, it is still a better choice than the social and environment costs of older technologies and the need to mobilize government and social resources for strict inspection, testing, and supervision and enforcement.

- ***Improve the national information management system for ODS phase-out and compliance with the MP, strengthen coordination, information communication and knowledge sharing between the MEE and local ecological environment departments.***

Currently there exists an overall on-line HCFCs information management system in China with functions including the management of HCFCs quota application, registration application and data reporting. Some provinces and municipalities established their own on-line registration system for registration management and data reporting. A more sophisticated information management system should be updated based on existing HCFCs information management system aiming to consolidate all local systems into an overall system, extend the scope to all ODS, get a picture of the overall situation of ODS production, sales and consumption in the country and promote information sharing between MEE and local EEBs. The assessment found capacity building efforts of local government requires strengthening in order to ensure and sustain future MP implementation.

- ***Enhance capacity for ODS detection and analysis, and strengthen and expand technical training on rapid detection equipment***.

Prior to 2018 there was a lack of necessary ODS testing equipment and monitoring personnel, in particular, basic environmental law enforcement agencies were not equipped with necessary testing equipment. Equipment is being provided but more is needed, as is standardized ODS sampling and testing.

Table of Contents

1 Project overview

1.1 Project background

According to the Decision 83/41 of the 83rd Meeting of the Executive Committee of MLF for the implementation of the MP, the MEE engaged a non-governmental consultant to undertake a study (including quantitative data, where available, and qualitative market information) to determine the regulatory, enforcement, policy or market circumstances that might have led to the illegal production and use of CFC-11 and CFC-12. The evaluation study was scheduled to be completed in August 2020. Through public bidding, the MEE commissioned ESD China Limited to undertake the evaluation study.

1.2 Project introduction

The objectives of this project are to evaluate the implementation effectiveness of the ODS phase-out policies, regulations and enforcement, through analysis of the existing policy and regulatory, the ODS related production and consumption data, the market information, and the special ODS enforcement at national/local level; to evaluates the effectiveness of the control measures for illegal ODS production and consumption, through the correlation and balance analysis of the production, demand and consumption data of relevant industries; and to put forward recommendations on ODS management, improvement of policy, regulations and enforcement system, and sustainable compliance with the MP.

The study is based on the available industry quantitative data and market qualitative information, and focuses its research mainly on CFC-11 and CFC-12. This report is the output of the study and is titled as the "Research Report on Regulations, Policies, Law Enforcement and Market Conditions of China’s ODS Management".

2 Research and evaluation principles and methods

2.1 Evaluation principles

The evaluation uses China's implementation goals and plans determined in accordance with the MP as its evaluation basis, conducts comprehensive analysis of relevant regulations, policies, law enforcement and market conditions for ODS phase-out, and focuses on the performance of CFC-11 and CFC-12 phase-out through analyzing available information and data. The evaluation examines the whole process of production, distribution, use and inventory, as well as the correlation and coordination among the evaluation elements. Qualitative, quantitative and logical inference methods are combined, with full consideration of the characteristics of the Government of China's inter-departmental management, the type of available data and information, and the degree of cooperation between relevant production and consumption enterprises.

2.2 Evaluation and working methods

According to the requirements of the TOR, this project has carried out through on-site visits to and interview with government agencies, industry associations, implementation support agencies of the phase-out plan, and enterprises to collect relevant information and data, conducted analysis and evaluation on the legal and policy framework of China's ODS control, the supervision and management system, and the quantitative and qualitative information on the ODS market, and prepared research report that include available quantitative data and qualitative market information. The overall technical approach of the project is shown in Fig. 2.2-1.

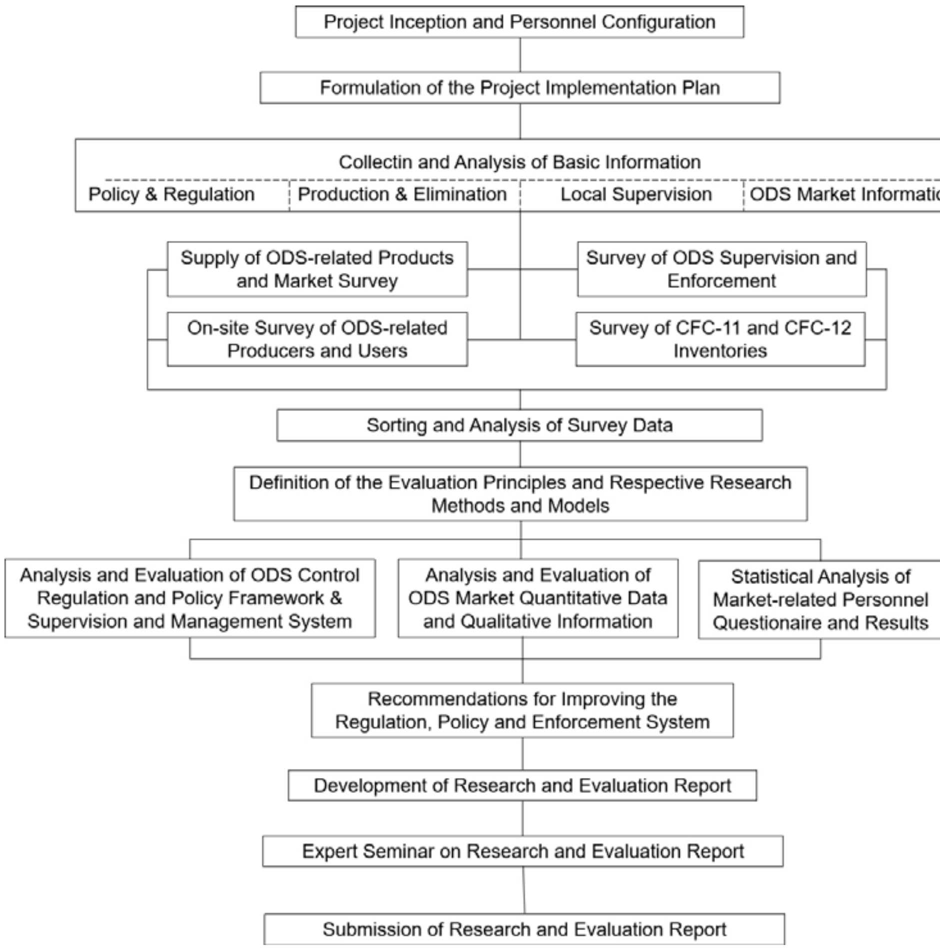

Fig. 2.2-1 Technical Roadmap for Project Implementation

The main working approach is to conduct consultation and interview with individuals of and collect information and data from industry associations, implementation support agencies of the phase-out plan, and enterprises. In order to understand the attitudes and opinions of ODS-related personnel on the main issues of this research, extensive questionnaire surveys and analysis were conducted. For in-depth technical issues, opinions from relevant professionals and experience of relevant experts in the industries have been obtained. Through analyzing the logical and interactive relationships between input and output elements, quantitative, qualitative and logical deduction methods are adopted to evaluate whether the regulations, policies, supervision and enforcement, and market conditions are effective as expected; the existing issues are analyzed; and constructive recommendations are put forward.

The main areas of research and evaluation include the possible raw materials, production, use and inventory of CFC-11 and CFC-12. In terms of raw materials, research is conducted on the characteristic raw material CTC; in terms of production, research is conducted on HCFC-22 production facilities that may be converted to CFC-11 or CFC-12 production; in terms of use, research is conducted on previous use area of CFC-11 and CFC-12, i.e., foaming agent and refrigerant; in terms of inventory, research is conducted on the inventory and use volume of CFC-11 and CFC-12.

The assessment of market conditions mainly adopts the method of material balance (mass-balance) to analyze the relationship between market supply and demand for CFC-11 and non-ODS foaming agent, polyether polyol system and HCFCs, so as to determine whether foam-related industries are still using banned/controlled substances. The possibility of converting facilities to CFC-11 or CFC-12 production is evaluated, based on the analysis of HCFC-22 production facilities' capacity, output, raw material consumption and operation, The risk of illegal CTC outflow is assessed, based on the analysis of methane chloride plant production, by-product output, conversion volume and sales volume. In addition, the inventory of CFC-11 and CFC-12 is analyzed to assess the possibility of their illegal outflow.

The study starts with the year 2008, when CFCs were completely phased-out in China, to 2018, the most recent year with available statistics, as the evaluation period.

3 Evaluation of China's ODS control policies/regulations and the implementation effects

In this chapter, first the framework of China's ODS control regulations and policy will be reviewed, especially various management systems such as total volume control and quota licensing system, filing (registration and documentation) system, and then evaluate the role of these laws, policies and systems in China's implementation of the MP in terms of the ODS life cycle management and the actual performance of both national and local government.

3.1 Analysis of China's ODS control policy and regulatory framework

3.1.1 Structure of the management policy and regulatory framework

China's ODS control policy and regulatory framework consists of the APPL, RAODS, relevant policies and local rules and regulations. The composition and functions are shown in Table 3.1-1.

Table 3.1-1 China's ODS Management Policy and Regulatory Framework

ODS Management Policies/Regulations	Level	Main Functions
APPL	National law	In the form of national law, this Law stipulates that the production and use of ODS will be phased out through total volume control and quota management, encourages and supports the production and use of substitutes, and authorizes the State Council to formulate applicable rules and regulations.
RAODS	National regulation	RAODS are specific regulations promulgated by the State Council for implementing the Law. These regulations are for life cycle supervision and inspection of ODS in all aspects, including: construction projects, production, distribution, use, import/export, emissions, recycling, reuse, destruction, development and production of substitutes, as well as accountabilities for violation of the regulations.
Relevant policies	National policy measures	Specific systems, plans and rules for the implementation of RAODS, promulgated by MEE and other relevant ministries, covering all aspects of ODS phase-out and NP implementation.
Local rules and regulations	Implementation rules	They are the refinement of national policy measures, mainly including how to operate in the process of ODS phase-out and NP implementation, which are promulgated by provincial governments.

As can be seen from the above table, in order to implement the MP, the Chinese government has constructed a set of systematic management framework, which consists of national laws - national regulations, rules and regulations - policies and measures - local implementation rules.

3.1.2 Response to international protocols

The Chinese government signed the Vienna Convention for the Protection of the Ozone Layer (VCPOL) in September 1989, joined the MP and its "London Amendment" in June 1991, becoming a contracting party operating in accordance with Paragraph 5 of the MP, and gradually reduced and banned CFCs, halons, CTC and TCA in accordance with the requirements and timetable. In April 2003, the Chinese government joined the "Copenhagen Amendment" to the MP, which added three groups of controlled substances (HCFCs, HBFC, and methyl bromide), and developed a corresponding phase-out schedule; in May 2010, joined the "Montreal Amendment" and the "Beijing Amendment", with the former requiring the establishment of an import/export licensing system for all controlled substances, and the latter stipulating control measures for the production and import/export of HCFCs.

After joining the international protocols, the Chinese government responded with a set of robust policies and regulations based on national conditions. First, in 1993, the NP was promulgated for implementation, which was revised in 1999, following with a series of policies and regulations issued successively for implementing ODS phase-out. In 2000, ODS control provisions were added into the APPL, and in 2010, RAODS was promulgated, see Fig. 3.1-1.

In terms of the time sequence of policy response, first China formulated the NP at the technical level in accordance with the requirements of the Executive Committee of MLF, and on the basis of existing policies and regulations, China continuously introduced relevant policies in various fields according to its national conditions so as to implement the NP. During the period of revising the APPL, ODS control provisions were added into the Law, thus providing a legal basis for ODS control. After approximately 9 years of ODS phase-out practice, based on the experience gained and lessons learnt, as well as the requirements of the MP amendments, RAODS that basically cover all aspects of ODS control were formulated and promulgated for implementation.

After joining the MP and formulating the NP, the Chinese government applied policy instruments to initiate and implement ODS phase-out management in a timely manner. China’s industrial system is fairly large and the situation is complex. The 1990s was an early stage of China’s reform and opening up with rapid economic development and changes. A certain period of time is needed to accumulate practical experience before formulating relevant laws and regulations with stable and long-term effect according to the implementation status and the amendment and requirements of the MP. Therefore, the approach of Chinese government’s response is chronologically appropriate.

In terms of specific content of response, the Chinese government has successively promulgated more than 100 regulations and policy measures, covering all aspects of ODS-related construction projects, production, use, import and export, production of substitutes, and supervision and management. In terms of the correspondence relationship with the requirements of the MP, laws and regulations have corresponding provisions that generally cover the requirements of the MP. The main requirements of the MP and the corresponding responses with China's policies and regulations are shown in Table 3.1-1. In terms of content, the content related to CFCs is highlighted. The following is further analysis and evaluation of specific laws and regulations.

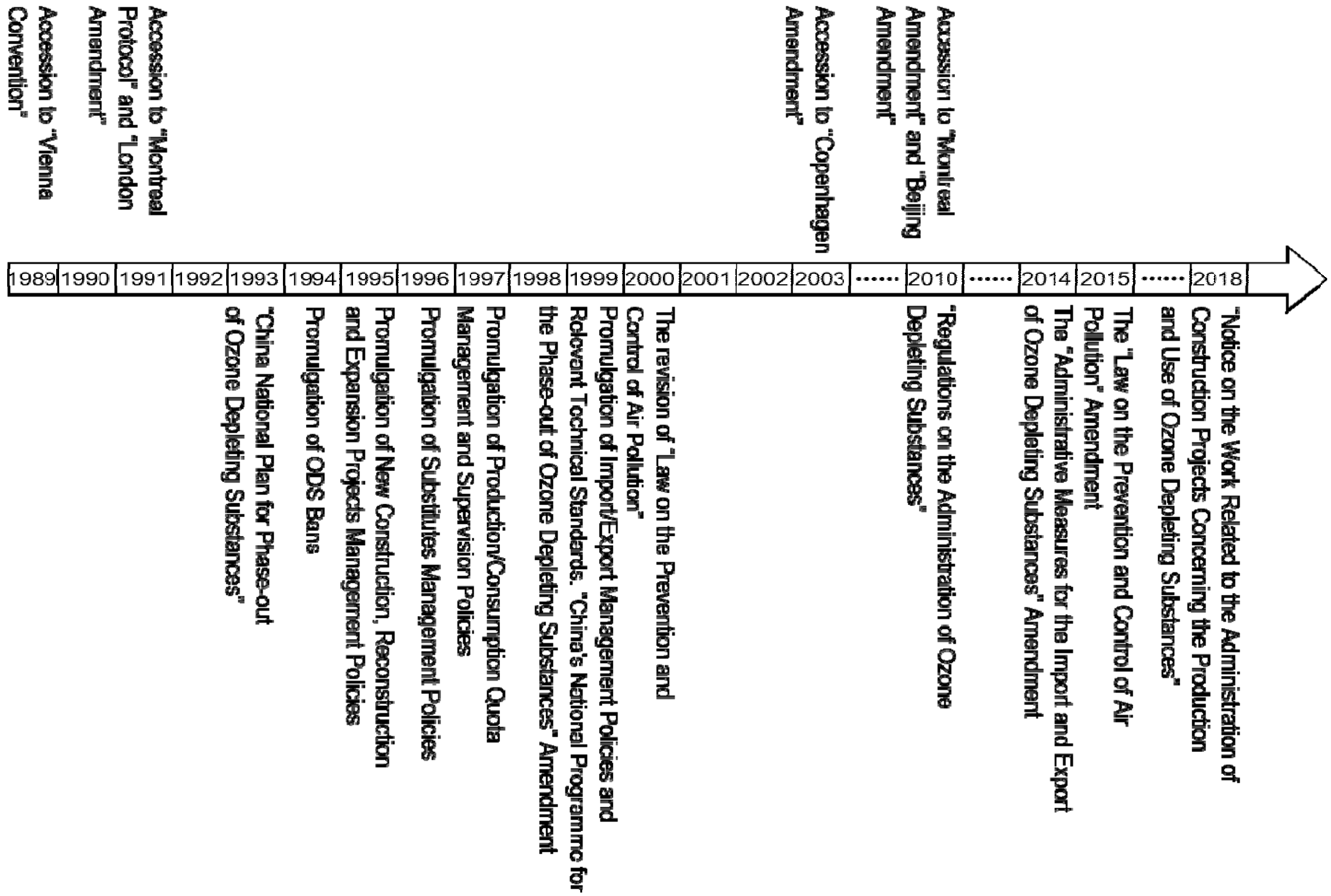

Fig. 3.1-1 Chronology of China becoming a Party to the MP and its Policy and Regulatory Responses

Table 3.1-2 MP Requirements and China's Management Policy and Regulatory Responses

Main Requirements of the MP		China's ODS Management Policy and Regulatory Response	
Classification	**Requirement**	**Category**	**Names of policies and regulations relevant to CFCs**
Control measures for controlled substances	Production and consumption phase-out (1) Eliminate CFCs, halons, other CFCs, CTC, TCA, HCFCs, methyl bromide, bromochloromethane, and HFCs according to the timetable; (2) Ensure the sustainability of phase-out actions; (3) Take measures to detect and prevent illegal production, import/export and consumption. (4) Use of raw materials 1) Report the production volume of raw materials to the Ozone Secretariat annually; 2) It is necessary to ensure that the use of raw materials does not fall into the controlled use.	In general	The APPL, RAODS, and the NP
		New construction, reconstruction and expansion projects	"Notice on Strengthening the Administration of the Expansion and Construction of CFCs" (HuaKeJunfa [1995] No. 340) "Notice on the Work Related to the Administration of Construction Projects Concerning the Production and Use of Ozone Depleting Substances" (HuanDaQi [2018] No. 5); "Catalogue for Guiding Industrial Restructuring" (2011)
		Production, consumption and quota management	"Notice on Controlling the Development of Aerosol Products Using Freon" (QingZongJi [1991] No. 32) "Notice on Strengthening the Administration of the Production and Construction of CFCs and Substitutes" (HuaKeFa [1993] No. 843) "Notice of the State Tobacco Monopoly Administration on Carrying out the Phase-out of Freon (CFC-11)" (GuoYanKe [2000] No. 782) "Notice on the Implementation of ChlorofluorocarbonsProducts (CFCs) Production Quota Licensing Management" (HuanFa [1999] No. 128) "Notice on the Implementation of Carbon Tetrachloride Production Quota Licensing, consumption quota Licensing and Sales Registration Management" (HuanHan [2005] No. 289) "Notice on Strengthening the Administration of Production, Distribution and Use of Hydrochlorofluorocarbons" (HuanHan [2013] No. 179)
		Bans	"Notice on Prohibiting the Use of CFCs in the Aerosol Industry" (HuanKong [1997] No. 366) "Notice on Stopping the Use of Freon Substances (CFCs) in New Car Production in China's Automobile Industry" (JiQiFa [1997] No. 099) "Notice on Stopping the Use of CFC-12 Automotive Air Conditioners in the Production of New Cars in China's Automobile Industry" (HuanFa [1999] No. 267) "Notice on Prohibiting the Use of Carbon Tetrachloride as a Cleaning Agent" (HuanHan [2003] No. 69)

Main Requirements of the MP		China's ODS Management Policy and Regulatory Response	
Classification	**Requirement**	**Category**	**Names of policies and regulations relevant to CFCs**
			"Notice on Prohibiting the Production and Sale of Commercial and Industrial Refrigeration Compressors and Related Products Using Chlorofluorocarbons as Refrigerant" (HuanHan [2004] No. 452) "Notice on Prohibiting the Use of Trichloromonofluoromethane (CFC-11) as a Tobacco Expander in the Tobacco Industry" (State Tobacco Monopoly Administration & State Environmental Protection Administration, [2006] No. 2) "Notice on Prohibiting the Production of Chlorofluorocarbonss (CFCs)" (State Environmental Protection Administration, [2007] No. 43) "Notice on Prohibiting the Use of Chlorofluorocarbons (CFCs) as Blowing Agents" (State Environmental Protection Administration, [2007] No. 45) "Notice on Prohibiting the Production, Distribution, Import and Export of Household Appliances Using Chlorofluorocarbons (CFCs) as Refrigerants and Blowing Agents" (HuanHan [2007] No. 200) "Notice on Strictly Restricting the Production, Purchase and Use of Carbon Tetrachloride" (Ministry of Environmental Protection, [2009] No. 68)
		Administration of substitute technologies	"Notice on the Plan of Using R134a in Automotive Air Conditioning Systems" (QiJiChanZi [1992] No. 062) "Catalogue for Guiding Industrial Restructuring" (2005, 2011, 2013) "Recommended Catalogue of Substitutes for Ozone Depleting Substances (ODS) (Revision)" (HuanHan [2007] No. 185)
		Administration of supervision and law enforcement	"Notice on Comprehensive Implementation of Pollutant Discharge Declaration and Registration" (HuanKong [1997] No. 020) "Notice on Strengthening the Supervision and Management Functions of Local Environmental Protection Departments in Protecting the Ozone Layer" (HuanKong [1997] No. 115) "Notice on the Use of Ozone Depleting Substances Declaration and Registration Database Management System" (HuanKongFa [1997] No. 43) "Implementation Measures for Plant-based Supervision of Chlorofluorocarbons Product Manufacturers" (HuanJingHan [2001] No. 58) "Administrative Measures for Plant-based Supervision of Carbon Tetrachloride Production Enterprise" (HuanJingHan [2003] No. 21) "Notice on Further Strengthening the Investigation and Punishment of Illegal

Main Requirements of the MP		China's ODS Management Policy and Regulatory Response	
Classification	**Requirement**	**Category**	**Names of policies and regulations relevant to CFCs**
			Production and Sale of Ozone Depleting Substances" (HuanBan [2004] No. 108) "Notice on Strengthening the Management Work of Eliminating Ozone Depleting Substances" (HuanFa [2007] No. 40)
Control measures for trade in controlled substances	(1) Establish an import/export licensing system to ensure that any import/export of controlled substance raw materials and exempted use are included in the licensing system. (2) Prohibit the import/export trade of controlled substances with non-contracting parties	No classification	"Administrative Measures for the Import and Export of Ozone Depleting Substances" (HuanFa [1999] No. 278) "Regulations on Strengthening the Administration of Import and Export of Ozone Depleting Substances" (HuanFa [2000] No. 85) "Emergency Notice on Prohibiting Enterprises from Unexpectedly Importing Controlled Ozone Depleting Substance Carbon Tetrachloride" (HuanFa [2000] No. 48) "Relevant Issues Concerning the Control of Imported Automobiles Using CFC-12 as Air Conditioning and Refrigeration Working Material and Automobile Air Conditioning Compressors" (HuanFa [2001] No. 207) "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China" (6 batches, 2000-2012) "Notice on Prohibiting the Import and Export of Industrial and Commercial Compressors Using CFCs as Refrigerants" (Ministry of Commerce; General Administration of Customs; General Administration of Quality Supervision, Inspection and Quarantine; State Environmental Protection Administration; [2005] No. 117) "Notice on the Total Quota for the Import of Controlled Ozone Depleting Substance CFCs and Cleaning Agent TCA in 2005" ([2004] No. 77) "Notice on Prohibiting the Import and Export of Industrial and Commercial Compressors Using CFCs as Refrigerants" ([2005] No. 117) "Notice on the Total Quota for the Import of Controlled Ozone Depleting Substance CFCs and TCA Used as Cleaning Agents in 2006 and Related Matters" ([2006] No. 37)
Data reporting	(1) Licensing system report: report on the establishment and implementation of import/export licensing system (2) Baseline year data report: report statistics on the production, import/export	No classification	RAODS "Notice on Comprehensive Implementation of Pollutant Discharge Declaration and Registration" (HuanKong [1997] No. 020) "Notice on the Implementation of Chlorofluorocarbons Products (CFCs) Production Quota Licensing Management" (HuanFa [1999] No. 128)

Main Requirements of the MP		China's ODS Management Policy and Regulatory Response	
Classification	**Requirement**	**Category**	**Names of policies and regulations relevant to CFCs**
	of each controlled substance during the baseline year (3) Annual data report: statistical data on annual production, raw material consumption, import/export volume, destruction volume, and import/export volume with non-parties for each controlled substance; the Ozone Secretariat is responsible for calculating the national annual consumption based on the formula: Consumption = production + import - export (all refer to volume of controlled use), in which: production volume = total production - raw material consumption - destruction volume; (4) Data report under the MLF: report the production volume, import/export volume, industry consumption, quota for import of each controlled substance, prices of controlled substances and substitutes, etc.		"Notice on the Implementation of Carbon Tetrachloride Production Quota Licensing, consumption quota Licensing and Sales Registration Management" (HuanHan [2005] No. 289) "Regulations on Strengthening the Administration of Import and Export of Ozone Depleting Substances" (HuanFa [2000] No. 85)

3.1.3 Laws and regulations

The APPL is the basic law relevant to ODS administration. According to Article 85,"The State encourages and supports the production and use of substitutes for ozone-depleting substances, and gradually reducing until eliminating the production and use of ozone-depleting substances. The state adopts total volume control and quota management of the production, use, import and export of ozone-depleting substances. The specific measures are stipulated by the State Council." The above-mentioned legal provisions express the State's attitude towards ODS substitutes, and the requirements for the phase-out of ODS under the principle of total volume control and quota management, which have met the core requirements of the MP in terms of NP implementation. The State Council is authorized to formulate specific rules and regulations, and responded with promulgation of RAODS.

RAODS that came into effect as of June 1, 2010 are important regulations for China's ODS control. The main content of RAODS is shown in Table 3.1-3.

Table 3.1-3 Main Content of RAODS

Chapter	Main Content
Chapter 1 General Provisions	It is required to establish a list of controlled ODS; It puts forward administration requirements for ODS production, distribution, use, disposal, etc.; It encourages the use of substitutes and substitute technologies; Reporting and handling of violations.
Chapter 2 Production, Distribution and Use	Quota licensing management system; Quota application conditions; Quota issuance procedure; Recycling and disposal standards; Three-year period for archive retention.
Chapter 3 Import and Export	The import and export licensing management system; Official release of the "Catalogue for the Import and Export of Controlled ODS from China"; It stipulates the application, approval and licensing procedures for ODS import/export.
Chapter 4 Supervision and Inspection	It requires supervision and inspection of ODS production, distribution, use, import and export, etc.; The supervision and inspection duties and responsibilities of government departments.
Chapter 5 Legal Liabilities	Penalties for violation of provisions of RAODS.
Chapter 6 Supplementary Provisions	The effective date of RAODS is June 1, 2010.

According to the analysis of the content of RAODS, corresponding provisions cover each link in ODS life cycle, including: construction projects, production, distribution, use, import/export, discharge, recycling, reuse, destruction, development and production of substitutes, etc., which also include requirements for supervision and inspection by relevant functional departments, as well as defined legal responsibilities for violations.

The "Administrative Measures for the Import and Export of Ozone Depleting Substances" (1999) stipulated that the MEE, the Ministry of Commerce (MOC, the former Ministry of Foreign Trade and Economic Cooperation) and the General Administration of Customs (GACC) as the unified agencies for supervision and management of ODS import/export. It established the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China" and the import and export quota licensing system, including the management procedures of import/export licensing and the responsibilities of import/export enterprises.

Logically speaking, the provisions of RAODS and "Administrative Measures for the Import and Export of Ozone Depleting Substances" completely cover the requirements of the MP and have set up the strong regulatory foundation for the management of ODS substances in China. It can effectively safeguard the ODS phase-out. However, the fulfillment of phase-out tasks is a long-term and continuous process. While China fulfilled its overall phase-out tasks or achieved goals set for each phase, its social, economic and in particular its market conditions also changed the same time. Over the years of their implementation, it has become clear that there are some shortcomings relevant to the provisions of RAODS. These shortcomings include: the weak regulations on the already phased out ODS, the lack of coordinated and consistent revision when other relevant laws are being revised, the lack of comparison of the similarities and differences between ODS emissions and the discharge of other common environmental pollutants, the lack of specific management requirements for ODS recycling and reuse, and the lack of vigorous punishment rules for violations.. Refer to Section 3.2.2 for detailed analysis and further discussion on deficiencies.

3.1.4 Main policy and regulatory measures for ODS control in China

3.1.4.1 Release of a list and catalogue of controlled substances

The MEE, in working with the National Development and Reform Commission (NDRC), the Ministry of Industry and Information Technology (MIIT) released, in 2010, the "China’s List of Controlled Ozone Depleting Substances"; and in working with the MOC, and the GACC, issued by the end of 2018, six(6) batches of the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China" applicable to the import and export of controlled substances. The "List" specifies the names of the controlled ODS, the reduction and phase-out goals, and the corresponding main uses of each type of controlled ODS; the "Catalogue" provides updated information on the commodity name of the controlled ODS according to the progress of the phase-out plan, as well as requirements for the prohibition or quota Licensing requirements. The above-mentioned list and catalogue is updated in accordance with the amendment of the MP and the status of China’s accession to the amendment of the MP.

3.1.4.2 Control relevant construction projects

From 1997, MEE has successively issued relevant policies, including the "Notice on the Administration of Construction Projects for the Production and Use of Ozone Depleting Substances" issued in 2018, which stipulates that new construction or expansion projects for production and use of controlled ODS shall not be approved, and the existing projects shall not launch new production capacity that is relevant to controlled ODS.

3.1.4.3 Implementation of quota licensing management

For the controlled substances listed on the "List of China for Controlled Ozone Depleting Substances" and in the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China", the MEE, in working with the MOC and other departments, is responsible for formulating the total amount of quotas for ODS production, use, import and export, and releasing to the public.

Enterprises that need to carry out the production and use of controlled substances must apply to MEE for production and consumption quota license, and file (i.e., register) with the Provincial Department of Ecology and Environment. Only those that have obtained a production and/or consumption quota license can produce or use the controlled substance, shall be in accordance with the quota license or registration document in terms of variety, quantity and time limit, and shall take effective measures in accordance with the regulations of MEE to prevent or reduce the leakage and discharge of controlled substances. Enterprises without a quota license or registration document for production or use shall not produce or use the controlled substances. The validity period of the production and consumption quota license is one year. Prior to the expiration of the validity period, relevant enterprises should apply to MEE for the next year’s production and consumption quota licensing, or apply to the Provincial Department of Ecology and Environment for the next year’s consumption registration, and submit relevant information on previous production, distribution and use of controlled substances.

Enterprises that need to import or export controlled substances listed in the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China" should report the information on the type, quantity, source and purpose of the ODS to be imported or exported to the national ODS import/export administration, and apply for import/export approval form; the maximum validity period of the import/export approval form is 90 days, which shall not be used after the validity period or across the year. Enterprises that have obtained the ODS import/export approval form can apply for an import/export license to the MOC, conduct customs clearance with the import/export license, and accept the inspection carried out by the entry-exit inspection and quarantine agency according to law.

3.1.4.4 Regulation on distribution and relevant activities

Enterprises engaged in the distribution of controlled substances shall apply to MEE or the Provincial Department of Ecology and Environment according to their sales volume of controlled substances, and obtain the sale certification of controlled substances before the sale of controlled substances; MEE or the Provincial Department of Ecology and Environment will release the list of sales enterprises of registered controlled substances. Trade of controlled substances can only be carried out between enterprises that have obtained the approval to produce, use, and sell controlled substances. For controlled substance sale enterprises must fully record the purchase and sale of controlled substances and keep relevant data for at least three years, and submit relevant data to MEE as required.

Enterprises that specialize in business activities such as the recycling, reuse or destruction of controlled substances should file with the local Provincial Department of Ecology and Environment; enterprises engaged in business activities such as maintenance and disposal of refrigeration equipment, refrigeration systems or fire extinguishing systems containing controlled substances, must file with the county department of ecology and environment. While engaged in relevant business activities, the said enterprises must conduct harmless disposal of controlled substances in accordance with relevant regulations and must not directly discharge controlled substances; at the same time, relevant business activities must be recorded and the record file must be kept for at least three years, and relevant data must be reported to the ecology and environment department in a timely manner as required.

3.1.4.5 Promotion of the development and production of substitutes

China encourages and supports the scientific research, technological development, and application of substitutes for controlled substances and substitute technologies. In 2004 and 2007, formulated and released the "Recommended List of substitutes for Substances that Deplete the Ozone Layer in China (First Batch)" and the "Recommended List of substitutes for Substances that Deplete the Ozone Layer in China (Amended)" respectively.

3.1.4.6 Prohibition orders

In order to ensure the implementation effects of the phase-out measures, the MEE, in accordance with the ODS phase-out plan and the actual progress, and in working with other relevant departments of the State Council, promptly issues a ban on the production, sale and use of controlled ODS. For example, in 2007, the "Notice of the State Environmental Protection Administration on Prohibiting the Production of Chlorofluorocarbons (CFCs)" was promulgated; in the same year, promulgated the "Notice of the State Environmental Protection Administration on Prohibiting the Use of Chlorofluorocarbons (CFCs) as Blowing Agent", and in working with the NDRC, the MOC, the GACC and the General Administration of Quality Supervision, Inspection and Quarantine, promulgated the "Notice on Prohibiting the Production, Distribution, Import and Export of Household Appliances Using Chlorofluorocarbons (CFCs) as Refrigerants and Blowing Agents".

3.1.5 Local rules and regulations

From 2002, some provincial governments in China have successively issued relevant local rules and regulations in accordance with national policies and regulations. Some examples are listed below:

- "Implementation Measures for Eliminating Ozone Depleting Substances" (2002, Hebei)
- "Opinions on Eliminating Ozone Depleting Substances" (2005, Yunnan)
- "Administrative Measures for Phase-out of Ozone Depleting Substances" (2006, Jilin)
- "Notice on Accelerating the Phase-out of Ozone Depleting Substances" (2006, Tianjin)
- "Notice on Accelerating the Phase-out of Ozone Depleting Substances" (2006, Hainan)
- "Implementation Plan for Strengthening the Phase-out of Local Ozone Depleting Substances (ODS)" (2008, Shanxi)
- "Notice on Eliminating Ozone Depleting Substances" (2008, Hunan)
- "Implementation Plan for Accelerating the Phase-out of Ozone Depleting Substances" (2008, Qinghai)
- "Work Plan for the Project of Capacity Building for Strengthening the Phase-out of Ozone Depleting Substances" ((2008, Henan)
- "Notice on Accelerating the Phase-out of Ozone Depleting Substances" (2009, Liaoning)
- "Notice on Strengthening the Registration Administration of the Production, Use, Sales, Recycling, Reuse and Destruction of Ozone Depleting Substances" (2015, Shandong)

The formulation of local rules and regulations is a feature of China’s policy and regulatory system. The policies and regulations issued by these local governments focus on combining national policies and regulations with local actual conditions, so as to make national policies and regulations more operational in the localities, and make local deployments for the implementation of the ODS phase-out plan. In other words, local policies and regulations are a supplement to national policies and regulations, with a focus on strengthening the operability of local implementation of national policies and regulations.

3.2 Implementation effects of China's ODS control policies and regulations

3.2.1 Policy and regulatory goals

In the NP, the phase-out goals of controlled ODS are specified. The phase-out goals, relevant to CFC-11 and CFC-12 in Group 1 CFCs and Group 2 CTC, are shown below in Table 3.2-1.

Table 3.2-1 CFC-11 and CFC-12 Related Goals of Controlled ODS Phase-out

Controlled ODS	Baseline Year	Phase-out Goals			
Annex A: Group 1 CFCs	1995~1997	1999.7.1	2005.1.1	2007.1.1	2010.1.1
		Freeze	*50%*	*85%*	*100%*
Annex B: Group 2 CTC	1998~2000	2005.1.1	2010.1.1		
		85%	*100%*		

3.2.2 Analysis of implementation of policy and regulatory measures

The process of implementing the aforementioned major policy and regulatory measures is as follows:

(1) Determination of the types of ODS through the "List" and the "Catalogue", and locking of the total amount of these substances through strict control of ODS-related construction projects since 1995, so as to ensure strict control of ODS total amount.

For the CFCs, starting from 1995, any construction projects must first obtain the approval of the former Ministry of Chemical Industry under strict restrictions. Without its approval, the MEE (then called the General Administration Agency of Environmental Protection) could not issue production permit. Starting 1997, all new construction, conversion and expansion of CFCs were totally stopped. For CTC production, starting 2003 all new construction, conversion and expansion of CFCs were stopped. Using CTC as raw materials needs quota permit

(2) Implementation of a production, sale and consumption quota permit and registration system and gradual phase-out of ODS. Based on NP and specific ODS phase-out goals, MEE determine annual total volumes, issues quota to enterprises for production and use in accordance with their capacity and performance, and disclose the quota to the public. The procedure for quota management is shown in Figure 4.3-1.

For CFCs, the quota permit and registration system started in 1999. MEE (then State Environmental Protection Administration), in working with then the Petroleum and Chemical Industry Administration (PCIA), is responsible for total annual quota volume and distribute it among enterprises. Enterprises must send their annual quota application in advance to MEE, and copy to PCIA and their local eco-environment and chemical departments. MEE, working with PCIA, decide the quota and issue the production permit by the end of February each year, and notify the local eco-environment and chemical departments. MEE and PCIA conduct inspection and document review under flexible schedule, local eco-environment and chemical departments assist review and on-site inspection. For enterprises violating the permitted quota, production and or use permit would be revoked and fine imposed.

(3) The implementation of ODS phase-out in China is mainly industry-specific activities, during which the system of quota licensing and registration is implemented for the administration of the production, use, sales, recycling, reuse, or destruction of controlled substances. The industries relevant to CFC-11 and CFC-12 phase-out include chemical production industry, CTC production industry, cleaning industry, PU foam industry, tobacco industry, aerosol industry, household refrigeration industry, industrial and commercial refrigeration industry, automobile air conditioning industry and refrigeration maintenance industry.

(4) Encouraging development and production of substitutes in all industries, as well as formulating technical standards for substitutes to ensure the industries' continuous implementation of production and sales activities.

(5) Timely issuance of ODS ban on schedule according to the industry-based phase-out progress, so as to fulfill the phase-out tasks and achieve the performance goals stipulated in the MP.

(6) Direct quota licensing management by the MEE, which is a top-down control implementation that requires strong central management capabilities, during which the direct engagement by MEE will play an important and key role.

Regarding how local government executes its policy and enforce the rules, Table 4.3-1 has the example of Tianjin.

The above-mentioned policy and regulatory measures are in line with China's national conditions, which provide comprehensive coverage and strong operability, and can ensure that ODS is eliminated according to the plan and the requirements stipulated in the MP are fulfilled. However, there are still shortcomings especially in ensuring the sustainability of phase-out and lack of the measures needed to strengthen the detection and prevention of illegal production, import/export and consumption. Specifically, these shortcomings include:

(1) In terms of policies and regulations, it is not enough to just issue a ban after the phase-out is completed, and additional and specific measures must be formulated to maintain the banning status for sustainability. The industry-based planned phase-out has strongly promoted the phase-out of controlled substances and the application and promotion of substitute technologies and substitute substances, and facilitated the achievement of the phase-out goals. However, due to the nature of the industry-specific and phase-out approach, the existing policy and regulations lack specific measures to maintain/sustain compliance status after the phase-out or phased tasks are

completed. For example, how to detect and prevent illegal production, import/export and consumption, and how to carry out routine and random inspection, supervision and management activities. Experience gained through national enforcement campaign and lessons learnt from enforcement case study discussed later in the report strongly suggest the need to form a mechanism for timely detection of illegal production, import/export and consumption. In this respect, the current policy and regulations are too vague to provide clear guidance.

(2) In terms of technology, the key and core issue of ODS phase-out and sustainable NP implementation is whether substitutes are technically effective and economically feasible. Therefore, research and development of cost-effective substitute technologies and substitute substances as well as promotion and application of newly developed substitute technologies and substitute substances should be the most critical policy content. However, there is no specific management policy or incentive mechanism to facilitate the research and development of substitute technologies and substitute substances, and or for the promotion and wide application of new substitutes. For example, when technically more suitable substitutes cannot be employed currently due to their relative high prices, the government should provide sufficient incentives to actively leverage the market for the use of such substitutes, gradually expanding the scale of production and sales volume to reduce the prices. In many cases, although the cost of developing, promoting and applying new technologies and products is fairly high, it is still a better choice compared with the social and environment costs of existing technologies and mobilization of government and social resources for strict inspection, testing, and supervision and enforcement.

(3) In terms of ODS recycling, reuse and disposal, the existing policy does not have specific measures, which are difficult for the local supervision departments to enforce.

(4) In terms of the involvement of the local government in implementation, local governments are relatively weak in MP implementation capabilities, professional knowledge, and supervision and law enforcement capabilities.

(5) In terms of punishment and sentencing for violations, the intensity of punishment is not high, the cost for violation is low, and the level of deterrence needs to be increased. The existing policy and regulation does not clearly state whether to follow penalty and sentence of toxic chemicals or environmental pollutants, causing uncertainty in enforcement when comes to illegal production and use, in particular discharge or emissions.

3.2.3 Implementation effects of major ODS phase-out

According to calculations based on publicly available statistical data, the phase-out goals of each group in Annexes A and B have been reached, and mostly ahead of schedule.

Group 1 controlled ODS listed in Annex A of the MP include CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115. The actual phase-out of this group of substances is shown in Table 3.2-2 (calculated based on ozone depleting potential (ODP) value, the same below).

Table 3.2-2　Group 1 Controlled ODS Consumption in Annex A

Year	Base Year	1999	2005	2007	2010	2013	2018
Consumption (ton)	57,818.7	42,983.4	13,123.8	5,832.1	968.6	-386.6	-12.6
phase-out goal		0	50%	85%	100%		
Actual phase-out rate		25.6%	77.3%	89.9%	100%		

Note: The negative number means that the amount of destruction or exports exceeds the sum of production and imports, meaning that the amount of destruction or exports is derived from inventory.

Group 2 controlled ODS listed in Annex B of the MP is CTC. The actual phase-out status is shown in Table 3.2-3.

Table 3.2-3　Group 2 Controlled ODS Consumption in Annex B

Year	Base Year	2003	2005	2008	2010	2018
Consumption (ton)	49,142.1	20,019.9	1,060.3	219.2	282.6*	236.5*
phase-out goal			85%		100%	
Actual phase-out rate			97.8%		99.4%	99.5%

* According to the resolution of the COP to the MP, it is used for permitted laboratory analysis or as auxiliary.

China has phased out the production and consumption of CFCs, Halons, CTC, TCA and MBr for controlled purposes, exceeded the HCFCs phase-out tasks for the first phase, completed the implementation goals required by the MP as scheduled, and gradually ceased essential use and critical use exemption. Till now, China has phased out some 280,000 tons of ODS, accounting for more than half of the ODS phased out by developing countries.

3.2.4Evaluation of the implementation effect of policies and regulations

After joining the international protocols, China responded with a robust set of policies and regulations based on its national conditions. First, the NP was implemented and a series of policies and regulations have been promulgated to implement ODS phase-out, and then the provisions of ODS control was included in the APPL, and RAODS was enacted for implementation. The chronological response is typical of China’s approach (i.e., national plan first, then law and regulations) and is deemed practical and effective. In terms of specific response, it covers each link in ODS life cycle, including: construction projects, production, distribution, use, import/export, emissions, recycling, reuse, destruction, development and production of substitutes, i.e., it covers all aspects specified in the MP.

The ODS provisions in the APPL have provided clear legal support for the ODS control, and integrated ODS control into the national system of laws and regulations, which is the core requirement of the MP in terms of NP implementation. RAODS specified and standardized life cycle ODS control measures. The NP is China's basic action plan for implementing the MP and an important basis for formulating and implementing phase-out plans for various industries and relevant policy measures. Over the past 30 years, the Chinese government has successively promulgated more than 100 ODS-related policies, regulations and control measures, and gradually established and improved the ODS control policy and regulatory system, which complies with the requirements of the MP.

China has issued a list and a catalogue of controlled substances for strict supervision on ODS-related construction projects. In addition, China has been implementing total volume control and quota licensing management systems to regulate production, sales and use activities. China's industry-based phase-out activities involve the whole-process management of the production, use, sales, recycling, reuse or destruction of controlled substances. China encourages the development and production of substitutes, and issues ODS bans in a timely manner to gradually fulfill the phase-out goals. These measures meet the requirements of the MP, guarantee the planned phase-out of ODS is based on China's national conditions, and provide full coverage and strong operability for guiding the implementation activities of enterprises to fulfill the requirements of the MP. Judging from the results of the implementation of ODS phase-out, China has been able to achieve the set goals ahead of schedule and comply with relevant provisions of the MP.

Based on the results of questionnaire survey, 100% government respondents think China has or almost has achieved the phased-out goals; 96.78% of the total respondents believe that the existing policy and regulation are effective or basically effective and can ensure the achievement of the phase-out plan. Therefore, Chinese policies and regulations not only have met the requirements of the MP, but are also effective in ODS phase-out.

However, China's policies and regulations have the following shortcomings: The results of questionnaire survey indicate that 87.10% of government respondents think China should focus on the revision and improvement of ROADS; 67.74% of the total respondents believe that the existing policy and regulatory framework needs revised provisions regarding legal accountability. Specific shortcomings include:

(1) In terms of the MSDOL implementation, RAODS only manages the phased-out ODS by the quota application system, i.e. it is forbidden to apply for a quota for phased-out ODS. The requirements for management of recycling, reuse and destruction are not specific. The differences between illegal ODS production and usage with the illegal emission of other environmental pollutants are not clarified, which may cause uncertainty in the enforcement of APPL or criminal law.

(2) The penalties for violations are not consistent with the costs of violations, and the

deterrence is not strong enough. According to RAODS, the highest penalty for illegal production and use are respectively RMB1million and RMB500,000, not enough to deter violation and potential economic gains. And prior 2019, there is no specific provision for criminal charge. Regarding the reasons for illegal production and usage, the questionnaire survey results indicate that 70.97% government respondents think it is due to the low cost/penalty of the violation; 83.78% HCFC producers, 75.00% ODS users, 64.52% government respondents, and 73.08% methane chloride producers believe China should increase the penalty.

(3) In terms of policy and regulatory measures, it is not effective enough to just issue a ban after the phase-out is completed, and specific regulatory measures must be formulated to maintain the banning status to sustain implementation. There are no clear and specific policies and regulations to ensure timely detect and prevent illegal production, import/export and consumption.

(4) In terms of substitutes and alternatives, it is not effective enough to just state that China encourages the development, promotion, application and production of substitutes. There should be practical and specific incentive policies for each industry. Based on the questionnaire survey results, 90.32% government respondents think it needs to further encourage and support the research, development and application of substitutes through market mechanisms; 48.39% government respondents believe illegal ODS production is due to the high price and poor product quality of the substitutes; 67.74% government respondents think government should support substitutes through economic policy and technical standards. 78.38% and 64.86% HCFC producers and users, 92.31% and 86.54% ODS producers and users believe the government should provide more incentive policy for research, development and application of substitutes.

(5) In the process of phase-out implementation, the local ecology and environment departments' implementation capacity, knowledge, supervision and law enforcement capabilities of local ecology and environment department and other relevant government departments have been weak. Based on the survey results, only 19.35% government respondents think the current capacity building efforts of local government can ensure and sustain the future MSDOL implementation；90.32% think it needs professional training to raise management level; 80.65% believe China needs a specific and modern information management system to centralize data and reports and streamline communication and exchange of information.77.42% think there is a need to establish a monitoring system and standardize ODS sampling and testing.

To make improvements for the above-mentioned insufficiency of policies and regulations, there are some challenges in the following aspects:

(1) Regulations on ODS are generally regarded as environmental regulations.. However, ODS production, sales, use activities involve a wide range of other sectors such as construction, trade, transportation, chemical and automobile industries, to just name a few. The regulations in

these sectors will continue to change along with the social and economic development. Since ODS phase-out and sustainable MSDOL implementation are long-term tasks, thus how to ensure the dynamic and consistent changes of ODS regulations, in order to work smoothly with laws and regulations in these other sectors would be a big challenge.

(2) Continued implementation after the phase-out goals are fulfilled requires the continued and smooth cooperation of other government departments with the ecology and environment department. Since there are various factors affecting the division of duties and responsibilities among various government departments, it would be a big challenge to delineate the roles and responsibilities in the ODS management and realize the smooth cooperation.

(3) How to quantify the degree of ODS violations and reduce the human and subjective factors in determining the degree of punishment is another big challenge. As in comparing with the common environmental pollutants, ODS has its speciality, such as CFC-11 has low hazards for people when only direct contact, ingestion or inhalation. But it is harmful for human and ecological system when it enter stratosphere and damage ozone.

(4) The development of substitute technologies is critical to achieving sustainable compliance with the MP. The government's incentive policies for substitute technologies lack further refined provisions, for instance, the lack of specific incentive measures. There are many factors involved in the development of specific policy measures to promote the sustainable development of substitute technologies. However, development of specific policy and regulatory measures requires consultation with and support from other sectors such as technological, economic and industrial sectors, which in turn is not a simple task.

4 Evaluation of China’s ODS supervision and management system and effect

Each country should establish an ODS supervision and management system suited to its own national conditions. In this chapter, first we’ll review the organizational structure and functions of China’s ODS supervision and management system, the main content, operation mode, and enforcement, including case study, of supervision and management, and then analyze and evaluate the effectiveness of the supervision and management system

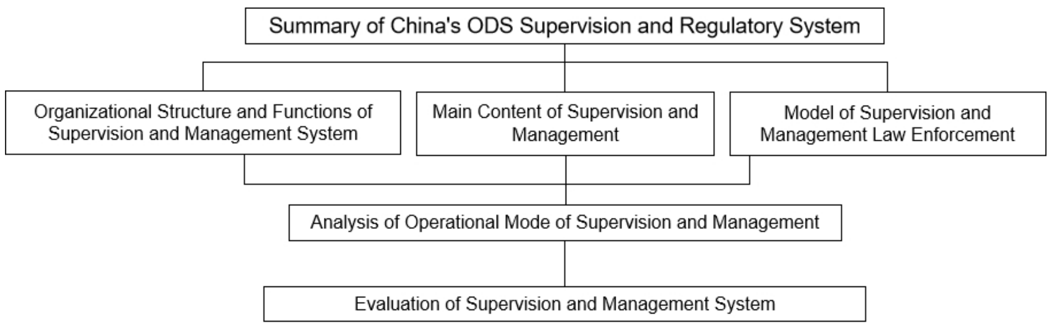

Fig. 4-1 The Roadmap for Evaluation of China’s ODS Supervision and Management System and Effect

4.1 Organizational structure and functions of China’s ODS supervision and management system

4.1.1 Organizational structure and functions of the national-level supervision and management system

China’s organization structure of ODS supervision and management system includes both the national and local levels. The national-level supervision and management agencies include the NLGPOL and its special agencies for compliance with MSDOL. The special agencies for compliance with MSDOL include the National Management Office for the Import and Export of Ozone Depleting Substances (I/E Office), the Coordination Group for the Compliance with the MP within MEE and its Office (also known as the National Ozone Unit (NOU)), and the PMO.

NLGPOL

China established the NLGPOL in 1991 as an inter-ministerial coordination agency. The leading ministry of the NLGPOL is the MEE, and its members include: the Ministry of Foreign Affairs (MOFA), the NDRC, the Ministry of Science and Technology (MOST), the MIIT, the Ministry of Finance (MOF), the Ministry of Transport (MOT), the Ministry of Agriculture and Rural Affairs (MARA), the MOC, the Ministry of Emergency Management (MEM), the GACC, the State Administration for Market Regulation (SAMR), and the China Meteorological Administration (CMA). The Office of the NLGPOL is located in the MEE and is responsible for the routine affairs of the NLGPOL. The composition of the NLGPOL is shown in Fig. 4.1-1.

The main functions of the NLGPOL are: to review China’s policies and work plans for the implementation of the VCPOL and the MP; coordinate the implementation of major issues of the VCPOL and the MP; supervise the implementation of the NP; and other matters submitted by relevant ministries to the NLGPOL for consideration or decision-making. The functions of members of the NLGPOL are described as follows.

The MEE is responsible for the ODS supervision and administration in the whole country. Jointly with the departments concerned under the State Council shall, and according to the NP and the ODS phase-out progress, it determines and publishes the restricted or prohibited categories of new construction, reconstruction and expansion of ODS production and use projects; promulgate and publish the catalogue for restricted or prohibited production, use, import and export of ODS; determines the national total annual ODS production, use, import and export quotas and makes a public announcement; formulates, adjusts and publishes the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China"; accepts the import and export applications of ODS listed in the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China" and issues related import and export approval documents; establishes and improves China's ODS data information management system; and collects, summarizes and releases ODS production, use, import and export data and information.

The MOFA is responsible for relevant foreign policies, laws and the affairs related to Hong Kong, Macao and Taiwan.

The NDRC is responsible for formulating macro-policies for the implementation of conventions.

The MOST is responsible for the organization, implementation and management of scientific and technological projects such as basic scientific research, the researches on related alternative technologies, as well as the development and demonstration of new products.

The MIIT is responsible for the formulation of policies for relevant industries in the industrial sector.

The MOF is responsible for the examination and arrangement of financial expenditures and the formulation and management of relevant fiscal and tax policies.

The MOT is responsible for the formulation of relevant policies in the field of transport.

The MARA is responsible for the formulation of relevant policies in the field of agricultural production.

The MOC is responsible for the formulation of relevant policies in the field of foreign trade, assisting in the formulation, adjustment and publication of the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China", and issuing the import and export licenses for ozone depleting substances.

The MEM is responsible for the formulation of relevant policies in the fields of fire fighting and safety.

The GACC is responsible for the supervision and administration of import and export and combating illegal trade, and assists in the formulation, adjustment and publication of the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China".

The SAMR is responsible for the comprehensive supervision, administration and standardization of the market.

The CMA participates in the work relating to atmospheric monitoring.

Special agency for compliance with MSDOL: I/E Office

The I/E Office is jointly organized by the MEE, the MOC, and the GACC, as shown in Fig. 4.1-2. Its main responsibilities are: to draft ODS import/export administration policies and regulations; draft the "Catalogue for the Import and Export of Controlled Ozone Depleting Substances from China"; propose the annual plan of ODS import/export volume and the allocation of import/export quotas, which shall be submitted to MEE, MOC and the GACC for approval, and then for promulgation and implementation; handle the enterprises' applications for ODS annual import/export quota and their applications for each batch import/export of ODS, and issue ODS "Import Approval Form" and "Export Approval Form"; collect and analyze ODS import/export volume data, assist in supervising and inspecting the enterprises' ODS import/export activities, and handle illegal ODS import/export cases; organize the training programs for Environmental, Commercial and Customs personnel, handle routine affairs of ODS import/export administration, manage the documents and archives, and carry out ODS import/export publicity; it's also responsible for external communication with international agencies and contracting states for coordinating ODS import/export administration.

Special agency for agencies for compliance with MSDOL: The Coordination Group for the Compliance with the MP within MEE and its Office

The Coordination Group for the Compliance with the MP within MEE is composed of 9 departments, bureaus and institutions of MEE, and the specific work is undertaken by its Office. At home, the Coordination Group Office undertakes the routine work of the NLGPOL and the work of the I/E Office. Internationally, it is China's NOU, acts as the national focal point of conventions, protocols and the Executive Committee of MLF, and is responsible for the routine contact with United Nations Environment Programme (UNEP) Ozone Secretariat, the MLF Secretariat and the International Executive Agency of the MLF. The Coordination Group Office is located in the Department of Atmospheric Environment of MEE, and its members are composed of the Department of Atmospheric Environment, the Department of International Cooperation and the Foreign Environmental Cooperation Center (FECO).

Special agency for agencies for compliance with MSDOL: PMO

Under the NOU, the FECO of the MEE established the PMO internally. PMO is a joint working group composed by personnel from FECO and industrial associations based on the industries involved in the phase-out work. Personnel from different aspects work together, select multilateral fund projects for the protection of the ozone layer, and coordinate, manage and supervise the implementation of the projects.

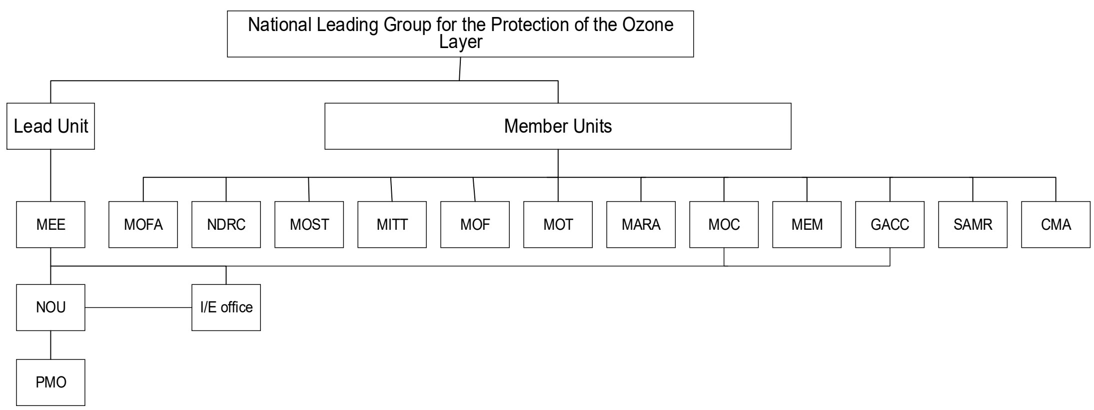

Fig. 4.1-1 National Leading Group for Ozone Layer Protection and its special agencies for compliance with MSDOL

4.1.2Organizational structure and functions of local-level supervision and management system

At local level, China' ODS supervision and management mainly involve the eco-environment departments of the provincial, municipal, and county governments, including the Provincial Department of Ecology and Environment, the Municipal Bureaus of Ecology and Environment, and the County Bureaus of Ecology and Environment. Its supervision and management function is to implement the national supervision and management policies and regulations, and conduct the supervision and management tasks arranged at the national level. The specific supervision and management work at local level is included in their routine scope of eco-environment supervision and eco-environment quality monitoring. In addition, the provincial, municipal, and county ecology and environment departments have respectively established their own eco-environmental law enforcement divisions to conduct and manage the work related to law enforcement.

4.2 Main content of China's ODS supervision and management

The main content of China's ODS supervision and management covers each link in ODS life cycle, including construction projects supervision and management, import/export supervision and management, ODS production/consumption quota and phase-out progress supervision and management, data declaration management, and eco-environment inspection and enforcement. Details are as described below.

4.2.1 Construction projects supervision and management

In accordance with the provisions of Article 6 of RAODS, it is the MEE that determines and announces the categories of new construction, reconstruction, expansion projects to be restricted or prohibited for their production and use of ODS, and establishes and releases a list of projects restricted or prohibited for their production, use or import/export of ODS.

Environmental impact assessment (EIA) of construction projects is one of the tasks that must be carried out for all new construction, reconstruction and expansion projects in China. The ecology and environment departments at all government levels in charge of the review and approval of EIA documents for construction projects involving controlled ODS, must comply with the requirements of the "List of China for Controlled Ozone Depleting Substances", the "Catalogue for Guiding Industrial Restructuring" and other relevant policies, so as to ensure the implementation of RAODS and the NP.

4.2.2 Supervision and management of import and export

According to Article 22 of RAODS, the MEE, the MOC and the GACC are responsible for the administration of ODS import/export, and the three ministries have jointly established the I/E office. Enterprises engaged in ODS import/export must apply to the national ODS import/export administration for the import/export quota; then apply to the MOC for an import/export license, and clear the customs with the import/export license. The customs shall supervise and release the import/export of ODS after checking the applicant's "Import/Export License" issued by the MOC. The MEE, the MOC and the GACC have the right to supervise and inspect the import/export operations of enterprises engaged in ODS import/export business.

4.2.3 Supervision and management of production/consumption quota and phase-out progress

The supervision and management of production/consumption quota and the phase-out progress involves ODS production, distribution, use, emissions, recycling, reuse, destruction, and development and production of substitutes. The main legal and policy basis includes the provisions concerning the production, distribution and use of ODS specified in Chapter 2 of RAODS; Article 8 concerning the scientific research, technological development, and application and promotion of ODS substitutes and substitute technologies encouraged/supported by the State; the policies for production and consumption quota management; policies for prohibiting ODS and policies for substitutes management and technical regulations.

The main areas of supervision and management include: the implementation of ODS production and consumption quota licensing system; ODS leakage and emission; ODS recycling, reuse and destruction activities; the implementation of the recommended list of ODS substitutes; the inspection and administration of implementation of ODS bans, and the accountability for violation of the bans.

4.2.4 Data declaration and management

Data declaration and management mainly refers to the collection and sorting of data information on the production, use, import/export of ODS by MEE and local ecology and environment departments, and the declaration of ODS production, import/export, sales and use data by relevant enterprises. According to the provisions of Article 28 of RAODS, the MEE has established an ODS data information management system to collect, aggregate and release data on the production, use, import and export of ODS. The period from 2008 to 2018 is the construction period of the ODS data information system. Currently there exists an overall on-line HCFCs information management system in China with functions including the management of HCFCs quota application, registration application and data reporting. Some provinces and municipalities established their own on-line registration system for registration management and data reporting, and a complete and nationwide data information system that involves each link in ODS life cycle has not yet been established. Based on the rapid development of the Internet, the MEE is currently establishing and improving the "ODS production and use information management system".

In addition, in accordance with RAODS, data reporting and management provision requires ODS producers and users to apply to MEE in writing for the next year’s production quota or consumption quota prior to October 31 of each year, and relevant enterprises should keep intact the original data on business activities for at least 3 years, and report relevant data to MEE in accordance with the regulations.

4.2.5 Eco- environment inspection and enforcement

According to the provisions of Article 25 and Article 26 of RAODS, the department of eco-environment and other relevant departments of the government at or above the county level have the right to inspect the production, distribution, use, import/export of ODS, and request the enterprises being inspected to provide relevant materials; the inspected enterprises must cooperate and truthfully report the situation and provide necessary information, and must not refuse cooperation or obstruct the inspection. Any illegal production, use, sale, import or export of ODS shall be investigated and punished by the eco-environment at or above the county level.

Ecological environment inspection and enforcement is the administrative law enforcement activities implemented by the eco-environment departments in accordance with the "Environmental Protection Law" and other regulations and normative documents. China has established eco-environmental inspection and enforcement divisions at the county level and above. The main responsibilities include: to supervise the implementation of laws and regulations; conduct on-site inspections on emissions from pollution sources, the operation of pollution prevention facilities, the implementation of environmental protection administrative licensing, and the construction projects' compliance of environmental protection laws and regulations, etc.; investigate and punish environmental violations; investigate, delegate and supervise complaints and reports on environmental pollution and ecological damage events, and in accordance with the division of responsibilities determined by the department of eco-environment, have the specific responsibility of mediating environmental pollution and ecological damage disputes; conduct investigation of serious environmental pollution and ecological damage issues; and conduct environmental inspections in accordance with respective duties.

4.3 Operation mode of China's ODS supervision and management system

4.3.1 Analysis of the operation of the supervision and management system

In terms of the supervision and management of the ecological environment, China implements a top-down supervision and a bottom-up reporting management system. Central government formulates policies and promulgates regulations; local governments at provincial, municipal and county levels carry out supervision, investigation, enforcement and management. This arrangement applies to the phase-out of ODS as well. Starting from 2004, MEE requires local eco-environment departments to include ODS as an additional component in their routine inspection and enforcement activities. The supervision and management of ODS is only a factor in the ecological environment supervision and management system. Local governments at all levels carry out supervision and management relevant to the phase-out of ODS within their respective responsibilities.

Structure of supervision and management

In terms of the structure of the supervision and management system, China has established a two-level supervision and management system from the State to the local administration, which is a top-down and vertical-oriented supervision and management system. For the national-level supervision and administration of ODS, the professional organizations mainly include the NLGPOL and its Office, the I/E Office, the Coordination Group for the Compliance with the MP within MEE and its Office, as well as the PMO; its routine ecological and environmental supervision and administration institution is the MEE, in which the Department of Atmospheric Environment and the Law Enforcement Administration are closely related to ODS. For the supervision and management of ODS at the local level, ODS is considered as a factor of the routine ecological and environmental supervision and management including atmosphere, water, soil and solid waste. There are provincial environmental protection bureaus, municipal environmental protection bureaus and county-level environmental protection bureaus at the local level, so it is a very large institutional system (for a municipality directly under the central government, it has a structure consisting of city, district or county).

Main contents of supervision and management

In terms of ODS supervision and management, it mainly includes construction projects supervision and management, import/export supervision and management, production and consumption quota and phase-out progress supervision and management, data declaration management and eco-environment supervision. These contents cover the following aspects: total mass control, quota licensing, industry-based phase-out, enforcement of bans, import/export administration and data reporting, all of which have formed a comprehensive correlation with various aspects of policy and regulation implementation.

Operation of supervision and management

In terms of the operation of supervision and management, at national level, the inter-ministerial organization such as the four special agencies is the decision-maker and or national coordinator. The MEE is both a member of the decision-makers and, the most important part, the central executive player. It directly carries out construction projects supervision and management, import/export supervision and management, production/consumption quota and phase-out progress supervision and management, data reporting management, and eco-environment inspection and enforcement. In specific, the supervision and management of construction projects is to approve relevant major construction projects based on the scale of the project; the supervision and management of production/consumption quota and phase-out progress is to approve and issue quotas, check the implementation of quota licensing, and check the enforcement of bans (refer to Figure 4.3-1 Flow chart of quota application and approval process); and the management of data declaration is to establish the data information management system to collect, summarize and examine the data reported by producers/users, and reports the production, use and import/export data to international organizations; the import/export supervision and management is to formulate and implement the import/export licensing system (refer to Figure

4.3-2 Flow chart of import and export application and approval process); the eco-environment inspection and enforcement is mainly from the top-down regular inspections and special enforcement actions for outstanding issues, which involves various aspects such as quota licensing, industry-based phase-out, enforcement of bans, and data reporting.

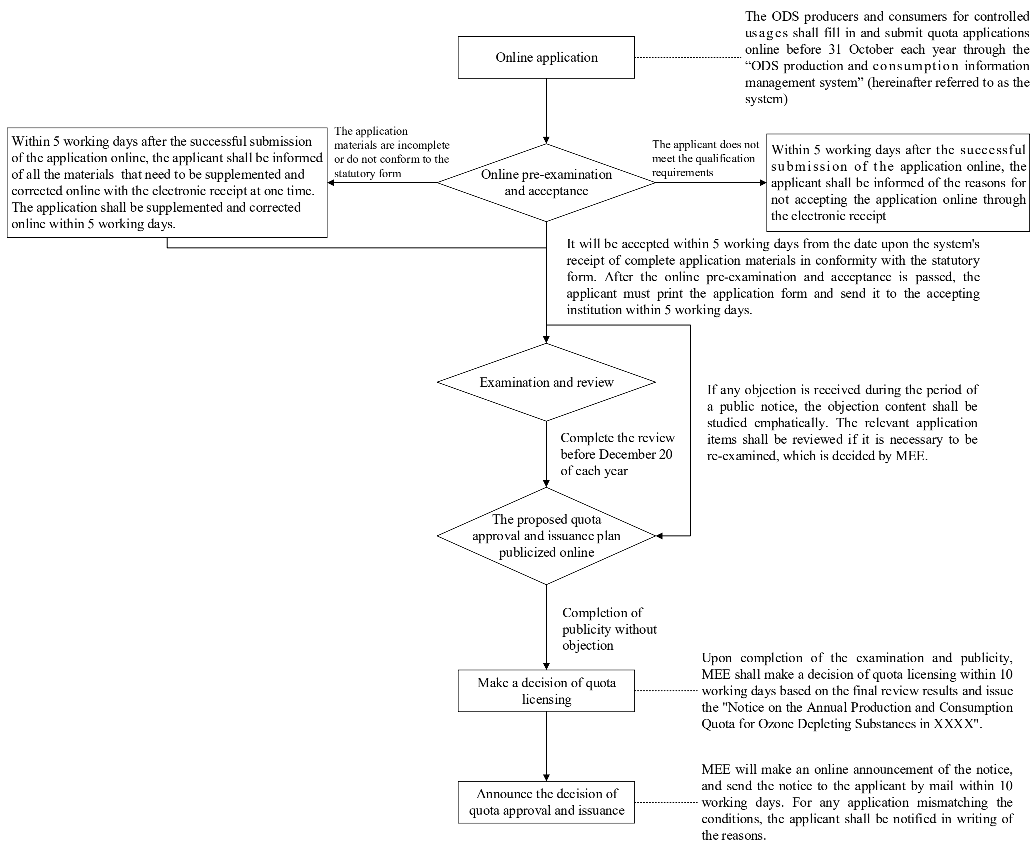

Figure 4.3-1 Flow chart of ODS production and use quota examination and approval

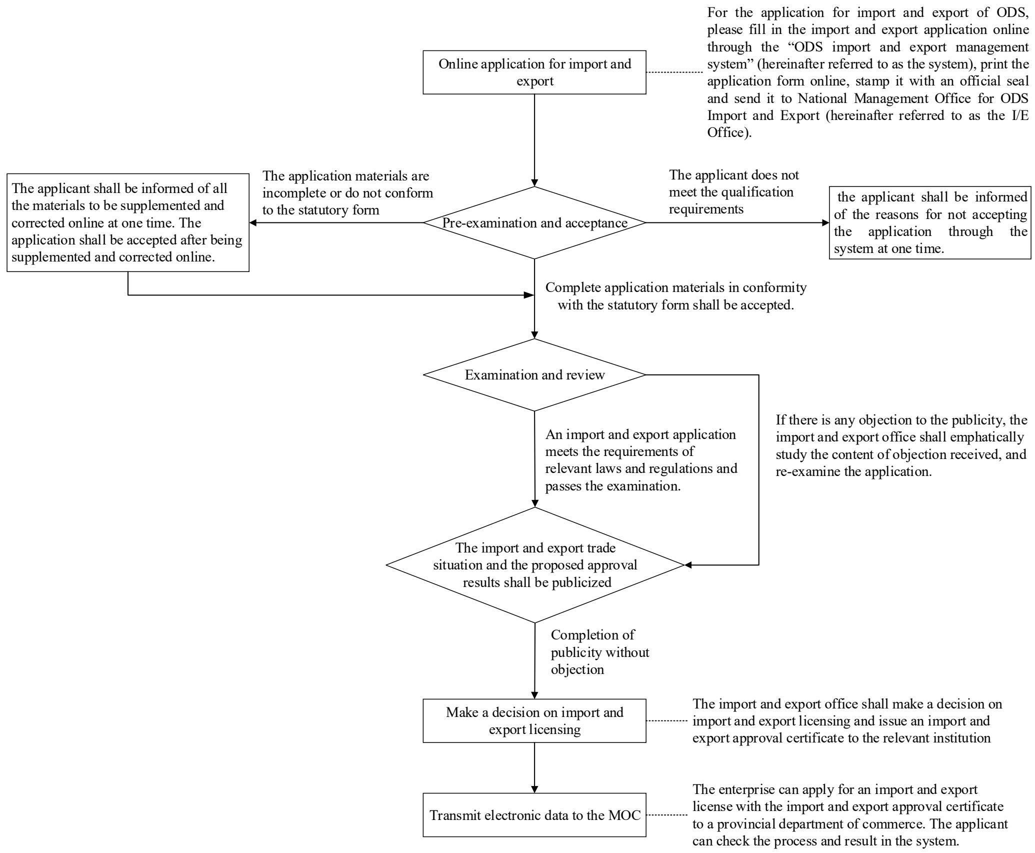

Figure 4.3-2 Flow chart of ODS import and export examination and approval

In terms of local supervision and management operation, the ecology and environment departments within provincial, city and county government are the local executives. Under the current government institutional arrangement, lower level eco-environment department is directly accountable to its higher level eco-environmental department. Among them, provinces, cities and counties have a direct top-to-bottom leadership relationship in ecological and environmental business. They mainly carry out routine ecological and environmental supervision and management including ODS factors. According to supervision and management regulations and national requirements, they're responsible for conducting construction projects supervision and management, import/export supervision and management, production/consumption quota and phase-out progress supervision and management, data reporting management, and eco-environment inspection and enforcement monitoring activities, and so on. In specific, the supervision and management of construction projects is to approve and authorize relevant construction projects based on the scales of the projects; the management of data declaration is to assist cooperate with the MEE in collecting, summarizing and reviewing the data reported by producers/users; the supervision and management of production/consumption quota and phase-out progress is to assist cooperate with MEE in carrying out relevant work; eco-environment inspection and enforcement supervision mainly involves direct enforcement actions, including quota licensing, industry-based phase-out, enforcement of bans, and data reporting. Table 4.3-1 uses Tianjin as an example how local supervision and management is conducted.

The local-level capacity has a significant impact on this operation mechanism for supervision and management. The MEE regularly organizes professional training for local law enforcement personnel, with a focus on ODS-related knowledge and relevant laws, regulations and policies. According to the information collected from government departments, from 2002, the MEE has organized more than 50 training courses for about 6,000 trainees from law enforcement offices. The provincial ecology and environment departments have also organized training courses on ODS control and NP implementation for city or county-level officials and corporate managers. More than 35,000 government officials and more than 13,000 corporate managers have received training. In addition, seminars on ODS control and law enforcement are held annually by MEE to promote communication and exchange of experience among local ecology and environment departments, thereby strengthening the capacity of local ecology and environmental departments in supervision and law enforcement. However, due to the weakness in the aspects of personnel, technology, monitoring and management capabilities at local level, the current lack of capabilities at the local level is still a weak link in the operations of the supervision and management system.

Table 4.3-1 The rules, regulations and supervision and management of Tianjin

Release and targets of Tianjin's local rules and regulations	
Local rules and regulations	Targets
In 2005, Tianjin People's Government issued the "*Notice of Tianjin People's Government on the Implementation Plan for Accelerating the Phase-out of Ozone Depleting Substances*".	The phase-out of CFCs and halon should be completed in the whole city before July 1, 2006; A regulatory system should be established to supervise the use of CFCs in maintenance and other industries which the CFCs is indispensable; It is necessary to seal the existing industrial and commercial refrigeration and central air conditioning units to prevent leakage; CFCs should be recovered when repairing and replenishing refrigerants and discarding large refrigeration equipment.
In 2003, Tianjin Environmental Protection Bureau issued the "*Notice on Strengthening the Management of Production, Sales and consumption of Ozone Depleting Substances*".	It is necessary to strengthen routine supervision and management; A system for project approval, application and registration, quota management, inspection and law enforcement should be established and implemented.

In 2014, Tianjin Environmental Protection Bureau issued the "*Notice on the File and Registration of Enterprises Related to Ozone Depleting Substances*".	It is necessary to publish the list of enterprises filed and registered by the Municipal Environmental Protection Bureau; It is necessary to publish the enterprises that need to be verified by district/county environmental protection bureaus; It is necessary to define the detailed requirements of the above work.

The implementation of national policies in the field of production in Tianjin	
Task	Responsible
According to the national lists of phase-out ODS and substitute products, the CFCs which are phased out in advance in Tianjin and their substitute products should be announced to the society.	Municipal environmental protection bureau
Since January 1, 2006, new CFCs and CTC production projects are prohibited to be built. No new refrigerator, air conditioner and other refrigeration equipment construction projects are permitted to be built with using CFCs refrigerants, and projects are also banned to be built with using CFCs, which is as refrigerants, cleaning agents or foaming agents, and CTC.	Municipal development and reform commission
Before July 1, 2006, all production lines using CFCs cleaning and foaming agents and CTC must switch to the usage of state-published substitute products, and it is prohibited to keep using CFCs cleaning and foaming agents and CTC.	Municipal economic commission and environmental protection bureau
The implementation of national policies in the fields of sales and consumption in Tianjin	
Task	Responsible
Since January 2006, the sales of CFCs refrigerants (cleaning, foaming agents) and CTC should be banned, which should be replaced by those in the list of substitute products issued by Tianjin. It is prohibited to sell or purchase the resident refrigerators, freezers and industrial commercial refrigeration equipment using CFCs refrigerants and the equipment using halon. The sales and storage of CFCs refrigerants for maintenance purposes should be registered with the municipal environmental protection department.	Municipal industrial and commercial bureau
It is forbidden to install the central air-conditioning refrigeration equipment using CFCs refrigerant and the fire-fighting equipment using halon in new large-scale construction projects, which should be included in the project inspection and acceptance.	Municipal construction committee
Pilot projects to phase out CFCs in central air conditioning and industrial and commercial refrigeration equipment.	The municipal environmental protection bureau is responsible for the task, with the coordination of the municipal development and reform commission, municipal

	commerce commission, municipal economic commission and municipal quality supervision bureau.
Enterprises that use CFCs refrigerants for automobile air conditioning, industrial and commercial refrigeration, and air conditioning maintenance in buildings must file with the municipal environmental protection bureau, and they can only engage in business after they are certified to have the CFCs refrigerant charging/recovery capacities.	Industrial and commercial bureau
The sales, storage, maintenance and replacement of CFCs refrigerants should be included in the annual review of enterprises engaged in the maintenance industries of automobile air conditioning, industrial and commercial refrigeration, and construction air conditioning refrigeration. The violators should be rectified, and only after reaching the standards can they pass the annual review.	Transportation bureau, industrial and commercial bureau
Enterprises eligible for dismantling scrapped vehicles must be equipped with and use special refrigerant recovery equipment. In the activity of dismantling scrapped vehicles, the remaining CFCs refrigerants in the vehicle air conditioners must be recovered first.	Municipal economic commission
It is necessary to establish a recycling and storage center for CFCs refrigerants.	The environmental protection bureau is responsible for the task, with the coordination of development and reform commission, construction commission and quality supervision bureau.
The implementation of national quota licensing and file management systems in Tianjin	
Task	Responsible
List of liaison officers for the phase-out of ODS	Each district / county environmental protection bureau
It is necessary to conduct a comprehensive survey of enterprises involved in the production, sale and use of ODS such as HCFCs and methyl bromide in the administrative area.	Each district / county environmental protection bureau
Local quota application, filing and registration should be carried out in accordance with the requirements of the "*Notice on Strengthening the Administration of the Production, Sale and Use of HCFCs*" (Huang Han [2013] No. 179)	Municipal environmental protection bureau, each district / county environmental protection bureau
A system of local supervision, management and enforcement should be established in	

Tianjin	
(1) Organizational structure	
Institutions	Composition and Responsibilities
Leading Group for the Work of Accelerating the Phase-out of ODS	The vice mayor is appointed as the group leader, and the director of the municipal environmental protection bureau and the vice director of the municipal economic committee are appointed as deputy group leaders. Its members include the municipal environmental protection bureau, the municipal economic committee, the municipal development and reform committee, the municipal construction committee, the municipal finance bureau, the municipal quality supervision bureau, the municipal industry and commerce bureau, the municipal public security and fire-fighting bureau, the municipal traffic committee, as well as the municipal commerce committee.
	It should be responsible for implementing international conventions and guiding the completion of obligations for the phase-out of ODS; coordinating the responsibilities among different departments and strengthening joint enforcement.
Office of the Leading Group for the Work of Accelerating the Phase-out of Ozone Depleting Substances	Its office is located in the atmospheric department of the municipal environmental protection bureau. It shall be responsible for routine work, inspecting and supervising the task implementation of accelerating the phase-out of ODS, and reporting the work progress to the leading group on a regular basis.
(2) Source of funds	
The cost of replacing CFCs refrigerants shall be paid by the refrigeration owners. Financial departments at all levels shall support the operational funds needed by the departments of environmental protection, industry and commerce, transportation, construction, quality supervision, public security, development and reform, economy, commerce and so on to carry out their work.	
(3) Work requirements	
It is necessary to put the phase-out of ODS high on the agenda and implement a system of leadership responsibility. Various relevant management departments shall further divide and refine the target and task of its own level and department. Municipal environmental protection bureau shall organize and coordinate the relevant departments, districts and county governments.	
(4) Management requirements	
Fields	Provisions
Replacement of refrigerants in the fields of in-use household refrigeration equipment (air	In-use household refrigeration equipment (refrigerators, freezers, air conditioners) and automobile air conditioners that use CFCs refrigerants can still be used.
	If CFCs refrigerants need to be filled in the maintenance process, CFCs refrigerants recovered in Tianjin shall be used at the maintenance points designated in Tianjin.

conditioners, refrigerators, etc.) and in the maintenance of automotive air conditioners	After the mature alternative products have been certified and announced by the relevant national authorities, the above-mentioned in-use household refrigeration equipment (refrigerators, freezers, air conditioners) and automobile air conditioners that use CFCs refrigerants shall be gradually replaced with alternative products that do not contain CFCs refrigerants during the normal maintenance process.
CFCs refrigerants for maintenance purposes	Since January 2006, any enterprises or individual engaged in the sales and storage of CFCs refrigerants for maintenance purposes must file with the municipal environmental protection bureau in advance, and it can only be carried out after the assessment and confirmation made by the municipal environmental protection bureau.
	Enterprises qualified to sell and store CFCs refrigerants and refrigeration equipment maintenance enterprises must keep detailed records of the sales and use of CFCs refrigerants and report to the municipal environmental protection bureau on a regular basis.
	The municipal environmental protection bureau shall be responsible for organizing the follow-up inspection and technical guidance of the use of CFCs refrigerants for maintenance purposes in the relevant fields, and the relevant results will be disclosed publically and regularly. After the national certification and announcement of mature alternative products, CFCs refrigerants shall not be used any more.
(5) Enforcement requirements	
The municipal construction committee, the municipal environmental protection bureau, the municipal industrial and commercial bureau, the municipal quality supervision bureau and the municipal public security and fire-fighting bureau shall set up hotlines for public reporting, investigate any public report, and provide the findings to the Office of the Leading Group for the Work of Accelerating the Phase-out of ODS.	

4.3.2 Law enforcement mode of supervision and management

In general, there are two modes of law enforcement for ODS supervision and management in China. One is routine law enforcement, on the basis of incorporating ODS supervision and management into the routine regular task of eco-environment inspection and enforcement, and law enforcement divisions carry out enforcement activities in accordance with policies, regulations and plans; the other is special law enforcement, where national or local supervision and management agencies design special law enforcement actions based on the particularity of the enforcement matters as well as relevant policies and regulations, and law enforcement divisions carry out enforcement activities in accordance with the arrangements made by superior departments. In addition, there is supervision and law enforcement on import/export activities.

Routine law enforcement

Routine law enforcement is mainly on-site inspection and enforcement of enterprises involved in the production and use of ODS. The operation team of the inspection and enforcement are composed of law enforcement personnel from the provincial/municipal ecology and environment department and professional staff from atmospheric divisions.

Inspections on the enterprises are generally carried out in random form factors considered in the random inspections mainly include the types of raw and auxiliary materials and products, scale of the company, enterprise’s recent production, enterprise’s history of compliance or violations. Usually the annual plan is made in advance and all activities will be carried out according to the plan.

There are no exact data and information on the frequency of random inspections. According to a small number of interviews with local government supervisors and inspectors, there are significance differences between different provinces and regions, and the inspection frequencies are changing over time and place.

The inspection activities mainly include on-site inspection of the raw and auxiliary materials and products, record review of relevant production processes, original transaction of raw and auxiliary materials and products, interviews with the enterprise’s management and technicians, and collection of ODS-related samples for independent testing. However, prior to 2018, due to limited capabilities of each province on ODS analysis and detection, the frequency of sample collecting was very low. From 2018, the frequency of sample collecting has been greatly improved, but statistical data relevant to the frequency of sample collecting have not yet been obtained. After 2017, the eco-environment law enforcement divisions in key regions such as Hebei, Tianjin, Shandong, and Henan have also been equipped with portable detectors.

Law enforcement based on reported information is also part of regular activities."12369" hotlines for reporting environmental violations have been set up throughout China to receive reports of environmental violations including ODS violations..

Once a violation case is confirmed, the local eco-environment department will impose penalties in accordance with the existing laws and regulations.

Special law enforcement

Special law enforcement is ODS supervision and law enforcement action specially planned and implemented by the MEE and provincial/municipal ecology and environment departments, based on the implementation process, the regional distribution of ODS-related enterprises, and the problems discovered and violations reported. There are national special law enforcement directly organized by the MEE, as well as special law enforcement organized by provincial/municipal ecology and environment departments. It is mainly to conduct on-site inspection and enforcement of enterprises involved in the production and use of ODS. According to different situations, the operation team of inspection and enforcement are composed of government officials and experts from the MEE, and government officials and law enforcement supervisors from the provincial/municipal ecology and environment departments.

The selection of enterprises for inspection varies according to different specific circumstances. Some are nationwide survey of key enterprises; some are regional investigations; some are investigations of reported cases, or simply random inspections; and yet some are for traceability analysis and preventative inspections. Generally, for nationwide and regional inspection, an annual plan and implementation procedures will be prepared in advance, and inspections are thus carried out according to the prescheduled plan and prepared procedures.

According to the limited number of interviews with local government inspection and enforcement personnel, the inspection frequency varies over time and there are great differences between different provinces/regions. In some regions, it's organized and carried once every few years, and yet in other regions, it's several times a year. In general, the frequency was very low prior to 2018, after which the frequency of special inspections from the central to the local level has been increasing. The MEE and local ecological and environmental departments have strengthened joint special law enforcement actions and have maintained a high pressure to crack down on illegal acts.

The inspection approaches mainly include on-site inspection of the raw and auxiliary materials and products, document review of relevant production processes, original transaction records of raw and auxiliary materials and products, interviews with the enterprise's management and technicians, and collection of ODS-related samples for testing. Statistics on the frequency of sample collection and testing have not yet been obtained. It is estimated that the number of samples collected prior to 2018 was very small, but it would be a much bigger after 2018. For example, according to the briefing by the MEE introduced at a regular press conference in August 2018, by August 20, 2018, a total of 1,172 enterprises received on-site inspections by provincial/municipal ecology and environment departments for investigating the production, use and sale of PU foam and combined polyether. According to the briefing by the MEE introduced at a regular press conference in August 2019, since the launch of the special enforcement action, the MEE had directly dispatched 67 person times in 11 working groups to inspect 656 ODS-related enterprises in 11 key provinces and municipalities, including Shandong and Hebei. Portable detectors were equipped to test and screen samples collected from all enterprises that met the sampling conditions, and laboratory follow-up tests were conducted for enterprises with problems in the initial screening test.

According to the briefing by the MEE introduced at a regular press conference in August

2019, the MEE directly organized 16 working groups to carry out on-site inspections on 16 CTC by-product manufacturers nationwide, dispatching 228 person times in total for this special enforcement action. It was required that all 16 CTC by-product manufacturers install CTC online monitoring facilities, and the installation work must be completed by the end of 2019.

For special enforcement actions in and after 2018, the MEE organized 6 training sessions for training a total of 600 staff, and distributed additional 50 ODS portable detectors to 30 provinces and cities. In addition, 8 laboratories qualified for ODS product testing were built by the end of 2019 to provide technical support for NIP implementation enforcement. The provincial ecology and environment departments have also organized numerous activities of law enforcement training. In short, an intensified enforcement and capacity building effort in and after 2018 was reported.

Import and export supervision and enforcement

China implements effective control over ODS import/export through implementing the ODS import/export licensing system and the pre-export prior informed consent mechanism (IPIC). From 2010, with the exception of exempted use, China has no longer issued import/export licenses for the four types of eliminated ODS substances with controlled use, including chlorofluorocarbons.

The GACC of China participated in the "Sky Patching Operation", "Sky Patching Operation II" and "Goddess of the Earth" initiated by the World Customs Organization to combat illegal trade in ODS; during the special operations to combat illegal trading activities organized by the GACC of China, i.e., "National Shield" and "Operation Green Fence", the combat against illegal trade in ODS was included.

According to the information collected from government departments, in order to strengthen the law enforcement capabilities of customs officials, from 2012 to 2018, the MEE and the GACC held 24 training courses in 14 local customs, and trained more than 2,000 customs officials in key areas. In addition, 150 portable detectors were distributed to help local customs officials to conduct effective inspection on the goods. Moreover, local customs have increased the random inspection ratio of ODS and relevant products, and strengthened the supervision on key enterprises and the testing of key products.

4.4 Analysis and evaluation of the effectiveness of China's ODS supervision and management system

4.4.1 Main effects of law enforcement

The effectiveness of law enforcement involves two aspects. The first and most important is the preventive supervision and enforcement inspections to eliminate illegal motives and opportunities; the second is the violation cases detected through law enforcement and their deterrent effect.

The following is a summary of the ODS enforcement cases, based on relevant information released at the regular press conferences of MEE, the progress report of the 83/41 resolution of the 83rdMLFExecutive Committee of the MP, and online news collected by the consultant.

(1) Regular press conference of MEE in October 2018:

"From 2010 to the first half of 2018, China investigated 24 cases of illegal production of ODS, 44 cases of illegal use of ODS, and 5 cases of illegal sale of ODS. Among them, 14 cases involved illegal production of CFC-11. Approximately 84 tons of illegal CFC-11 were destroyed and the production facilities have been dismantled; penalties were imposed on 4 enterprises being charged with illegal use of CFC-11. In August 2018, the MEE organized the ecology and environment departments of all provinces (autonomous regions and municipalities) across China to carry out ODS special enforcement inspections. On the one hand, the special enforcement inspection started from the source and collected extensive information to look for clues to illegal production, and dismantled 2 illegal production facilities of CFC-11 in Liaoning and Henan provinces, and seized 177.6 tons of raw materials and 29.9 tons of illegally produced CFC-11 products. Currently, the above-mentioned raw materials and products have been properly sealed for disposal by qualified enterprises. The persons involved in these two cases have been transferred to the judicial authorities for criminal responsibility. On the other hand, investigation extended to the user end to crack down illegal use of ODS and trace the source of illegal ODS substances. A total of 1,172 relevant enterprises were investigated nationwide, and it was found that in some batches of materials from 10 enterprises, combined polyether is found to contain CFC-11, and the local ecology and environment department have imposed penalties."

(2) The Progress report on the 83/41 resolution of the 83rdMLF Executive Committee of the MP:

In July 2018, the MEE shut down two illegal CFC-11 production facilities in Liaoning and Henan based on tip-offs it received.

"From August to October 2018, the MEE organized various provinces to carry out ODS special enforcement actions, and investigated 1,172 enterprises, and 394 batches of combined polyether were tested using portable fast detectors. Twenty-six inspection teams were dispatched to conduct special inspections in 9 provinces with larger number of ODS production and consumption enterprises. One enterprise's composite polyether was retested by the laboratory and found that the content of CFC-11 in the sample exceeded 0.1%, 0.25 tons of composite polyether was seized and disposed of, and a fine of 100,000 yuan was imposed; 8.96 tons of CFC-11 from another composite polyether enterprise was seized and incinerated and a fine of 208,000 yuan was imposed. Some batches of products from four foam enterprises were retested by the laboratory and found to contain CFC-11. A total of 2.99 tons of combined polyether and 5.32 tons of foam insulation materials were seized and disposed of, and a fine of 1,113,500 yuan was imposed."

"From June to August 2019, the MEE directly dispatched law enforcement officers and local enforcement officers to form a joint enforcement team to conduct special inspections and combined investigations in 11 key provinces and cities including Shandong, Hebei, Henan, Jiangsu, Zhejiang and Guangdong. Among the 656 polyether and PU foam enterprises being investigated, and some batches of products from 322 enterprises have been tested using portable fast detectors, and CFC-11 was found contained in the samples from 37 enterprises (including 6 combined polyether enterprises and 31 foam product enterprises). These samples are currently undergoing laboratory retest." After the retest, it was found that 16 enterprises are engaged in illegal use of CFC-11.

(3) News report by Industry Online (www.chinaiol.com) in 2015:

According to the news release of the website (http://re.chinaiol.com/p/0924/54159651.html), "In response to the re-emerging production of the ozone-depleting substance CFCs in Shandong Province, from 2013, fifteen illegal production sites in 8 cities (Linyi, Tai’an, Yantai, Heze, Liaocheng, Dongying, Zibo and Jinan) were inspected by law enforcement teams, and they were found to be producing the eliminated ODS CFC-11 and/or CFC-12. Among the 5 arrested suspects, 2 criminals have been sentenced. The Shandong Provincial Department of Environmental Protection regularly audits the violation cases that are being investigated and handled, and conducts post-inspection of the cities and counties that have not been thorough in investigating and handling of violation cases, so as to ensure that each case is properly handled to minimize environmental damage."

(4) Government information disclosure by the MEE on its website (www.mee.gov.cn) in April 2020 :

According to the government information disclosure on the website (http://www.mee.gov.cn/xxgk2018/xxgk/xxgk15/202004/t20200427_776487.html), "It is investigated and confirmed that Minghe Company illegally purchased and used 849.5 tons of CFC-11 for producing composite polyether in the past three years. The investigation team successively went to Jiangsu, Henan and Shandong to arrest all 4 suspects involved in the upstream supply of CFC-11, including the suspect Mr. Han.""Mr. Qi, the legal representative of Huzhou Deqing Minghe Insulation Material Co., Ltd., was sentenced to 10 months imprison by the local court for crime of environmental pollution for illegally using CFC-11 to produce polyethers."

Based on the above data and excluding duplicate reports, it can be estimated that 14 cases involving illegal production of CFC-11were investigated and punished during 2010-2018, and 10 enterprises were involved in illegal use of CFC-11. Case reports date back to as early as 2010, including some cases reported in 2013-2015. The above law enforcement case report shows that as of 2010, China has carried out ODS supervision and law enforcement, and carried out continuous supervision and law enforcement operations prior to 2018.Starting in 2018, intensive supervision and law enforcement operations were carried out, and some violation cases were discovered. The quantity of CFC-11 involved was not large, and they were disposed of in a timely manner, and the level of information disclosure was adequate.

Based on the above-discussed law enforcement, it is considered that China's current supervision and law enforcement system is functioning and can be very effective. However, there are issues such as incompetent capability of law enforcement personnel and insufficient detection mechanisms for violation cases, especially inadequate for collecting samples for analysis and testing.

4.4.2 Analysis of illegal production/use cases

Illegal production

Case 1: In July 2018, the MEE shut down an illegal production site in a village in Dandong City, Liaoning Province, based on the tip-offs it received. The illegal production site was hidden in the backyard of a seafood processing workshop. Law enforcement officers found 2 sets of CFC-11 production equipment in the workshop and seized 145 tons of CTC. But no trace of CFC-11 was found, nor did they find any production and sales record. There was no label on the CTC barrels, no clue to trace its origin. The local public security department subsequently set up a special team to investigate, and announced the information on the wanted suspects Mr. Quan and Mr. Zhuang on the Internet. Mr. Quan surrendered under pressure. Later, due to insufficient evidence and considering his surrender behavior, the procuratorate decided not to arrest Mr. Quan. The real operator Mr. Zhuang is still at large. The local authorities imposed administrative penalties on the case, including ordering to stop illegal activities, confiscation of CTC found on the spot, confiscation and destruction of production equipment and facilities, dismantling of the plant, and, a fine of RMB 1 million yuan was imposed. The above administrative penalties have been implemented and the case was closed.

Case 2: In May 2019, the MEE shut down the illegal production site of CFC-11 in a village in Bo'ai County, Henan Province based on the tip-offs it received. Approximately 70 tons of illegally produced CTC, 13 tons of CFC-11, and 2 sets of CFC-11 illegal production equipment were seized on the spot. The capacity of the two reactors was 2.5 and 1.2 m^3 respectively. No production record and records related to CFC-11 sales were found on site. This production started in June 2018, and according to the electricity consumption records provided by the local power supply bureau, a total of about 900 tons of CFC-11 were illegally produced by May 2019. In July 2019, all production equipment and facilities at the illegal production site were dismantled. On January 13, 2020, the Bo'ai County People's Court ruled in accordance with the law: Mr. Ju committed the crime of illegal business operations and was sentenced eight months in prison, plus the confiscation of RMB 84,000 yuan of illegal gains and a fine of RMB 85,000 yuan; Mr. Lu committed the crime of illegal business operations and was sentenced eight months in prison, plus the confiscation of RMB 11,000 yuan of illegal gains and a fine of RMB 12,000 yuan. Two other suspects are still at large.

Case analysis: The above two cases of illegal production of CFC-11 occurred in different provinces, but they have the following same characteristics:

First, these illegal CFC-11 production sites were hidden in relatively remote and economically underdeveloped rural areas. There was no physical environment suitable for these illegal CFC-11 production activities in urban and economically developed rural areas. Although it is not easy to be discovered, constrained by weak power facilities in remote villages and poor traffic conditions, relatively quiet environment, various building restrictions, illegal operations can be easily spotted by passing villagers, thus a large-scale production is not feasible, nor the possibility of long-term production.

Second, the equipment for illegal production of CFC-11 had no or adequate basic normal production process conditions and control measures, the quality of the product was low, the production capacity was very weak, and the production output was small.

Third, the people engaged in illegal production were mostly village and town residents. Since the price of substitutes for CFC-11 is fairly high and the cost of illegal production of CFC-11 is quite low, it can appear to be a big incentive for people in poor economic conditions even though illegal production of CFC-11 is not highly profitable. Moreover, CFC-11 production technology and equipment is easy for non-professionals to operate.

And fourth, although those engaged in illegal production knew it was illegal production, they didn't understand the seriousness of the matter. They even thought that since CFC-11 is not harmful to human health, it's just a minor violation.

Based on the above analysis, it is concluded that there is no large-scale illegal production of CFC-11 except for sporadic existence. Illegal production of CFC-11 looks appealing in terms of economic benefits and easy operation. However, with the spread of the deterrence of ODS illegal production cases, such kind of illegal and highly risky production activity will find no space to survive.

Illegal use

Compared with illegal production of CFC-11, illegal use of CFC-11 is more concealed. According to public news reports, 10 cases of illegal use of CFC-11 have been successively investigated and pun10 cases of illegal use of CFC-11 have been successively investigated and punished during 2010-2018, involving combined polyether and PU foam producers in multiple provinces and municipalities. A case of illegal use of CFC-11 discovered in Huzhou City, Zhejiang Province was sentenced by the local court on March 6, 2020.

Case 3: In July 2019, in a national ODS law enforcement special action, law enforcement officers took a variety of measures and found out that a company in Deqing County, Huzhou City, Zhejiang Province was illegally using CFC-11 to produce combined polyether. After on-site inspection, it was found that warehousing inventory indicates the inflow of raw materials marked as "F11", and some of the formula lists also indicate materials marked as "F11", and a 2 kg reagent bottle of CFC-11 was found in the laboratory refrigerator. The law enforcement officers immediately reported the evidence to the higher-level eco-environmental authority. Under the supervision of relevant departments, the government of Deqing County immediately established a task force and initiated a joint investigation. Public security, procuratorial organization, people’s court, and eco-environment department cooperated closely to conduct investigations. It was found that from September 2017 to May 2019, this company successively purchased 36 batches of CFC-11 from illegal sources in Shaoxing (Zhejiang), Suzhou (Jiangsu), Linyi (Shandong) and Yantai (Shandong), 849.5 tons in total. The raw material was used for producing combined polyether, and about 2,427 tons of products were sold. No effective pollution prevention facilities were adopted during the production process, which had caused direct emission of CFC-11 gas into the atmosphere and resulted in serious pollution of the environment. The amount of illegal profit was at least RMB1.46 million yuan. After the case was heard and ruled by the local people’s court, the company violated the criminal law for using CFC-11 to produce polyethers, and was fined RMB 700,000 yuan and more than RMB 1.4 million yuan of illegal income was confiscated. The legal representative of the company, Mr. Ren, was sentenced to 10 months in prison and fined RMB 50,000 yuan for the crime of environmental pollution. Meanwhile, the upstream CFC-11 supplier Mr. Han and other 3 people were also arrested. This case is the first one in domestic PU foam industry that was sentenced to a real punishment for illegal use of ODS.

Case analysis: Judging from the cases that have been identified, most of these cases are illegal use of CFC-11 to produce combined polyether and PU foam. Due to low industry concentration, such enterprises were often scattered in location and small in scale. The illegal use of CFC-11 during the production process was not easy to discover, which causes a lot of difficulties for the eco-environment authorities in investigation. In particular, it is necessary to equip the law enforcement personnel of the local department of ecology and environment with portable and fast testing equipment and strengthen the testing of relevant products.

4.4.3 Evaluation of the effectiveness of the supervision and management system

Based on the above discussion of the structure and functions, the main content, operation and enforcement, including enforcement case study, the effectiveness of China's ODS supervision and management system is evaluated as follows:

In terms of supervision and management institutions, China has established a two-level system of supervision and management with the State and the local level. In terms of functions, the national-level functions are focused on decision-making, planning and directing, and the local-level functions at implementation and routine enforcement; they are well divided and coordinated to meet the requirements of supervision and management. In terms of the content of supervision and management, it covers each link in ODS life cycle and corresponds to the requirements set by laws and regulations. In terms of the operation mode of the supervision and management system, the division of responsibilities and the cooperation between national-level and local-level authorities have met the requirements for implementing policies and regulations. In terms of enforcement mode, there are both conventional and normative enforcement, as well as more flexible and targeted special enforcement, which reflects both universality and particularity. Through preventive supervision and inspections, the risk of violation case occurrence has been effectively reduced, and a number of violation cases have been investigated and ruled through law enforcement.

The organizational structure are clear, the coverage content meets the policy and regulatory requirements, the inspection and enforcement is effective, and the system is relatively complete and comprehensive..It is concluded that the ODS supervision and management system established by China is in line with national conditions and is basically effective. For decades, it has ensured that the phase-out of ODS production and use has been successfully implemented as planned, and the pre-set goals have been met.

However, there are still some illegal CFC-11production activities in China, which mainly exists in the suburbs or rural areas where the eco-environmental supervision and management is relatively weak. The small-scale production and short duration, as well as the small workshop in hidden place have caused great difficulties to the eco-environmental supervision and management. At the same time, because the illegal production of CFC-11 does not have high requirements on the process technology, and the penalties were not high enough during the past years, some people would like to illegally engage in CFC-11 production activities under the temptation of economic benefits. In terms of illegal use, according to the results of the questionnaire survey, it mainly occurred in the PU foam industry.

Regarding the reasons for illegal production, according to the results of the questionnaire survey, the contributing factors include: regulatory and policy issues, national and local level supervision and reporting channel issues, monitoring technical capabilities, coordination issues between eco-environment and other government departments, technical standard issues, relatively high price of substitutes in the market and their undesirable quality parameters (see Section5.1.1.6 for detailed information), low cost for violations, weak punishment, and low awareness of environmental protection.

According to the questionnaire survey and on-site investigation, the outstanding issues include: low level of professional knowledge and skills mastered by the local ODS-related personnel, insufficient number of inspection and enforcement professionals, inadequate capabilities of local government departments, high cost for the inspection and enforcement by government departments, high cost for producers and users to abide by the law, and low cost for producers and users to break the law.

Comprehensive review of the supervision and management system indicates that there still exist the following deficiencies:

(1) The modern ODS information management system is incomplete

The lack of a comprehensive national ODS information and database platform has resulted in low efficiency of data collection, storage, reporting, verification and analysis; highly dispersed storage of various information, low degree of intelligence; and lack of timely and effective sharing of data and information between the State and local authorities. Thus it is impossible to provide timely and accurate technical and information support for law enforcement.

(2) Local government departments lack adequate professional knowledge, technical and monitoring capabilities, and adequate enforcement powers.

According to the results of the questionnaire survey, some local law enforcement officers do not have a systematic and comprehensive understanding of ODS-related policies, regulations and relevant production technologies, and a small number of law enforcement officers do not have the basic knowledge of ozone layer protection and ozone-depleting substances. In particular, the raw materials of ODS have multiple uses and the production situation is complicated. For the production and use of raw materials, it is necessary to understand the corresponding chemical production process, equipment operation, and production parameters to properly carry out law enforcement, supervision and inspection. Therefore, it’s necessary for experts with relevant professional knowledge to participate in law enforcement.

ODS analysis and detection capabilities are the eyes for accurate law enforcement. Prior to 2018, and even as of today, there is still a lack of necessary ODS testing equipment and monitoring personnel, especially that the basic environmental law enforcement agencies are not equipped with necessary testing equipment. A nationwide atmospheric ODS monitoring system is not established in regions with ODS production and intensive distribution, and there is no standardized data on the concentration of atmospheric ODS in the land area.

(3) The inter-sectoral and cross-regional joint action mechanism for ODS supervision and law enforcement is not yet well established.

At the national level, the MEE, the GACC and other relevant ministries tend to organize the supervision, enforcement and inspection activities of ODS phase-out using various methods such as routine supervision and special enforcement actions. However, the inter-ministerial joint action and cooperation mechanism has not yet well established. There is a lack of traceability analysis on their respective cases, and the sharing of information on confirmed cases lacks timeliness. At the local level, because ODS production, distribution and use is a long industrial chain involving multiple links and multiple players, thus these activities are often cross-regional. Based on previous case study, most of the local supervision and law enforcement work is carried out by provincial and city eco-environmental departments, lacking the strong participation by public security, commerce and other authorities; most of the investigation is concentrated in local jurisdictions, and there is a lack of effective investigation and punishment of cross-regional cases.

(4) Low cost for breaking the law

Currently, for the production of ODS without production quota licensing, the penalty measures stipulated in Article 31 of RAODS are to confiscate raw materials used for illegal production of ODS, confiscate illegal income from illegal production of ODS, dismantle and destroy illegal production ODS equipment and facilities, and impose a fine up to RMB 1 million yuan. For those who use ODS without a quota license, according to Article 32 of RAODS, the penalty measures are to confiscate the illegal raw material ODS, the products produced through illegal use of ODS and the illegal income, and impose a fine up to RMB 200,000 yuan; for cases with serious circumstances, a fine of RMB 500,000 yuan shall be imposed, and the equipment and facilities used for illegal use of ODS shall be dismantled and destroyed. In many cases, compared with illegal profits, the cost for illegal production, especially those with false data, is much lower, and the punishment after the violation is discovered is not adequate, thus the overall cost of violation is low. In addition, the high operational cost for high-density and high-frequency supervision and enforcement by the eco-environmental protection law enforcement agencies further compound and worsen the problem caused by the low costs for violations.

To overcome the above shortcomings, there are still some substantial challenges ahead. For example, the formation of a fast, accurate and low-cost detection mechanism for discovering illegal production and use of ODS is a systematic work, which involves the collection of routine information, automatic analysis and alarm warning; the level of sample analysis and test capability; the design of the public reporting system; and the capacity building for local supervision and law enforcement personnel. Thus, while the establishment of a sound discovery system is critical, it still faces substantial challenges.

5 Qualitative Information and Quantitative Data Evaluation of the ODS Market

Since ratifying the MP and its *London Amendment* in June1991, China has formulated and implemented ODS phase-out activities in accordance with MP requirements. On July 1, 2007, China completely phased-out the production and consumption of CFCs and halons for controlled purposes, fulfilling CFC phase-out as per plan two and a half years ahead of schedule. On January 1, 2010, China fulfilled the task of phasing out production and consumption of four categories of ODS for controlled purposes, including CFCs, halons, CTC and TCA. The phase-out involved primarily industries such as those related to chemical production, household appliances, foaming, precision cleaning, industrial and commercial refrigeration, automobile air conditioning, tobacco, and fire suppression.

Since CFCs were phased out, various industries have adopted and used relevant substitutes. However, as CFC-based products constituted a relatively large and ingrained system of industries and applications with many influencing factors, new challenges are posed on sustained compliance with the MP, subsequent to CFC phase-out. In this Chapter, the potential of illegal production and use of CFC-11 and CFC-12 having occurred over the past 11 years will be evaluated through qualitative and quantitative data analysis of the production and use of CFC substitutes in the market during this period (2008-2018), together with data analysis of possible related raw material or inputs in other production industries and facilities.

CFC-11 was mainly used as a foaming agent for flexible and rigid PU foam, refrigerant for chillers in industrial and commercial refrigeration, as a propellant in aerosols and, as a tobacco fluffing agent. The alternative technology in tobacco fluffing is low-cost and improves product quality, and thus there is no driving force for illegal use of CFC-11, so the following analysis has excluded tobacco fluffing. CFC-12 was mainly used as a foaming agent for extruded polystyrene (XPS) foam, refrigerant for household appliances and industrial and commercial refrigeration, refrigerant for automobile air-conditioning and an aerosol propellant. During 2008-2018, as the foaming agent for XPS had already been effectively replaced by HCFC-22/HCFC-142b with rational price and favorable XPS product quality, and the other non-CFC foaming agents, such as dimethyl ether and CO_2 plus ethyl alcohol, were used in the XPS foam production with lower price and acceptable XPS product quality, there were no drivers for illegal use of CFC-12. The following research does not include the XPS sector.

5.1 Qualitative information and quantitative data evaluation of ODS-related industries

5.1.1 PU foam industry

5.1.1.1 Introduction of the problem

As an industry, the PU foam sector covers a wide range of important areas of the national economy such as buildings, household appliances, the cold chain, refrigeration equipment, large industrial products and basic necessities. PU foam is primarily used for thermal insulation but also as a filler.

At the end of 2007, CFC-11 was completely phased-out in China's PU foam industry, and was correspondingly banned as a foaming agent for PU foam, and CFC-11 based foaming equipment was destroyed (particularly under MLF projects). However, after 2008, due to the habit of using CFC-11 and the inferior thermal insulation performance and production cost of the foam made via substitutes, it is posited that illegal use of CFC-11 could have appeared in this profit-driven market. In order to understand the scale and temporal distribution of such possible illegal use, it is necessary to evaluate the market through the analysis of qualitative information and quantitative data.

5.1.1.2 Polyurethane foam and market applications

Polyurethane is a kind of polymer material produced by reaction between the main raw materials including isocyanate (commonly known as "black material") and polyol polymer (polyether polyol or polyester polyol, commonly known as "white material"). The production of PU foam also requires PU auxiliary agents, such as catalyst, foaming agent, fire retardant, PU foam stabilizer (foam stabilizer), antioxidant, and cross-linking agent, in addition to the isocyanate and polyol polymer. By changing the variety, specification and chemical structure of raw materials and the formula ratio, PU can be made into PU products with various properties.

Of the varieties of PU products, PU foam accounts for the largest proportion. Being porous, it has low relative density. PU foam can be further broken down into rigid PU foam, flexible PU foam and integral skin foam. Currently, ODS foaming agents are used for rigid PU foam and integral skin foam.

In terms of applications, flexible PU foam is mainly used in industries like furniture, automobile, shoe material, toys, basic necessities, packaging and building materials (sound insulation, anti-vibration, decoration and heat insulation); rigid PU foam and integral skin foam are mainly used in refrigerator and freezer, water heater, thermal insulation of pipeline, spray coating of building, plate, filler, cold room, auto parts, furniture parts and other miscellaneous industries.

For more than a decade, China has seen a rising trend in demand for PU foam products. Just by looking at the PU output from 1978 to 2018, China's annual PU output increased from 500 tons to 10 million tons, more than 45% of the total global scale. PU foam has become the most important PU material, making up more than 50% of the total output of PU products.

From the industry distribution aspect, PU foam manufacturing is mainly concentrated in

China's eastern and southern coastal provinces as well as central and western regions with Wuhan and Chongqing as the centers, particularly Shanghai-centered Yangtze River Delta region, Yantai-Tianjin-centered Circum-Bohai Sea region, Guangzhou-centered Pearl River Delta region, Chongqing-centered southwest region and Quanzhou-centered economic zone in Fujian Province.

5.1.1.3 ODS Polyurethane foam and ODS

The connection between PU foam and ODS is that the production of PU foam requires auxiliary agents including foam blowing agents, and certain foam blowing agents have been and are ODS. A prefatory analysis of the potential for illegal production and use of ODS from the perspective of foam blowing agents used for flexible and rigid PU foam follows.

(1) Foaming agents for flexible PU foam

The main raw materials of flexible PU foam include toluene diisocyanate (TDI), polyether polyol or polyester polyol, catalyst, foam stabilizer and the foaming agent.

The basic foam blowing agent for flexible PU foam is water, which reacts with TDI to produce carbon dioxide. Before CFC-11 was phased out, it was used as an auxiliary foaming agent. Around 2000, the flexible PU foam industry took the lead in ceasing the use of CFC-11 and adopting alternative foam blowing technologies.

When the density of flexible PU foam is greater than $21kg/m^3$, only water is used as the foaming agent, and no other auxiliary physical foaming agent is needed. When producing flexible PU foam with lower density, other auxiliary foaming agents will be added.

Alternative technologies for assisted foaming of low-density flexible PU foam include:

(a) Dichloromethane-assisted foaming. This technology uses water as the main foaming agent, produces good-quality products and is at low investment and operation cost. Although it is not an ODS or greenhouse gas, dichloromethane has health risks including causing disease and being a potential carcinogen.

(b) Liquid CO_2-assisted foaming. This technology is based on water as the main foaming agent and liquid CO_2 as the auxiliary foaming agent. Liquid CO_2 is injected into the raw material before or during the mixing, and the CO_2 becomes the foaming agent and carries away heat after gasification.

(c) Variable-pressure foaming technology. This technology uses water as the main foaming agent, requires foaming equipment to be installed in a pressure-controlled environment, and foams under decompression by virtue of the changing relationship between the environment pressure and the volume of the foam.

Since the price of substitutes of assisted foaming is generally low and were even lower than the CFC-11in the pre-phase-out period, the quality of the foaming products is sufficient, the production technology is mature with nearly 20 years of market use, there are no technical or market drivers for the flexible PU foam industry to revert to CFC-11 as the auxiliary foaming agent. Therefore, the possibility of illegal use of CFC-11 in this industry can be completely ruled out.

(2) Foaming agents for rigid PU foam

The main raw materials for the production of rigid PU foam include: polymeric MDI, polyether polyol or polyester polyol, catalyst, foam stabilizer, fire retardant and the foaming agent.

CFC-11 used to be the main foaming agent for rigid PU foam. During and after the phase-out, substitutes and technologies were adopted, primarily HCFC-141b, HC, HFC, HFO, water and methyl formate.

(a) HCFC-141b foaming agent

One of the most mature products to replace CFC-11 in the market was HCFC-141b. It is a direct replacement without requiring additional equipment, and the amount needed to generate the foam with same density and similar physical characteristics is less than that of CFC-11.

However, with ODP and global warming potential (GWP) values of 0.11 and 725 respectively, HCFC-141b is a transitional foaming agent. Therefore, considering the export and future requirements, most large refrigerator manufacturers went directly to hydrocarbon (HC) foam blowing agent when carrying out CFC phase-out before 2000. In accordance with the China HCFC PU foam phase-out plan, HCFC-141b consumption was capped at the baseline level in 2013, then was cut by 17.5% in 2015, 30% in 2018, 45% in 2020 and will be completely phased out in 2026.

Compared to CFC-11, the price of HCFC-141b was higher at about RMB1,1000-22,000/ton from 2008 to 2018, due to the high and increasing price of raw materials as well as the gradual tightening of the annual production quota. In addition, the thermal conductivity coefficient of HCFC-141b products is higher than that of CFC-11, so thicker foam is needed to achieve the same thermal insulation effect. Meanwhile, in order to ensure foam strength, the density of HCFC-141b foam must also be higher than that of CFC-11-based foam.

(b) HC foaming agent

HC foaming agent is composed entirely of carbon and hydrogen. Common PU HC foaming agents mainly include n-pentane, cyclopentane, isopentane, isobutane, and n-butane. The ODP of these foaming agents is zero and GWP is low; far less than that of HFC foaming agents.

HC used as a PU foaming agent is primarily cyclopentane. Notably, rigid foam systems based on cyclopentane has an acceptable product thermal conductivity coefficient (but is slightly higher than that of CFC-11 and HCFC-141b) and anti-aging performance, and it is often used in the refrigerator and freezer, cold store, pipe insulation and building heat insulation board applications. The solubility of cyclopentane in polyether polyol is relatively low, so low-viscosity polyether polyol is generally used. Cyclopentane can be mixed with isopentane to improve fluidity of the foam. In addition, cyclopentane has a higher boiling point. In order to prevent foam collapse, foam density is higher than that of CFC-11 and HCFC-141b.

The mixture of n-pentane and isopentane in different proportions can meet the requirements of different types of foaming. It can also be used as a foaming agent for rigid PU foam if mixed together with cyclopentane, as high-efficiency foaming agent for polystyrene, deasphalting solvent, and solvent of catalysts for polyethylene production.

HC is flammable or explosive, so there are strict requirements for production equipment, plants, transportation and storage, and even higher requirements for enterprise staff in ensuring safe handling and product quality. Thus, there are some limitations of the technology. It is generally suitable for large-scale producing enterprises, while small ones often cannot afford the safety costs. When CFCs were under phase-out, the price of HC foaming agent was relatively high compared to that of CFC-11. With the mass production and widespread application of HC foaming agent however, its cost gradually decreased, particularly in recent years to about RMB 8,000 to 13,000/ton from 2008 to 2018.

(c) HFC foaming agent

HFC compound with an ODP value of zero, is a substitute of both CFC-11 and HCFC-141b. At present, the main varieties for foam blowing include HFC-245fa and HFC-365mfc. These substances have similar characteristics as CFC-11, and their thermal conductivity coefficient is within the same range as HCFC-141b, with extremely low toxicity and good dimensional stability.

Due to the advantages such as non-combustibility, low toxicity, low gas thermal conductivity, and good compatibility with polyols, HFC-245fa can produce rigid foam with good performance and excellent electrical insulation. HFC-245fa is mainly used for the foaming of rigid PU and polyisocyanurate insulating plastic. The GWP of HFC-245fa is 1030, indicating a long atmospheric lifetime.

HFC-365mfc has a high boiling point, flammability, and foaming properties comparable to HFC-245fa. The GWP of HFC-365mfc is 794.

The high price of HFC foaming agent has resulted in limited market sales. In China, HFCs are generally used in combination with HC foaming agent to improve the thermal insulation performance of HC foaming. The price from 2008 to 2018 is about RMB 40,000 to 60,000/ton.

(d) HFO foaming agent

HFO foaming agent has not only zero ODP, but also a very low GWP. This foaming agent is non-inflammable, does not contain volatile organic substances, and has low toxicity. HFO-based foam has excellent mechanical strength, good compatibility with polyol, excellent fluidity and density distribution, so it can meet the various technical and environmental requirements of the PU foaming industry. With a boiling point close to indoor temperatures, it can be easily handled. Since it is non-flammable, the foaming process does not require explosion-proofing. Therefore, HFO is a new generation, ideal alternative foaming agent for CFC, HCFC and HFC foam blowing agents.

With optimization of formula and process parameters, the PU foam produced by HFO foaming agents has a lower thermal conductivity coefficient as compared to the existing HFC-245fa and cyclopentane agents. For example, the thermal conductivity coefficient of refrigerators is reduced by 7-12%, and energy consumption of the complete machine is lowered by 3-7%.

At present, some large refrigerator manufacturers in China have begun to use HFOs to replace HFCs. However, due to the short commercialization period, strict requirements for use of the production technology and high production costs, the resulting costs of HFO products is high. During 2015-2018, the price of HFO-1233zd (E) was about RMB83,000/ton. In recent years, some producers are setting strategic plans on producing HFO foaming agent in China. Many companies however have filed a large amount of patents on this HFO blowing agent application which could result in high prices for a while. In addition, if this foaming agent cannot be produced on a larger scale, it is estimated that the price will remain at a relatively high level.

(e) Water foaming agent

Water foaming is a chemical foaming technology. The principle is that water reacts with isocyanate to produce CO_2, which is left in the foam cells as the foaming agent of foamed plastics. The foam preparation process with all-water-blown foaming is simple and safe. CO_2 has no ODP, is non-toxic and safe; and retrofitting of foaming equipment is not needed. Although the thermal conductivity coefficient of CO_2 based foaming products is high, foamed plastics with tiny cells, smooth surface and low thermal radiation can be produced by adjusting the internal chemical structure of PU and isocyanate. However, there are also many problems in all-water-blown foaming. For example, the higher viscosity of polyol in an all-water-blown foaming process leads to higher foaming pressure and temperature of the foam and because the diffusion rate of CO_2 is fast and the air enters the cells slowly, the dimensional stability of foamed plastics will be affected;

foam products will have a high thermal conductivity coefficient and great brittleness. In addition, the amount of polymeric MDI required when foaming with water is relatively large, so the foam production cost is greatly influenced by the market price of polymeric MDI, which is also one of the factors restricting the wider application of water foaming agent. However, the price of polymeric MDI has been hovering at a low level since 2018, which is conducive to the current application of water-based foaming technology.

In general, water as a foaming agent is only suitable for scenarios under which a low thermal conductivity coefficient is less stringent. When thermal insulation requirement is stringent, water is often used as an auxiliary foaming agent mixed with other alternative foaming agents. At present, all-water-blown foaming agent is mainly used for the production of thermal insulation material for heat supply pipes, filler foam, and solar water heaters which do not have high thermal insulation requirements.

However, other types of foaming agents are usually mixed with water. From this perspective, water, as a foaming agent, has been used in various industries and applications.

(f) Methyl formate foaming agent

Methyl formate is a colorless and aromatic volatile liquid. It is a widely-used solvent with low boiling point and a foaming agent with excellent miscibility, which is compatible with most of the foaming agents, solvents, surfactants and catalysts currently in use.

Very close to HCFC-141b in terms of boiling point and solubility, methyl formate can be used as an HCFC-141b substitute. At the same time, methyl formate has a saturated vapor pressure point that is lower than that of HFC245fa, flammability is lower than that of HC foaming agent, and it has excellent solubility among all PU components, which is conducive to improving the flame retardancy, dimensional stability and compression strength of the foam. Methyl formate is chemically stable but must be kept away from strong acid or alkali.

At present, methyl formate is often used in combination with other foaming agents, and the proportion of its use as the foaming agent is relatively small.

With an ODP of 0 and GWP of less than 1.5, methyl formate is a more environment-friendly foaming agent than most used in the past. However, methyl formate has an obvious swelling effect on rigid PU foam materials, so it is difficult to produce foam with an ideal strength and thermal insulation performance. As implied above, methyl formate is unstable in an acidic or alkaline environment, and is consequently easy to decompose to formic acid and methanol when exposed to water, which seriously affects the foaming process. In recent years, methyl formate has been applied in the rigid PU foam industry in combination with water, HCFC, HFC, HFO and other foaming agents, but the application proportion of methyl formate foaming agent is still comparatively low. From 2015 to 2018, the price of methyl formate is about RMB9000 to 11,000/ton.

(3) Possibility of illegal use and production of foaming agents for rigid PU foam

In fact, the above-mentioned mixed foaming agents are increasingly used in the market, that is, “mixed foaming agents” are used. Many manufacturers have their own special formula for different products, which on the one hand balances the technical defects of a particular foaming agent and on the other hand reduces the overall cost of foam products. In particular, foaming agents such as HFC, HFO, methyl formate and water are often used in such a mixed manner. Therefore, one could surmise that CFC-11, if available could also be used as a component of the mixed foaming agents.

A desk analysis of the technical and economic situation was conducted for various foaming agents from the perspective of technical performance and cost. According to the analysis, the substitutes (except water) for CFC-11 foaming agent of rigid PU foam would be at higher market prices than the cost to make CFC-11, especially HFO which is the ideal substitute but at a much higher cost, while the overall technical performance of the alternative foaming agents (except HFO) is not much better, and some even lower. Therefore per this analysis, there could be incentive for illegal production and use of CFC-11.

The study then proceeded with evaluation through production and market investigation, and, research and analysis of the main raw materials and foaming agents used in rigid PU foam.

5.1.1.4 Applications and rigid PU foam subsectors

With wide applications rigid PU foam can be divided into the following sub-industries, or subsectors if regarded as one industry or sector.

(1) Refrigerator and freezer. It is the largest one among PU foam sub-industries, including household refrigerators and freezers, commercial and medical freezers, display cases, disinfection cabinets and others. The main manufacturing provinces include Guangdong, Zhejiang, Shandong, Jiangsu, Anhui and Henan.

(2) Water heater. This sub-industry mainly consists of electric thermal storage water heaters and solar water heaters, as well as heat pump water heaters and other small household appliances. The main manufacturing provinces include Guangdong, Zhejiang, Shandong, Jiangsu and Yunnan.

(3) Pipe insulation. This sub-industry mainly comprises insulation of heat supply and cooling pipes as well as oil transport pipes. In addition to the low thermal conductivity coefficient, the PU insulating layer also has waterproof and vapor-proof performance, therefore it can reduce the corrosion of the pipeline and prolong the product life. Manufacturers are spread over almost

every province in the north of the Yellow River region, and North China, Northeast China and Northwest regions.

(4) Spray foam. Rigid PU foam spraying is an important PU foam sub-industry. The main functions of spray foam are thermal insulation and water resistance. Spraying is the process during which the polymeric MDI and polyether polyol as main raw materials are subject to the action of auxiliary agents such as foaming agent, catalyst and fire retardant and mixed by special equipment, then the formed mixture is sprayed to the base insulating materials (such as wall) through high pressure, thus realizing on-site foaming and forming a high-molecular polymer. The thermal insulation effect of manual spraying is closely linked to the skill of spray operator. Spray foam is more often applied to walls, and when applied on roofs helps in waterproofing. Its biggest advantage is its mobile operations which can be realized at different sites, although it does make supervision and management more difficult. Therefore, spray foam enterprises are scattered, but mainly in provinces of the Northeast, North, East and in Central China.

Sprayed rigid PU foam has high chemical stability and good thermal insulation, with a thermal conductivity of 0.024W/(m.K). The continuous insulating layer formed through spraying can ensure the integrity of the insulation material and the wall, and effectively block the thermal bridge. Sprayed rigid PU foam has no cavity structure and is strongly wind-resistant. Rigid PU foam firmly adheres to the wall without any joint and cavity, reducing the damage from wind pressure, especially negative pressure, to the exterior wall insulation of high-rise buildings. Its excellent resistance to moisture, heat and water truly integrates the water resistance and thermal insulation into one so that the construction related to these two characteristics can be completed at once. Sprayed rigid PU foam can also serve as a kind of flame-retardant and self-extinguishing material after adding fire retardant. It has good construction performance, which enables quick construction speed and high efficiency, and is especially conducive to reducing the subsequent material loss and improves the construction quality and efficiency for inside and outside corners.

(5) Plate. This sub-industry mainly produces a variety of thermal insulation section steel and plates, used for the thermal insulation of buildings, structures, and equipment. Plate is a standardized material with stable thermal insulation performance and uniform specifications for construction and operations. It is especially suitable for large buildings and flat surfaces, and is adopted by plate production manufacturers engaging in building walls, large cold stores, and prefabricated houses made of PU sandwich panel. These manufacturers are mainly distributed in Shandong, Hebei, Liaoning and Zhejiang.

(6) Cold storage. This refers to the production of refrigeration containers, rooms, and vans. Enterprises of this sub-industry are mostly concentrated in several large conglomerates, such as four companies of the CIMC group and two foreign-owned enterprises, and are highly

concentrated in Jiangsu and Shandong.

(7) Filler. Only rigid foam filler is included in this subsector while flexible foam filler without using polymeric MDI is excluded. This mainly includes filler and reinforcing PU foam used in coal mines as well as filler the inner cavity of theft-proof doors. Its solidified foam elastomer has excellent properties such as adhesion, water resistance, thermal expansion and contraction resistance, heat insulation, sound insulation and even flame retardancy (limited to flame-retardant type). Manufacturers are mainly distributed in Zhejiang, Shandong and Guangdong.

(8) Automobile. There is a wide range of materials used in automobiles. Rigid foam can be used for the inner door panel, roof lining, seat back covers, engine cover, trunk backing plate, spare tire cover and other parts; while integral skin foam can be used for the steering wheel, instrument panel, handle lever, handrail, air filter gasket, switch button, and horn cover. The automotive sub-industry consequently includes rigid foam and integral skin foam of polymeric MDI. Enterprises are widely distributed across East China, Northeast China, South China, North China, South Central China and Southwest China.

(9) Others. In addition to the above applications, rigid PU foam can also be used for the production of synthetic wood materials, insulation board of central air conditioning, insulating layer of industrial equipment, portable insulation box, insulating layer of LNG hulls, spray insulation of fishing boat cabins, vegetation protection, and, as ballast foam fixtures on tracks. Molded high-resilient flexible foam with polymeric MDI has excellent mechanical properties such as high resilience, low hysteresis loss, and foaming with moulds can be done at one time. High resilience molded flexible foam is widely used in auto seats, backrest, headrest, motorcycle seats, bicycle seats, sofa cushions and mattresses.

5.1.1.5 Production and market of polymeric MDI

(1) Reasons for choosing polymeric MDI data as the basis for analysis

As indicated previously, polymeric MDI is commonly known as "black material", and the mixture of polyether polyol or polyester polyol, catalyst, foam stabilizer, fire retardant and foaming agent is commonly known as "white material". Foaming agents involved in this study are only one component of "white material". The composition of "white material" is complicated as involves various ratios, which makes it difficult to obtain statistical data on its production and market. The "black material" only contains polymeric MDI, and the main purpose of polymeric MDI is to produce rigid PU foam and integral skin foam. Therefore, it is a better choice to use the production and amount of consumption of polymeric MDI as the base data for the quantitative mass balance estimates in the PU foam market.

(2) polymeric MDI and its production

The production of polymeric MDI involves two steps, namely synthesis of diphenylmethane diisocyanate (MDI) precursor and production of polymeric MDI through rectification.

In 2008, there were three companies in China engaged in the synthesis of MDI precursor—Wanhua Chemical, Shanghai Lianheng and Shanghai Covestro (then Shanghai Bayer). Their production capacity of synthetic mother liquor was 1.09 million tons/year, and the actual output was 557,000 tons, with an overall operating rate of 52%. In 2018, there were four companies working on synthesis of MDI precursor. In addition to the above three companies, BASF PU Chongqing Company had joined, contributing to a production capacity of synthetic mother liquor of 3.29 million tons per year and an actual annual output of 2.523 million tons, with an overall operating rate of 76.7%.

In 2008, there were five companies engaged in the production of polymeric MDI through rectification - Wanhua Chemical, Covestro (then Bayer), BASF, Huntsman, and Tosoh (then NPU), with a total output of 344,000 tons. Over the years, the output of polymeric MDI has increased year by year. By 2018, the output has increased to 1.624 million tons, with an average annual compound growth rate reaching up to 15%. Among them, Wanhua Chemical is the largest polymeric MDI producer in China, and its polymeric MDI output exceeds half of China's total output.

(4) Consumption of polymeric MDI

Consumption = Output + Import volume-Export volume

The import and export volume of polymeric MDI is obtained according to the statistics of the GACC.

From 2008 to 2018, China's import volume of polymeric MDI was relatively stable, averaging from 100,000 to 300,000 tons per year. The export volume has been increasing year by year. The export volume was 71,000 tons in 2008, and reached 616,000 tons in 2018, realizing an 8-fold growth in 11 years. China has transformed from a net importer to a net exporter of polymeric MDI. The production capacity of Chinese polymeric MDI manufacturers has expanded rapidly, and the export volume has equally rapidly increased.

According to market statistics, the amount of consumption of polymeric MDI in China is also increasing year by year. It was 550,000 tons in 2008 and 1.239 million tons in 2018. In 11 years, it has increased by 1.2 times (amount of consumption in 2018 is 2.2 times that in 2008), and the average compound annual growth rate is 7.6%, comparable to China's GDP growth rate during the same period.

Table 5.1-1 Statistics of output and total consumption of China's polymeric MDI

Year		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
China's polymeric MDI output (10,000 tons)		34.4	55.6	65.8	81.7	95.1	105.2	116.4	122.6	130.3	156.2	162.4
polymeric MDI import volume (10,000 tons)	Import volume	28.7	26.2	32.6	29.1	22.3	35.2	31.8	26.6	21.1	23.3	31.7
	Import volume excluding crude MDI	27.7	21.7	28.3	23.3	15.9	26.3	24.1	20.1	14.5	15.0	23.1
Export volume of polymeric MDI (excluding crude MDI export) (10,000 tons)		7.1	13.3	17.1	19.2	21.9	22.9	33.9	38.2	42.4	56.2	61.6
Amount of consumption (10,000 tons)		55.0	64.0	76.9	85.8	89.0	108.5	106.5	104.5	102.4	115.0	123.9

5.1.1.6 Production and market of the foaming agent of rigid PU foam

(1) HCFC-141b foaming agent

(a) Production and import and export conditions

In October 2009, the former Ministry of Environmental Protection issued the *Notice on Strictly Controlling Newly-built HCFCs Production Facilities*, stipulating that, except for special purposes, no new HCFC production facilities shall be built or used in China. In 2013, all HCFC producers must hold production quota licenses. Enterprises that use more than 100 tons for controlled purposes must also hold HCFCs quota licenses, and production and use must be managed within the quota. The former Ministry of Environmental Protection determined the total annual production and usage quota amount and allocation plan based on the phase-out plan.

From 2008 to 2012, China's HCFC-141b output for controlled purposes increased steadily, reaching 117,131 tons by 2012. Since 2013, the production of HCFC-141b in China has all been subject to quota management, and the output of HCFC-141b for controlled purposes has begun to decline. In 2015, Hangzhou Fushite Chemical Co., Ltd. dismantled its production line that had an annual output of 15,000 tons of HCFC-141b. Output of HCFC-141b for controlled purposes was therefore sharply reduced to 65,877 tons. From 2015 to 2018, the output of Zhejiang Juhua, CHANGSHU 3F, Zhejiang Sanmei, and Zibo Luxuan continued to decrease based on quotas. In 2018, China's HCFC-141b production output for controlled purposes was 57,465 tons.

After 2008, China’s import volume of HCFC-141b was very small and after 2011, there was no import volume at all, while the export volume has been relatively large. The export volume was basically maintained at more than 40% of the output before 2016. Since 2017, it was reduced to about 38%. The output and import & export volume from 2008 to 2018 are shown in Table 5.1-3.

(b) Market conditions

HCFC-141b in China is mainly consumed in the PU foam sector. There is a small amount of consumption in the field of cleaning and aerosol sprays, but it only accounts for about 7-10% of the total amount of consumption. So the following section discusses only the market conditions related to the PU foam sector.

From 2008 to 2013, the continuous development of the industry, the increasing fierce market competition and the steady improvement of domestic technologies all contributed to a continuous decline in the price of HCFC-141b. The price of HCFC-141b in 2008 was RMB 16,700/ton and RMB 10,400/ton in 2013. In 2013, China began to implement a production quota system for HCFC-141b produced. With the reduction of the issued production quota, domestic HCFC-141b production has shrunk, and product prices have begun to rise. In 2015, with the tightening of the national environmental protection policy, the production cost of HCFC-141b increased. When

Hangzhou Fushite Chemical Co., Ltd., dismantled its production line, this led to a tightened market supply and a rise in the price of HCFC-141b. In 2016, the price of domestic HCFC-141b products spiked from RMB 12,900/ton in 2015 to RMB 19,100/ton. Since 2018, the country has further tightened its environmental protection policies and shrunken the HCFC-141b production quotas, which has increased the price of HCFC-141b, and caused a more prominent contradiction between supply and demand. In 2018, the price of HCFC-141b products reached RMB 21,800/ton.

Figure 5.1-1 China's HCFC-141b product price trend from 2008 to 2018

After CFC-11 was phased out, HCFC-141b was widely used as a foaming agent in various sub-sectors of rigid PU foam. In recent years, HCFC-141b was phased out in the subsectors of refrigerators and freezers, refrigerated containers and electric water heaters. In October 2018, the MEE issued the *Announcement on Prohibiting the Production of Refrigerator Freezer Products, Refrigerated Container Products, and Electric Water Heater Products With Monofluorodichloroethane (HCFC-141b) as the Foaming Agent*. The Announcement specifies that no enterprise may use HCFC-141b as the foaming agent to produce refrigerator and freezer products, refrigerated container products, and electric water heater products as of January 1, 2019.

Overall, from 2008 to 2018, HCFC-141b products were widely used in refrigerators and freezers, water heaters, pipe insulation, spray coating of buildings, plates, filler, cold store, automobiles and other miscellaneous industries. By 2018, HCFC-141b was less prominent in refrigerators and freezers, refrigerated containers, electric water heaters and other applications, but mainly applied in areas where other foam blowing agents were not commercially viable or popular, such as plate, pipe insulation, and spray foam. From 2008 to 2018, the demand for HCFC-141b for refrigerators and freezers and water heaters has declined. Although large scale factories have already begun to use HC foaming agent, small factories, especially small freezer manufacturers have had more difficulty to obtain safety permits for the use of HC foaming agents. Nevertheless, they entered into the final period of HCFC-141b use in 2018, pending effectiveness of the ban. The demand for HCFC-141b in spray foam in building, for panels, and refrigerated containers has fluctuated based on market changes, but there is no obvious trend towards reduced demand for HCFC-141b. Because water is used more as a foaming agent for pipeline insulation and filler, the demand for HCFC-141b is relatively small, but some demand remains. Automotive and other miscellaneous industries also account for a relatively small proportion of demand, but demand remains despite some fluctuation based on market changes.

The amount of consumption of HCFC-141b in the rigid PU foam market in 2008-2018, is shown in Table 5.1-3 and Figure 5.1-2.

Table 5.1-2 Output, import and export volume and consumption amount of HCFC-141b Unit: ton

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Output	81298.00	91879.88	98857.06	111922.30	117131.30	87123.91	86911.31	65876.85	66165.38	64334.49	57464.81
Import volume	32.00	3.86	0.00	10.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Export volume	41191.00	41561.19	42176.27	43600.15	53267.38	36113.58	35063.53	27292.5	27021.23	24295.73	19408.07
Consumption amount	40139.00	50322.54	56680.79	68332.25	63863.94	51010.33	51847.78	38584.35	39144.15	40038.76	38056.74
PU foam consumption amount	38100.00	45971.00	52068.79	63570.24	59108.94	46338.49	46863.67	34201.81	34821.19	36438.76	34176.74

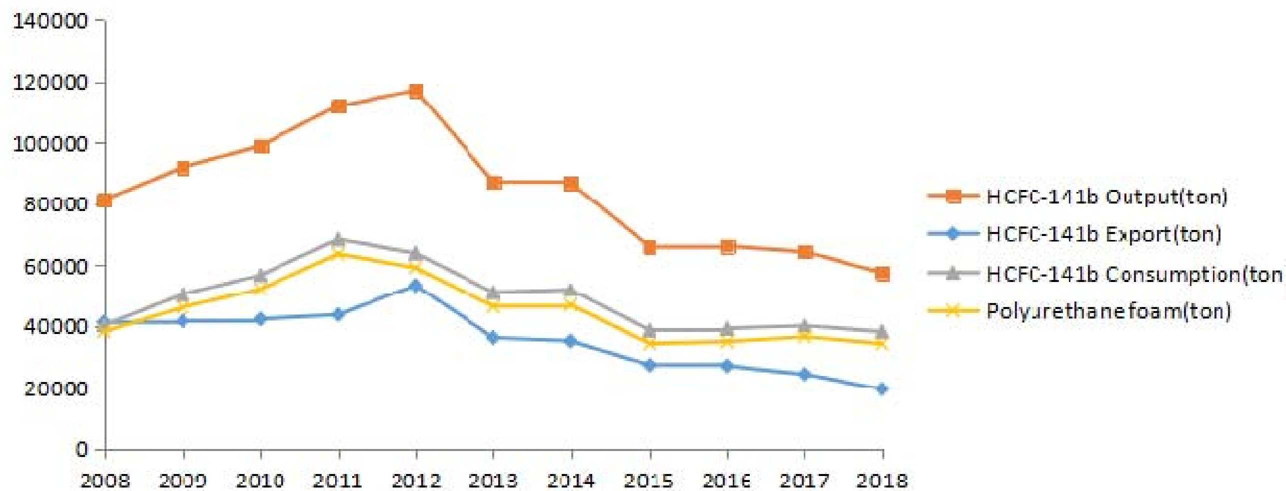

Figure 5.1-2 Output and export volume of HCFC-141b and consumption amount of PU foam from 2008 to 2018

(2) HC foaming agent

(a) Production conditions

2008-2018 was a period when the market demand for HC foaming agent in China continuously rose. During this period, the production capacity of the industry continued to expand and the output rose steadily. The growth rate was relatively stable. The annual output increased about 5,000 tons in average compared with that in the previous year, with the average annual output growth rate of about 11.5%. In 2013, the output of HC foaming agent was 23,200 tons; in 2018, the output of HC foam blowing agent was 76,300 tons.

(b) Market conditions

The price of HC as a foaming agent is affected by many factors such as the production cost, and market supply and demand, but production cost is the most important factor.

From 2008 to 2010, due to an underdeveloped industry, where enterprises were relatively limited in number with relatively backward technologies and low production efficiency, HC prices were high in face of a continuous growth trend. In 2010, the price of HC foaming agent was RMB 12,900/ton.

From 2011 to 2015, following development of the overall HC industry, the industry for producing HC as a foam blowing agent also improved. Great progress was made in technology and production. The number of companies has continued to increase, and market competition has become increasingly fierce, resulting in a constant drop of prices. In 2015, the price of HC foaming agent was RMB 8,000/ton. After 2015, China's environmental protection policies became stricter, and the chemical industry was the first to bear the brunt and become the major subject of environmental protection controls, causing the price of products including HC foaming agents to ascend again. In 2018, the price of HC foaming agent products reached RMB 11,200/ton.

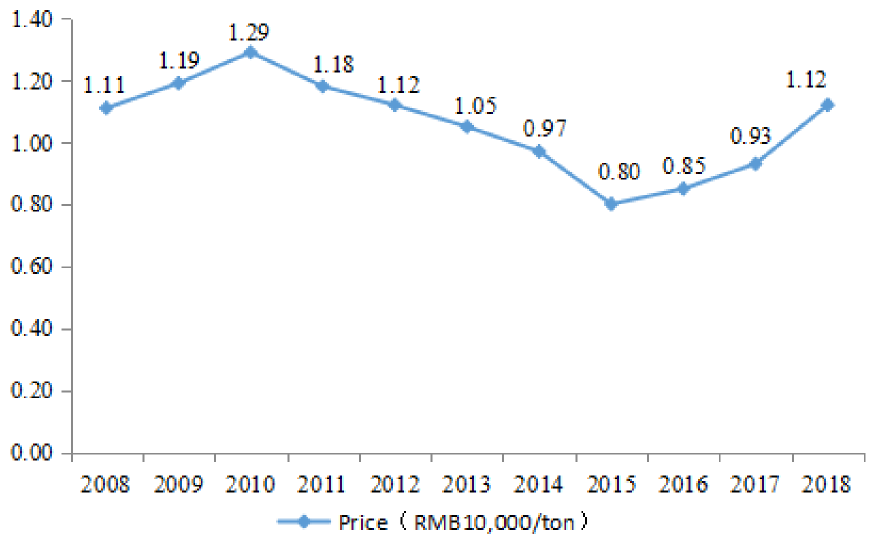

Figure 5.1-3 China's HC foaming agent products' price trend from 2008 to 2018

In China, HC foaming agent products are mainly used in refrigerators and freezers, cold store, electric water heaters and other applications, as well as in plates, pipe insulation, automobiles and other various fields. From 2008 to 2018, the demand for HC foaming agent for refrigerators and freezers has maintained a relatively large market proportion, and refrigerated containers, electric water heaters, pipe insulation, plates, automobiles and other sub-sectors also have demand for HC. Due to characteristics of environmentally-friendly, good technical performance and cost-effective, large PU foam companies will generally consider using it. However, due to safety concerns, many small PU foam factories must forego HC foaming agent, not able to meet the necessary safety standards. HC foaming agent is barely used in spray foam, filler and other industries for similar reasons of safety and related costs and capacity requirements.

(3) HFC foaming agent

(a) Production conditions

At still a relatively small market scale, China's HFCs industry has developed late, and has mainly relied on imports to meet demand in the early stages. In 2014, an HFC-245fa production line with capacity of 12,000 tons was established and put into operation by Sinochem Lantian Honeywell New Materials Co., Ltd., which has stimulated the development of China's HFCs industry.

From 2008 to 2018, China's HFCs industry was in development, shifting from import to independent production. From 2008 to 2014, due to technical limitations, the production capacity of China's HFC foaming agent industry was relatively low, and only a small amount of HFC-245fa could be produced. In 2014, the output of HFCs was 3,500 tons.

In October 2014, with the HFC-245fa production line established by Sinochem Lantian Honeywell New Materials Co., Ltd. officially in operation, coupled with technological breakthroughs, the HFC foaming agent industry in China saw continuous growth in a number of companies – both in production capacity and output. In 2015 the output of HFC foaming agent was 12,300 tons and grew to 23,100 tons in 2018, with the number of HFC-245fa suppliers increasing to three. In addition, China imported and continues to import hundreds of tons of foaming agents such as HFC-365mfc and 227ea each year.

(b) Market conditions

The price of HFC foaming agent products is affected by many factors such as production cost, market supply and demand, and raw material inputs, among which production cost and inputs are the most significant.

From 2008 to 2014, HCFC-141b in China featured relatively sufficient in supply at a relatively low price, and the demand for HFC foaming agent was small. With the increasingly fierce competition and the improvement of technologies, the price of HFC foaming agents showed a declining trend with some fluctuation. In 2014, the price of HFC foaming agent products was RMB 29,400/ton.

From 2015 to 2018, with the tightening supply of HCFC-141b, the demand for HFC-245fa products increased rapidly, and the product prices were relatively higher, pushing up the average price level of the HFC foaming agent industry. In addition, with the tightening of environmental protection policies, the enterprise production costs have also risen, and their prices had shown an upward trend. In 2018, the price of HFC foaming agent was RMB 60,000/ton.

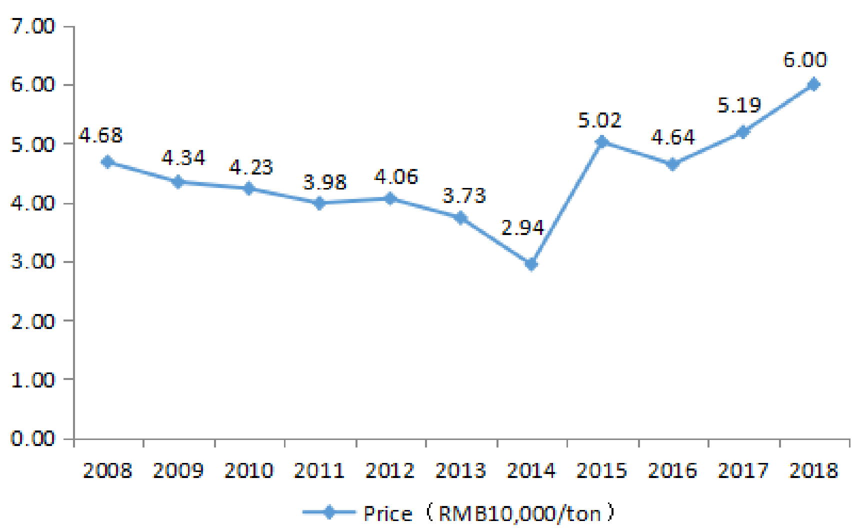

Figure 5.1-4 China's HFC foaming agent price trend from 2008 to 2018

In terms of the overall scale of China's HFC foaming agent market, the market value of the HFC foaming agent industry in 2008 was RMB 61 million but growing. In 2014, affected by the decline in product prices, the HFC foaming agent industry suffered negative growth, but retained a market size of RMB267 million. In 2015 driven by the production at the first HFC-245fa facility in China, the share of HFC-245fa products in the HFC foaming agent market increased rapidly, which in turn, caused the average price of HFC foaming agents to rise sharply. This resulted in an explosion of the HFC market with it reaching RMB677 million and an annual growth rate of 153.6% (the highest level in recent years). Since that time, the HFC foaming agent production industry has maintained high growth with the value of the HFC-245 market in China reaching RMB925 million as of 2018.

HFC products are considered to be the ideal substitute for HCFC-141b, but due to their high GWP, neither the MP nor the Chinese government promote this ODS substitute. In addition, because they are more expensive than HCFC-141b and HC foaming agents, HFC-based applications in China's foam industry is restricted. Downstream applications of HFC foaming agents are limited mainly to insulation for refrigerators and freezers, refrigerated containers, electric water heaters, and other niche applications. They are mixed with HC foaming agent to improve product insulation performance. There is also some demand for solar water heaters, panels, automobiles, spray coating and other sub-sectors with high-end applications. However, there is very little demand in sub-sectors such as pipe insulation and filler.

The level of HFC consumption in rigid PU foam between 2008 and 2018 is shown in Table 5.1-3.

(4) HFO foaming agent

(a) Production conditions

At present, the main HFO foaming agent used for rigid PU foam on the market is mainly HFO-1233zd (E), and the trade name given by the manufacturer, Honeywell is Solstice® LBA. In the second half of 2014, Honeywell's Solstice® LBA production facility in the United States was put into production. On September 15, 2014, DuPont's fluorine chemical business unit announced that it would start the large-scale commercial production of the similar, HFO-1336mzz in a factory in China by the second half of 2016. At present, there is no news of the status of production.

(b) Market conditions

Compared with HCFC-141b, HFC-134a, HFC-245fa and other products, HFO-1233zd (E) products have a shorter commercialization time, higher production cost, and consequently a higher price. In recent years, with the increase in demand for HFO-1233zd (E), the price of HFO-1233zd (E) products has dropped slightly. Among them, the 2018 price of China's HFO-1233zd (E) was

RMB 82,900/ton.

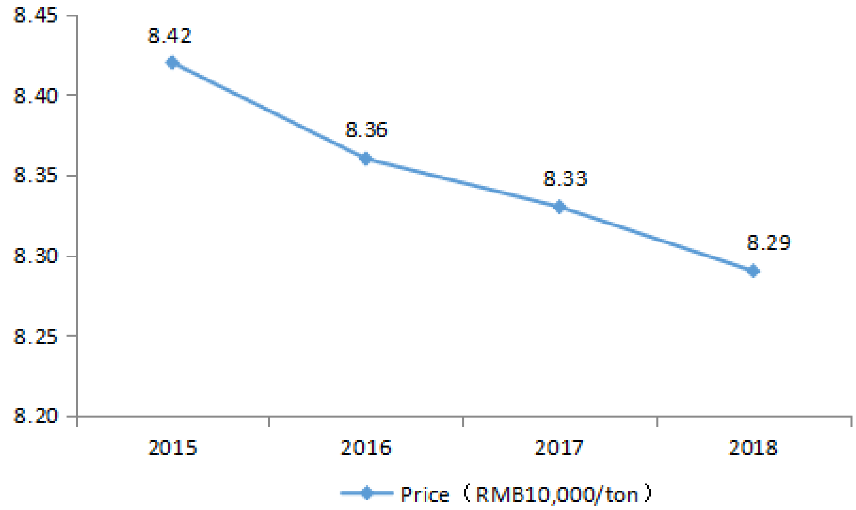

Figure 5.1-5 China's HFO-1233zd (E) price trend from 2015 to 2018

HFO-1233zd (E) is mainly used in the household appliances subsector, and the main domestic home appliance companies have praised it for improving energy efficiency performance. Since 2015, Haier, Midea, Hisense and other large Chinese household appliances companies have begun to apply HFO-1233zd (E) in larger quantities, which has promoted the expansion of the HFO-1233zd (E) market in China. However, compared with other foaming agent products, HFO-1233zd (E) currently has a high price, resulting in a smaller market size. The main applications of HFO-1233zd (E) in China are at large household appliance companies, with relatively few uses in other subsectors. In 2018, the China's market size of HFO-1233zd (E) was RMB158 million.

HFO-1233zd (E) is a new chemical product. In the process of global promotion, patent registration needs to be completed according to the regulations of various countries and regions, which involves a huge cost. At present, there are as many as 14 home appliance companies (including Whirlpool in the United States, Haier, Midea and Hisense in China, and Fisher&Paykel in New Zealand) and as many as 20 white material, spray coating and plate manufacturing companies in the world that are applying the HFO for commercial purposes.

The consumption amount of HFO foaming agent used in rigid PU foam in the market from 2008 to 2018 is shown in Table 5.1-3.

(5) Water foaming agent

(a) Production conditions

Water is a kind of chemical foaming agent but has no special chemical requirements.

Therefore, its production and supply are sufficient and inexpensive. Water works two ways as a foaming agent. The first is in all-water-blown foaming, that is, mainly or completely using water as the foaming agent; the second is application of water as a mixed foaming agent, that is, there will be different levels of water content in the white material. Whether intentionally or unintentionally, water will act as a foaming agent when it reacts with polymeric MDI.

(b) Market conditions

Generally, water as a foaming agent is only suitable for circumstances where the requirement for thermal conductivity is not very strict, and it is often used as an auxiliary foaming agent in combination with other physical foaming agents. Water foaming agents are being applied in various sub-sectors, mainly in the production of heating and cooling pipe insulation material, automobiles, filler, solar water heaters, and plates. Pipe insulation, automobile, and filler applications account for the highest proportion of use. Since water exists in almost all white material, various sub-sectors will also occasionally use water as a foaming agent.

The level of consumption of water foaming agents in rigid PU foam in 2008-2018 is shown in Table 5.1-3.

(6) Methyl formate foaming agent

(a) Production conditions

Methyl formate is a basic chemical and mature production technology with a wide range of applications. Its use as a foaming agent for rigid PU foam accounts for only 1%-3% of its total demand. All Chinese companies producing methyl formate can supply this product but methyl formate has a low market penetration for PU foam. Due to the low demand, market competition among methyl formate manufacturers is relatively low.

In serving as a foaming agent, methyl formate's consumption varies with the change in demand. From 2008 to 2018, the demand for methyl formate foaming agent in China showed fluctuation, which in turn led to a fluctuation in its consumption levels. The amount of methyl formate used in 2008 was 324 tons, which dropped to 250 tons in 2014 but increased to 348 tons in 2018.

(b) Market conditions

From 2008 to 2018, methyl formate prices fluctuated according to raw material price fluctuations, changes in market supply and demand, market competition, and environmental protection policies. The price of methyl formate in 2008 was RMB9,700/ton; from 2015 to 2018, due to the impact of environmental protection policy, the production cost of methyl formate rose slightly to RMB11,100/ton by 2018.

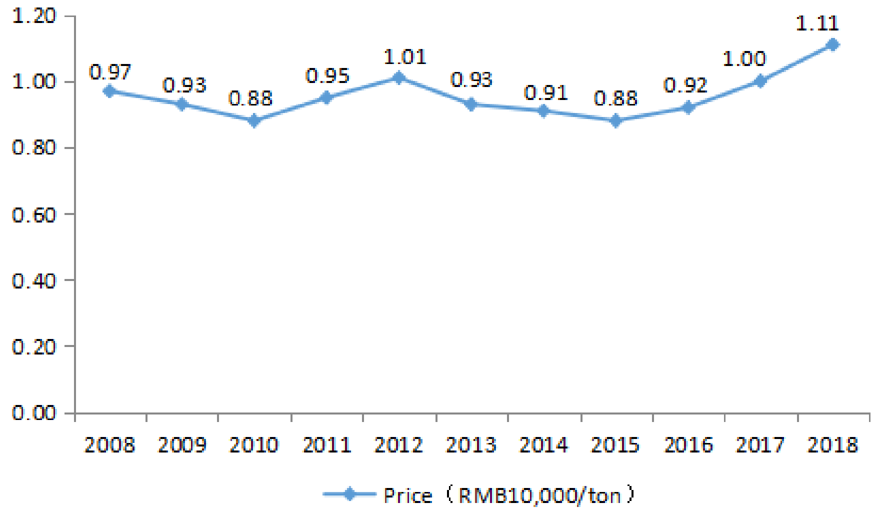

Figure 5.1-6 Price trend of methyl formate from 2015 to 2018

From 2008 to 2014, methyl formate was only used for experiments in the PU foam industry; from 2015 to 2018, with some new application of the technology by mixing methyl formate with other foaming agents, the demand for methyl formate foaming agent increased, and its market scale also expanded to some extent. The market size of methyl formate foaming agent in China in 2008 and 2018 was RMB3.07 million and RMB3.68 million, respectively.

Methyl formate is now mostly applied in combination with other foaming agents. Although there is a lot of research on the mixing of methyl formate with other foaming agents in China, there are few commercial products. Because of its mixed use with other foaming agents, methyl formate applications are relatively dispersed, and the proportion of each sub-sector's demand is relatively even and responsive to market demand.

The amount of methyl formate used in rigid PU foam on the market from 2008 to 2018, is shown in Table 5.1-3.

(7) CFC-11 foaming agent

Before the phase-out of CFC-11 in 2007, it was used as the main foaming agent for rigid PU foam, and it still ranks at the top among foaming agents in terms of technical performance. In2005, its market price range was about RMB 8,000-12,000/ton. The main raw materials for the production of CFC-11 are CTC and Anhydrous Hydrofluoric Acid (AHF), whose prices are not high. Particularly, CTC, as an inevitable co-product of methane chloride production, will not increase rapidly in its price. In comparison, the average price of HCFC-141b from 2008 to 2010 was RMB 15,300/ton. Considering that now, the cost of CFC would exclude tax, would entail poor and inexpensive production equipment, and there is no quality control nor EHS measures for the illegal production, the price of illegal CFC-11 would be relatively low.

Table 5.1-3 Market survey statistics of foaming agent consumption levels

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HCFC-141b consumption amount (10,000 tons)	3.81	4.60	5.21	6.36	5.91	4.63	4.69	3.42	3.48	3.64	3.42
HC consumption amount (10,000 tons)	2.05	2.43	2.81	3.29	3.99	4.81	4.86	5.22	5.60	5.90	6.48
HFC consumption amount (10,000 tons)	0.09	0.11	0.15	0.21	0.47	0.71	0.82	1.05	1.42	1.65	1.54
HFO consumption amount (10,000 tons)	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.13	0.16	0.17	0.19
Water consumption amount (10,000 tons)	0.27	0.29	0.32	0.34	0.35	0.59	0.60	0.65	0.72	0.75	0.78
Consumption amount of methyl formate and other products (tons)	346	363	371	368	332	324	272	289	317	334	379

Note: HCFC-141b, HC (cyclopentane, etc.), HFC, HFO, methyl formate and other foaming agent data are mainly obtained through historical data collection, enterprise database data collation, and production enterprise surveys. Water consumption is obtained through historical data collection and estimation of the output of PU products produced by water foaming agents.

5.1.1.7 Production and consumption balance model for rigid PU foam

(1) Development of the Model

In the production of rigid PU foam, according to process requirements, the ratio of black material to white material and the proportion of various foaming agents in white material are relatively consistent. In refrigerators and freezers, water heaters, pipe insulation, spray coating, plates, cold store, filler, automobiles and other sub-sectors, the application proportions of the foaming agents HCFC-141b, HC, HFC, HFO, water and methyl formate also have obvious characteristics and relationships. According to the relationship of these process parameters, matrix analysis can be used to establish a mathematical model with regard to the balance of the black material and foaming agent material.

As polymeric MDI has a high production threshold and limited large-scale manufacturers, its market consumption statistics are relatively accurate. Using polymeric MDI data as the base data, the corresponding balance quantity of the foaming agent can be calculated through the above-mentioned material balance mathematical model. Comparing this MDI quantity with the market research statistics of foaming agents, it can be known whether there are other potential foaming agents in the market, other than those known to exist through data. The roadmap for material balance calculations is shown in Figure 5.1-7.

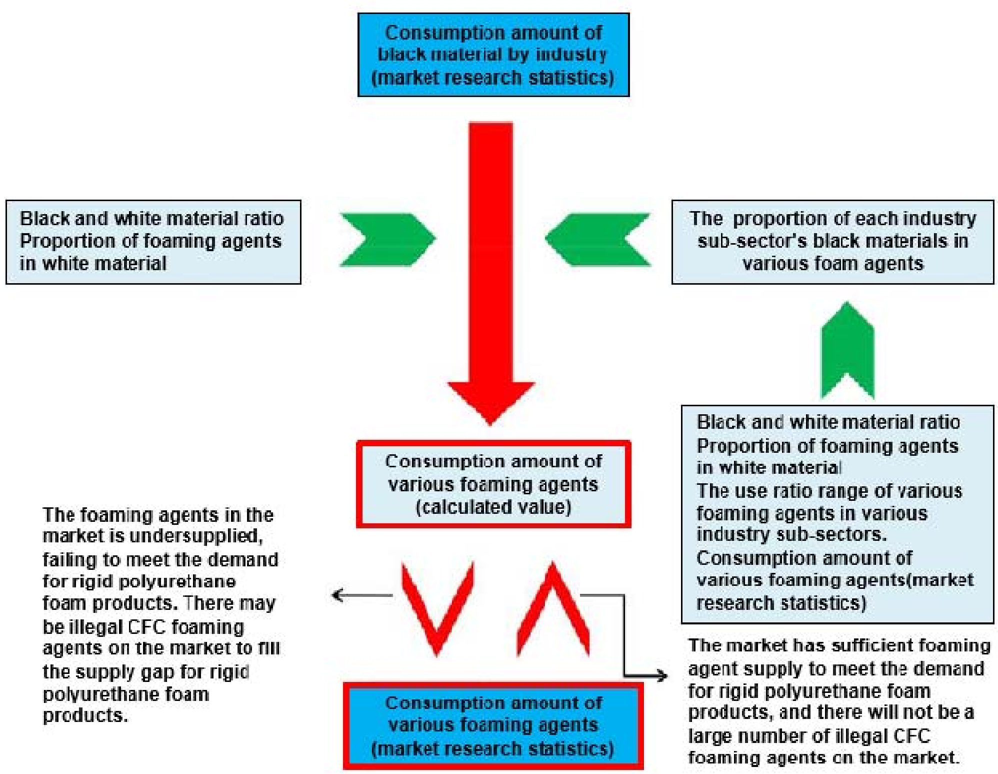

Figure 5.1-7 Roadmap for material balance calculation of rigid PU foam

(2) Material balance calculation methodology for rigid PU foam

(a) First, use the ratio of black and white materials, the proportion of foaming agents in white materials, the use ratio range of various foaming agents in various industry sub-sectors, and the proportions of various foaming agents' consumption amounts to estimate the proportion of the black material in various sub-industries and various foaming agents.

(b) Then, the consumption of various foaming agents in each sub-industry and total consumption of various foaming agents are calculated according to statistical data of black materials from the market survey and the proportional relationship acquired from (a).

(c) Compare the total amount of various foaming agents every year acquired from the calculations and the total consumption amount acquired from market statistics.

If the calculated value is less than or equal to the market statistical value, it indicates that the quantity of normal foaming agents on the market is sufficient to fully meet the demand for rigid PU foam products, and it would not be possible to have a significant amount of illegal CFC-11in the market.

If the calculated value is greater than the market statistical value, it means that the supply of normal foaming agents on the market is insufficient and cannot meet the demand for rigid PU foam products. There may be, as a result, illegal CFC-11 foaming agent in the market to fill the supply gap for rigid PU foam products.

(d) Estimate the approximate amount of illegal CFC based on the difference between the calculated value and the market statistical value.

For details of the material balance calculation method for rigid PU foam, see Annex 1.

5.1.1.8 Analysis on production and consumption balance of rigid PU foam

(1) Model input

The following five kinds of data need to be inputted into the rigid PU foam material balance model:

1) Consumption of polymeric MDI in various sub-industries from 2008 to 2018: the data is the result of investigation during implementation of the study and basically comes from the network and engagement of consultant firm that have worked on collecting and sorting data and information on the PU production and consumption market for many years. See Annex 1 for details.

2) Consumption of rigid PU foaming agent from 2008 to 2018: the data is the result of investigation during the implementation of the study and basically comes from consultant firm

engaged in data collection and sorting information on the production and consumption market of various foaming agents and chemical products over many years. See Table 5.1-3 for details.

3) The mass proportion of various foaming agents in polyether polyol system (white material) for rigid PU foam, the mass proportion of polymeric MDI (black material) and polyether polyol system (white material) in rigid PU foam, and the application of the proportion of various foaming agents in various sub-industries from 2008 to 2018: the above data are the results of market research, and basically come from analysis of the status of rigid PU foam industry, analysis of the production process of rigid PU foam, analysis of the characteristics of various foaming agents, and the estimation of many professionals who have long been engaged in production, teaching and management in China's rigid PU foam industry.

(a) Mass proportion of various foaming agents in polyether polyol system (white material)for rigid PU foam

The proportion of foaming agent in polyether polyol system (white material) varies slightly with different manufacturers and different product usages. However, for various types of foaming agents on the whole, the average ratio or common value can be regarded as a comprehensive weighted average value of various products of manufacturers. Therefore, the common value is used in the calculation of the model. See Table 5.1-4 for details.

Table 5.1-4 Mass proportion of various foaming agents in polyether polyol system (white material) for rigid PU foam

Foaming agent	Minimum	Maximum	Common value
HCFC-141b	19%	22%	20%
HC	10%	12.50%	11.50%
HFC-245fa/365mfc	10%	12.50%	11.50%
HFO	15%	20%	15%
Water	2.50%	5%	4%
Methyl formate	2.50%	5%	4%
CFC-11	22%	28%	25%

From the perspective of manufacturers and sub-industries as a whole, it is impossible for all sub-industries and all manufacturers to adopt a maximum or a minimum at the same time. Therefore, the characteristics of different industries should be considered if using maximum or minimum values. Considering the high prices of polymeric MDI and white material, the manufacturers pay more attention to efficient use of the materials.

The sub-industries are considerably consistent in the ratio of foaming agent to polyol and other inputs, except for the spray foam sub-industry.

In rigid foam spraying, polymeric MDI and polyether polyol (the main raw materials) and other inputs such as foaming agent, catalyst, flame retardant, are mixed through special equipment, sprayed on the insulation matrix (such as wall) under high pressure, and foamed on site to form a high molecular polymer. The formation of PU foam involves two stages: foaming and aging. Rigid PU foam spraying can be divided into three types: high-density, medium-density and low-density spraying. Because of its good impermeability and heat resistance, high-density foam is usually used outdoors and on roofs. With low vapor permeability, medium-density foam is usually used in continuously insulated, interior filled walls and unventilated attics. In blocking air but letting steam and moisture to permeate, low-density foam which has a low specific gravity is usually used in interior walls, ventilated or unventilated attics, pipes, ceilings, or for caulking and sound insulation.

There are multiple factors that influence spray foam. For example, material ratio deviation: the density difference between machine-made foam and hand-made foam is large where the black-and-white material ratio of machine-made foam can be generally as low as 1:1, but that of hand-made foam can be as high as 1.4:1. Plus the great difference among white materials of different manufacturers, the ratio of hand-made foam is more difficult to determine. Another example is ambient temperature: when the ambient temperature is low (such as below 18℃), part of the heat will be dissipated into the environment. On the one hand, the loss of heat prolongs the maturation period and on the other hand increases the shrinkage of the foam. The foaming volume of the same foaming material when the ambient temperature is 15℃ is 25% smaller than that when the ambient temperature is 25℃. Therefore, it is necessary to increase the amount of foaming agent and even polymeric MDI. In addition, the wind speed also has an impact. Generally, the wind speed should be less than 5m/s. When the wind speed is high, heat will be lost and the surface becomes brittle. Therefore, it is necessary to increase the ratio.

In each sub-industry, only the spray foam sub-industry involves spraying in an open environment and a lot of manual operation, so the material loss, especially the foaming agent loss, will be larger than in other sub-industries.

According to the above analysis, there are changes in the proportion of foaming agent in the spray foam industry. However, considering the differences between spraying for high, medium and low density, this change will be averaged. Basically, there is no need to consider a higher proportion of foaming agent in the spray foam industry. However, in order to analyze an extremely unfavorable situation (worst case/conservative scenario), the study allowed the whole spray foam sub-industry to adopt a maximum for all foaming agents at the same time (virtually impossible in reality), and the model calculation is carried out with this “extreme” scenario.

(b) Mass ratio of polymeric MDI (black material) to polyether polyol system (white material) in rigid PU foam

For the mass ratio of polymeric MDI (black material) to polyether polyol system (white material) in rigid PU foam, the minimum, maximum and common values are listed in Table 5.1-5. For specific rigid PU foam products, these values are basically fixed. From the overall perspective of the rigid PU foam industry, the proportion of black and white materials corresponding to each foaming agent is basically a common value. Therefore, when using the model analysis, the common value is used for calculation.

Table 5.1- 5 Mass ratio of polymeric MDI (black material) to polyether polyol system (white material) in rigid PU foam

Foaming agent	Minimum	Maximum	Common value
HCFC-141b	1.05	1.12	1.08
HC	1.05	1.12	1.10
HFC-245fa/365mfc	1.20	1.40	1.20
HFO	1.30	1.50	1.35
Water	1.30	2.00	1.50
Methyl formate	1.10	1.50	1.20
CFC-11	1.05	1.20	1.10

As mentioned above, in each sub-industry, the spray foam sub-industry has a large proportion of manual operation and relatively large material losses. At the same time, considering the extreme scenario where the operator would use less black material and adopts the minimum black-white ratio, the whole spray foam sub-industry would simultaneously adopt the minimum black-white ratio. The model’s calculations are carried out in such an extreme situation.

(c) Application ratios of various foaming agents in various sub-industries from 2008 to 2018

From 2008 to 2018, with the introduction and replacement of HCFC-141b, the ratio of foaming agents in each sub-industry changed. According to the industry survey and expert judgment, the application ratio of various foaming agents in each sub-industry according to each year is obtained. See Annex 1 for details.

(2) Model output

Input the data needed into the aforementioned model for calculation and analysis, and the calculation results are as follow:

1) Normal proportion of foaming agent in polyether polyol system (white material)

Table 5.1-6 Consumption of foaming agent calculated according to the consumption of polymeric MDI in each year Unit: ton

Foaming agent	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HCFC-141b	37981	43161	54647	62056	54281	44670	45309	32231	28572	31111	31149
HC	22166	25919	29042	32420	35702	47044	47953	48226	44221	47868	55453
HFC	1161	1249	1944	2161	4541	7055	6239	8876	11711	13816	13689
HFO	0	0	0	0	0	0	530	1149	1391	1473	1799
Water	2039	2553	3207	2985	2990	5217	4834	5059	5268	6312	7201
Methyl formate	288	330	332	316	292	306	229	281	244	286	367
Others	0	0	0	0	0	0	0	0	0	0	0

Table 5.1-7 Difference between annual consumption and estimated consumption surveyed in the foaming agent market Unit: ton

Foaming agent	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HCFC-141b	119	2810	-2578	1514	4828	1668	1555	1971	6249	5328	3027
HC	-1666	-1619	-942	480	4198	1056	647	3974	11779	11132	9347
HFC	-261	-149	-444	-61	159	45	1961	1624	2489	2684	1711
HFO	0	0	0	0	0	0	-130	151	209	227	101
Water	661	347	-7	415	510	683	1166	1441	1932	1188	1299
Methyl formate	58	33	39	52	40	18	43	8	73	48	12
Others	0	0	0	0	0	0	0	0	0	0	0

Notes:
Difference = Consumption of foaming agent in market research – Consumption of foaming agent based on the consumption of polymeric MDI in market research
The difference value > 0, indicating that the amount of foaming agent consumed in the market satisfied the consumption amount of polymeric MDI;
The difference value < 0, indicating that the amount of foaming agent consumed in the market does not satisfy the consumption of polymeric MDI. In addition to the above mentioned foaming agents, other foaming agents may be used in the market.

Table 5.1-8 Demand by filling the difference with CFC-11 Unit: ton

Type of charged foaming agent	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HCFC-141b	>0	>0	-3163	>0	>0	>0	>0	>0	>0	>0	>0
HC	-3703	-3599	-2094	>0	>0	>0	>0	>0	>0	>0	>0
HFC	-632	-360	-1077	-148	>0	>0	>0	>0	>0	>0	>0
HFO	0	0	0	0	0	0	-265	>0	>0	>0	>0
Water	>0	>0	-59	>0	>0	>0	>0	>0	>0	>0	>0
Methyl formate	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0

Others	0	0	0	0	0	0	0	0	0	0	0

Notes:
The value > 0, indicating that there is no shortage of foaming agent in the market, and no other foaming agent is needed to fill the shortage of consumption. The value indicates the tendency.
The value < 0, indicating that the amount of foaming agent consumed in the market does not satisfy the consumption of polymeric MDI. It is assumed that CFC-11 is used as the foaming agent for the gaps.

2) Extreme proportion of foaming agent in polyether polyol system (white material)

Model calculation is carried out in the most extreme situation where the whole sub-industry of spraying adopts maximum at the same time.

Table 5.1-9 Consumption of foaming agent calculated according to the consumption of polymeric MDI in each year Unit: ton

Foaming agent	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HCFC-141b	39608	44826	56943	64422	56159	47079	47632	33980	30168	32817	32995
HC	22236	26170	29155	32533	36008	47139	48224	48583	44595	48219	55897
HFC	1176	1255	1965	2195	4575	7140	6311	9007	11784	13963	13795
HFO	0	0	0	0	0	0	534	1274	1432	1508	1920
Water	2116	2632	3340	3067	3090	5402	4957	5234	5458	6492	7348
Methyl formate	303	344	349	331	304	317	238	302	261	308	382
Others	0	0	0	0	0	0	0	0	0	0	0

Table 5.1-10 Difference between annual consumption and estimated consumption surveyed at the foaming agent market Unit: ton

Foaming agent	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HCFC-141b	-1508	1145	-4874	-852	2950	-741	-768	222	4653	3622	1181
HC	-1736	-1870	-1055	367	3892	961	376	3617	11405	10781	8903
HFC	-276	-155	-465	-95	125	-40	1889	1493	2416	2537	1605
HFO	0	0	0	0	0	0	-134	26	168	192	-20
Water	584	268	-140	333	410	498	1043	1266	1742	1008	1152
Methyl formate	43	19	22	37	28	7	34	-13	56	26	-3
Others	0	0	0	0	0	0	0	0	0	0	0

Notes:
Difference = Consumption of foaming agent in market research – Consumption of foaming agent based on the consumption of polymeric MDI in market research
The difference value > 0, indicating that the amount of foaming agent consumed in the market satisfies the consumption amount of polymeric MDI;
The difference value < 0, indicating that the amount of foaming agent consumed in the market does not satisfy the consumption of polymeric MDI. In addition to the above mentioned foaming agents, other foaming agents may be used in the market.

Table 5.1-11 Demand by filling the difference with CFC-11 Unit: ton

Type of charged foaming agent	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HCFC-141b	-1851	>0	-5982	-1046	>0	-910	-942	>0	>0	>0	>0
HC	-3858	-4156	-2345	>0	>0	>0	>0	>0	>0	>0	>0
HFC	-669	-375	-1127	-231	>0	-96	>0	>0	>0	>0	>0
HFO	0	0	0	0	0	0	-273	>0	>0	>0	-41
Water	>0	>0	-1197	>0	>0	>0	>0	>0	>0	>0	>0
Methyl formate	>0	>0	>0	>0	>0	>0	>0	-87	>0	>0	-19
Others	0	0	0	0	0	0	0	0	0	0	0

Notes:
The value > 0, indicating that there is no shortage of foaming agent in the market, and no other foaming agent is needed to fill the shortage of consumption. The value indicates the tendency.
The value < 0, indicating that the amount of foaming agent consumed in the market does not satisfy the consumption of polymeric MDI. It is assumed that CFC-11 is used as the foaming agent for the gaps.

5.1.1.9 Risk analysis of illegal production and use of CFC-11 in rigid PU foam industry

(1) Normal Scenario (industrial norm scenario)

Under normal circumstances, the mass-balance is calculated separately for each type of foaming agent in the rigid PU foam industry. In Table 5.1-8, only the foaming agent amount calculated according to the consumption of polymeric MDI for rigid foam in 2008-2011 and 2014 was larger than the market survey statistics. It is mainly because HC, HFC and HFO left a void in the market which might be filled by other foaming agents. But even if all of the gaps were filled up CFC-11, the estimated quantities would be at a very low level.

For other years, the actual consumption of foaming agent on the market was fully sufficient to support the consumption of polymeric MDI, and there was no shortage of foaming agent. Therefore, the study is confident that no other foaming agents, including CFC-11, existed in the market, and if there was CFC, it would not exceed the calculation error range of the model.

(2) Extreme Scenario (conservative scenario)

Under extremely adverse conditions which would not actually happen as described before, the mass-balance is calculated separately for each type of foaming agent in rigid PU foam industry. In Table 5.1-11, from 2008 to 2011, the years that the foaming agent amount calculated according to the consumption of polymeric MDI on rigid foam was larger than the market survey statistics.. It is mainly due to insufficient supply of HCFC-141b, HC, HFC, HFO, water and methyl formate in the market. This gap might be filled up by other foaming agents.

For the other years, according to the material balance calculation for the whole industry, the actual consumption of foaming agents in the market was fully in line with the consumption of polymeric MDI, and there was basically no significant shortage of foaming agent. Therefore, the study is confident that no other foaming agents, including CFC-11, existed in the market, and if there was CFC, it would not exceed the calculation error range of the model.

(3) Comprehensive analysis (conclusion)

According to the mass-balance analysis and calculation for raw materials linked to the rigid PU foam industry under the industrial norm and conservative scenarios, widespread production and consumption of CFC-11 was unlikely during the period of 2008-2018.Based on the balance conditions between the market survey amounts of foaming agent and that derived from polymeric MDI market data, a foaming agent shortage may have occurred during 2008-2010 right after the phase-out of CFC-11. As a consequence there could have been some illegal CFC-11 use to fill the shortage. Considering, however, that some pre-2008 CFC-11 stocks might have also existed in the market after 2007, CFC-11 demand could have been met from these stocks or from low level illegal production (or both).

5.1.2 Household appliances industry

China's household appliance industry included refrigerators, freezers and room air conditioners. Before 1995, CFC-12 was the main refrigerant for refrigerators and freezers, whereas CFC-12 was never employed in room air-conditioning manufacturing in China. On May 28, 2007, the *Announcement on Prohibiting the Production, Sale, Import and Export of Household Electrical Appliances Using CFCs as Refrigerant and Foaming Agent* was officially released, and the phase-out of CFCs in the household appliance industry was successfully completed. Although no enterprise was allowed to produce household appliances with CFC-12 as the refrigerant since July 1, 2007, considering the price or technical caveats of corresponding substitutes, the inventory of CFC-12 refrigerant, and maintenance needs of installed household appliances, the illegal use of CFC-12 might have still existed. Based on market data of refrigerant consumption, this section assesses the potential risk of illegal use of CFC-12 in the household appliances industry.

5.1.2.1 Refrigerator industry

(1) Overview of refrigerant market in refrigerator industry

(a) Overview of the industry

China began industrialized production of refrigerators in the early 1980s. According to the data of the *China Statistical Yearbook* from 2008 to 2018, in the past decade, China's refrigerator production increased from 47.57 million in 2008 to 78.77 million units in 2018, with an average annual growth rate of 5.17%. From 2008 to 2018, the export volume of refrigerators increased from 24.85 million to 52.49 million units, with an average annual growth rate of 7.76%. In addition, the import volume of refrigerators in China was not large, accounting for 0.5% of the total domestic consumption. Therefore, the impact of this element can be ignored when calculating domestic demand, that is, the domestic demand represents the difference between the output and the export volume. The growth trend of domestic refrigerator demand was congruent to that of output – from 2008 to 2013, the quantity increased from 22.72 million units to 57.95 million units, with negative growth since 2014. At present, the penetration rate of refrigerators in cities and rural areas has reached 100.9% and 95.9% respectively, and is in an almost saturated state.

(b) Application of refrigerants and substitutes

The refrigerator industry initially used CFC-12 as the refrigerant. CFC phase-out plans were implemented starting in the mid-1990s, and by 2008, CFC-12 was obsolete. Alternative refrigerants mainly included HFC-134a, Isobutane (R600a), MP39[1].

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[1] MP39 is a common mixed refrigerant in refrigerator industry and consists of 53% HCFC-22, 13% HFC-152 and

The output proportion of refrigerators by refrigerant in the refrigerator industry between 1995 and 2008 is shown in Table 5.1-12. It can be seen that the use proportion of CFC-12 decreased year by year, and completely stopped since 2008. The use proportion of MP39 increased gradually in the initial years, reaching 21.2% in 1998, then decreased year by year, and was completely stopped in 2006. The use proportion of HFC-134a gradually increased, reaching 43% in 2001, and then decreased year by year, where only 8% was retained in 2008 for mainly export. The use proportion of R600a has increased annually, and occupies the dominant position in the use of refrigerants in the refrigerator industry, reaching 92% by 2008. At present, the use proportion of R600a has reached over 99%.

Table 5.1-12 Output proportion of refrigerators by refrigerant in China from 1995 to 2008

Year	CFC-12	HFC-134a	R600a	MP39
1995	96.9%	0.5%	0	2.6%
1996	74.4%	8.6%	1.1%	15.9%
1997	62%	12.4%	5.2%	20.5%
1998	47.1%	19.2%	12.5%	21.2%
1999	35.9%	24.2%	23.4%	16.6%
2000	28.2%	27.4%	39.1%	5.3%
2001	9.6%	43%	40%	7.3%
2002	8.8%	36.4%	48.9%	5.9%
2003	7.9%	29.8%	57.8%	4.5%
2004	7.0%	23.2%	66.7%	3.1%
2005	6.1%	16.6%	75.6%	1.7%
2006	5.7%	10%	84.3%	0
2007	3.8%	9%	87.2%	0
2008	0	8%	92%	0

Note: The proportion of output comes from China Household Electrical Appliances Association

(2) Estimation of CFC-12 refrigerant consumption in refrigerator industry

CFC-12 refrigerant consumed in the refrigerator industry was mainly used for servicing CFC-12 based refrigerators manufactured before 2008. The calculation formula is as follows:

$$C_t = m_t \times a$$

In which: C_t is the consumption of refrigerant for servicing in the t-th year; m_t is the domestic refrigerator maintenance quantity in the t-th year; a is the charging volume of refrigerant for maintenance of each refrigerator.

According to the average assembly level of refrigerators in the past, the relevant parameters selected for specific estimation of refrigerant consumption are shown in Table 5.1-13.

Table 5.1-13 Related parameters in refrigerant consumption estimation for CFC-12 refrigerator maintenance

Type	Initial charging	Life	Maintenance rate	Recharging	Maintenance	Residual quantity	Recovery rate

34% HCFC-124.

	volume			maintenance rate	charging quantity	upon scrap	
Refrigerator	0.2kg	15years	3%	40%	0.2kg	20%	5%

Note: The parameters come from Environmental Benefit Analysis of CFC Phase-out in China's Refrigerator Industry and Research Report on Non-CO_2 Greenhouse Gas Emission Reduction Potential in the Whole Life Cycle of Domestic Refrigerators and Room Air Conditioners in China

The inventory of CFC-12 refrigerators from 2008 to 2018 can be calculated based on the output proportion of refrigerators using various refrigerants in Table 5.1-12 above, and then the refrigerant consumption of CFC-12 refrigerators estimated according to the formula and relative parameters, as shown in Table 5.1-14. It can be seen from the table that new demand for CFC-12 decreased annually, and it was necessary to purchase 466.18 tons of CFC-12 from the national inventory of CFCs for servicing demand from 2008 to 2018. According to the inventory changes of CFC-12 in ***5.6 Inventory and stock list of CFC-11 and CFC-12***, the national inventory of CFC-12 could meet the maintenance needs of installed refrigerators, which also shows that there was no driver for illegal use of CFC-12 in the refrigerator servicing and maintenance industry.

Table 5.1-14 Estimation of refrigerant consumption for CFC-12 refrigerator maintenance

Year	Inventory of CFC-12 refrigerator (10k units)	Recharging maintenance quantity (10k units)	Maintenance consumption of CFC-12 (tons)	Scrap quantity of CFC-12 refrigerator (10k units)	CFC-12 recovery (tons)	New demand of CFC-12 (tons)
2008	4887.90	58.65	117.31	449.55	8.99	108.32
2009	4335.90	52.03	104.06	552.00	11.04	93.02
2010	3624.90	43.50	87.00	711.00	14.22	72.78
2011	2819.67	33.84	67.67	805.24	16.10	51.57
2012	2205.87	26.47	52.94	613.80	12.28	40.66
2013	1682.59	20.19	40.38	523.28	10.47	29.92
2014	1260.57	15.13	30.25	422.02	8.44	21.81
2015	911.98	10.94	21.89	348.59	6.97	14.92
2016	658.18	7.90	15.80	253.80	5.08	10.72
2017	572.16	6.87	13.73	86.02	1.72	12.01
2018	497.36	5.97	11.94	74.80	1.50	10.44

(3) Analysis on the possibility of illegal use of CFC-12 in the refrigerator industry

The refrigerator industry has completed the phase-out of CFCs. The alternative R600a is not only economical and efficient, but also boasts a mature technology and high market acceptance. Therefore, there was no subjective and objective conditions for illegal use of CFC-12. Discussion is conducted from different perspectives as follows.

(a) Economic cost

R600a which has a large calorific value of evaporation enables a smaller amount of charging in the refrigerator, thus reducing the cost. Table 5.1-15 shows the operating cost changes of a company's single refrigerator product because of refrigerant replacement at the beginning of replacement plan implementation, indicating that the cost of R600a as refrigerant was lower than that of CFC-12. With the progress of technology, the cost advantage of current products becomes more obvious.

Table 5.1-15 Changes in operating costs of a company's single refrigerator product after refrigerant replacement

Year	Refrigerant	Average charging volume per unit (kg)	Price (RMB/kg)	Cost (RMB/unit)	Cost change (RMB/unit)
2003	CFC-12	0.158	19.00	3.00	0
	R600a	0.053	29.05	1.54	-1.46
2018	R600a	0.053	16.00	0.85	-2.15

(b) Technology

(I) The refrigerant performance of R600a is better than that of CFC-12. At the beginning of the replacement, the refrigerator with R600a as refrigerant achieved an energy efficiency improvement of more than 10%. With the progress of technology, the energy efficiency was much improved, and the product gained significant advantage in technology and quality.

(II) The refrigerator industry in China adopted the production line approach, which involves complex processes. In the process of refrigerant replacement, the production assembly line was reformed according to the substitution technology characteristics of R600a, with replacement of the baseline chargers, vacuum pumps and leak detectors. In order to change the refrigerant in the production process, it was also necessary to adjust the above production components, which involved modernization and a high cost, greatly affecting the production efficiency as well.

(III) Different refrigerants most often require different product designs. For R600a refrigerant, it is necessary to design a compressor with a large capacity and the technical performance of parts such as pipes, condenser, evaporator, capillary tube, heat exchanger and energy accumulator must also meet relevant international and domestic standards. At present, key parts are developed and matched to the alternative refrigerant technology, and efficient and low-cost supply of these parts has long been realized.

(c) Market

China is the largest refrigerator manufacturer, with an annual output of 80-90 million units, about 40% of which are exported. The R600a refrigerant currently used is green – environment-friendly and energy-efficient, and has been recognized as such and accepted in the international and domestic markets. A fully mature product market has been developed.

In conclusion, for the refrigerator industry, the cost and product risk of illegal use of CFC-12 is higher than that of R600a, so there is no possibility of illegal use of CFC-12 in this industry.

5.1.2.2 Room air conditioner industry

(1) Overview of status quo of room air conditioner industry

China began to produce room air conditioners in the early 1980s. According to the data of *China Statistical Yearbook* from 2008 to 2018, in the past decade, China's room air conditioners production increased from 81.47 million in 2008 to 204.86 million in 2018, with an average annual growth rate of 9.66%. From 2008 to 2018, the export volume of room air conditioners increased from 38.6 million units to 57.9 million units. Affected by the economic crisis in 2009, the export volume increased slightly from 2008 to 2015, and began to grow rapidly since 2016, with an average annual growth rate of 9.77%. In addition, the import volume of room air conditioners in China is not large, accounting for 0.05% of the total domestic consumption. Therefore, the impact of this element can be ignored when calculating the domestic demand, that is, the domestic demand represents the difference between the output and the export volume. Demand growth of domestic room air conditioners is similar as that of output, from 42.9 million units in 2008 to 150.99 million units in 2018. At present, the penetration rate of room air conditioners in cities and rural areas has reached 142.2% and 65.2% respectively, still with room for growth.

(2) Application of refrigerants and substitutes

Since the beginning of its development, China's room air conditioner industry has chosen HCFC-22 as the main refrigerant, which made the industry one of the largest HCFC-22 consuming industries. After the HCFC adjustment to the MP in 2007, HCFCs were targeted for accelerated phase-out, and China began to implement phase-out plans for HCFC production and consumption by 2013. Therefore, the room air conditioner industry began to develop and use alternative refrigerants, including HFC-410A, R290 and HFC-32.

The output proportion of air conditioners using various refrigerants in the room air conditioner industry from 2008 to 2018 is shown in Table 5.1-16. It can be seen that the utilization proportion of HCFC-22 increased slightly in 2009 and then decreased year by year, accounting for only 30% in 2018. The use proportion of alternative refrigerants has increased year by year since 2009 and reached 70% in 2018; among them, R410A occupied a dominant position as the alternative refrigerant before 2014. The use proportion of R32 has also increased annually starting in 2014 and has reached about 30% in 2018; R290 is currently mainly used in production lines of portable air conditioners, dehumidifiers and split room air conditioners which are manufactured from converted production lines financed by the MLF, but with a low overall utilization proportion.

Table 5.1-16 Output proportion of air conditioners using various refrigerants in room air conditioner industry from 2008 to 2018

Year	R22	R410A and others
2008	86.4%	13.6%
2009	89.3%	10.7%
2010	77.3%	22.7%
2011	69.6%	30.4%
2012	54.2%	45.8%
2013	53.7%	46.3%
2014	49.3%	50.7%
2015	45.3%	54.7%
2016	42.9%	57.1%
2017	33.2%	66.8%
2018	30.0%	70.0%

Note: The proportion of output comes from China Household Electrical Appliances Association

(3) Analysis on the possibility of illegal use of CFC-12 in the room air conditioner industry

At the beginning of its development, China's room air conditioner industry used HCFC-22 as the main refrigerant and almost all air conditioners produced before 2000 used HCFC-22 as refrigerant. As mentioned previously, there is no history of using CFC-12 refrigerant. After nearly 40 years of development, the technical system of HCFC-22 refrigerant and its substitutes became mature, economical and profitable with high market acceptance. Therefore, there are no subjective and objective conditions for the illegal use of CFC-12. Discussion is conducted from different perspectives as follows.

(a) Economic cost

From 2008 to 2018, the price of HCFC-22 fluctuated greatly, ranging from RMB7,000 to RMB 18,000/ton. The initial charge of HCFC-22 in room air conditioners was only 1.15 kg/unit, and the refrigerant cost was RMB 20 at most, accounting for only a very small part of the air conditioning cost (about 1%); Room air conditioner enterprises would not take risks (of using CFCs) for the 1% cost.

(b) Technical analysis

As the main refrigerant used in the room air conditioner industry, HCFC-22 has similar refrigeration coefficient values as compared to CFC-12, but has a larger refrigeration capacity per unit volume, better thermal conductivity, and better thermodynamic properties. In addition, if the refrigerant is replaced, the production line and related supporting product design would also need to be changed, which not only costs a lot of money, but also costs a lot of time.

(c) Market analysis

China's air conditioning industry ranks first in the world in terms of scale and sales. Most of the enterprises produce more than one million units per year, and about 40% of the room air conditioners are exported. Therefore, as large enterprises which want to avoid reputational risk, they tend to abide by national and international standards and requirements, including in the use of refrigerants.

In addition, if a large number of air conditioners were charged with illegal refrigerant and sold and circulated in the market, they would be easily exposed and have to bear this high exposure risk and related costs of law violation.

To sum up, for the room air conditioner industry, there is no driver for illegal use CFC-12 refrigerant.

5.1.3 Industrial and commercial refrigeration industry

Industrial and commercial refrigeration equipment refers to refrigeration equipment widely used in industrial and commercial fields. CFC-11 was mainly used as refrigerant for centrifugal compressors, and CFC-12 mainly used as refrigerant for other air conditioning equipment, freezer, cold storage, and cold chain equipment. The *Announcement on Prohibiting the Production and Sale of Compressor and Related Products for Industrial and Commercial Refrigeration with Perfluoroolefin as Refrigerant* was promulgated in December 2004, marking the complete phase-out of CFCs in the industrial and commercial refrigeration industry.

Although since May 1, 2005, no enterprise is allowed to produce industrial and commercial refrigeration compressors and related products using CFCs as refrigerants, considering the high price of the corresponding substitutes or the immature state of technology, there might have been or be illegal use of CFCs. This section will analyze whether there is a possibility of illegal use of CFCs in the industrial and commercial refrigeration industry by studying the consumption of refrigerants.

5.1.3.1 Overview of status quo of refrigerant market

(1) Overview of the industry

Industrial and commercial refrigeration equipment is characterized by a wide range of products, wide applications and a great number of manufacturers. Since the early 1990s, with the continuous and healthy development of China's economy, China's industrial and commercial refrigeration industry has made great progress. The output value of industrial, commercial refrigeration and the air conditioning industry has maintained an over double-digit average annual growth rate, until its growth rate slowed down after a turning point in 2012. According to the statistics of China Household Electrical Appliances Association, the output value of the industrial and commercial refrigeration industry in 2018 is about RMB 383.9 billion[2]. The main types of products in industrial and commercial refrigeration industry include refrigeration compressor, compressor condensing unit, water chilling (heat pump) unit, heat pump water heater, unitary air conditioner, multi-connected air conditioner, industrial and commercial refrigeration equipment.

(2) Application of refrigerants and substitutes

After China's industrial and commercial refrigeration industry successfully phased-out CFCs, the alternative refrigerant became HCFCs which mainly included HCFC-22, HCFC-123 and HCFC-142b. With the implementation of the HCFC phase-out plan, the consumption proportions of HFC refrigerants and natural refrigerants have gradually increased, among which the HFCs consumed include HFC-134a, R410A, R407C, R404A, and the natural refrigerants include NH_3 and CO_2. The refrigerants used for different end product types are shown in Table 5.1-17.

Table 5.1-17 Refrigerants used by different product types in the industrial and commercial refrigeration industry in China

Product type		HCFCs refrigerant	HFCs refrigerant	Other refrigerants
Household water chilling (heat pump) unit		HCFC-22	R410A	/
Industrial and commercial water chilling (heat pump) unit	Reciprocal type water chilling (heat pump) unit	HCFC-22	HFC-134a, R404A, R507A	NH_3
	Scroll type water chilling (heat pump) unit	HCFC-22	R410A, R407C	/
	Screw type water chilling (heat pump) unit	HCFC-22	HFC-134a, R407C, R507A	NH_3
	Centrifugal water chilling unit	HCFC-123	HFC-134a	/
Heat-pump water heater		HCFC-22	HFC-134a, R410A, R407C	/
Unit air conditioner		HCFC-22, HCFC-142b	R410A, R407C	/
Multi-connected air conditioning (heat pump) unit		HCFC-22	R410A	/
Train air conditioning		HCFC-22	/	/
Industrial and commercial refrigeration equipment		HCFC-22	HFC-134a, R404A	NH_3, CO_2
Compression condensing unit		HCFC-22	HFC-134a, R404A	NH_3, CO_2

Note: R404A is made of 44% HFC-125, 4% HFC-134a and 52% HFC-143a. R507A is made by mixing HFC-125 and HFC-143a in the proportion of 50%/50%.

5.1.3.2 CFC refrigerant consumption

As mentioned above, CFC-11 and CFC-12 refrigerants are no longer used in new industrial and commercial refrigeration equipment; and the replacement of refrigerants have been completed in some existing CFCs refrigeration equipment that can carry out technical transformation;

[2] The output data of the industrial and commercial refrigeration industry is represented by output value.

however, there are also some refrigeration equipment that is not suitable for system modification and refrigerant replacement. The measures that can be taken on them are to prevent leakage and strengthen recovery and recycling. For example, centrifugal chillers with CFC-11 as refrigerant still needed a small amount of CFC-11 for maintenance from 2008 to 2018. According to the survey results in 2005, for the CFC-11 centrifugal chillers still in use, the age is shown in Table 5.1-18.

Table 5.1-18 Year of Manufacturing of CFC-11 centrifugal chillers in use

Year	Quantity
1975 and before	0
1976-1980	4
1981-1985	220
1986-1990	501
1991-1995	524
1996-1998	43
Total	1292

According to the survey results, a conservative estimate is that the average life of CFC-11 centrifugal chillers is 20 years, and the average CFC-11 charge capacity per single unit is 488.6kg, and the average annual replenishment rate is 12.78%. If the refrigeration equipment needs to be topped up with refrigerant every year, the remaining refrigerant would account for 87.22% when the equipment is scrapped, and the recovery rate would consequently be about 80%. Based on this, the maintenance consumption of CFC-11 from 2008 to 2018 can be calculated, as shown in Table 5.1-19. It can be seen from the table that the recovered amount of CFC-11 can satisfy the servicing demand of that year, with no need to use new, virgin CFC-11. It shows that there is no use of CFC-11 from illegal sources in the CFC-11 centrifugal chiller in use.

Table 5.1-19 Consumption of CFC-11 of old chiller Units: ton

Time	CFC-11 existing stock	CFC-11 maintenance consumption	Scrap quantity (unit)	CFC-11 recovery
2006-2010	455.14	66.69	220	75.00
2011-2015	241.63	35.41	501	170.80
2016-2018	18.32	2.69	524	178.64

5.1.3.3 Analysis on the possibility of illegal use of CFC-11 and CFC-12 in the industrial and commercial refrigeration industry

After CFC-11 and CFC-12 were successfully phased-out in the industrial and commercial refrigeration industry, most of the industrial and commercial refrigeration equipment adopted HCFC-22 in lieu of CFC-12, and some unitary air conditioners used HCFC-142b; while centrifugal chillers adopted HCFC-123 in lieu of CFC-11. After more than 10 years of product development, HCFC substitutes are a mature and reliable technology which is also economically feasible. They have taken over a large part of the market, so there is little possibility of illegal demand for CFC-11 and CFC-12.

(1) HCFC-22 and HCFC-142b

The refrigeration coefficient values of HCFC-22 and CFC-12 are similar at low temperature, and replacing CFC-12 with HCFC-22 in refrigeration system will not cause significant reduction of refrigerator efficiency. The refrigerating capacity per unit volume of HCFC-22 is about 60% higher than that of CFC-12, which can significantly increase the refrigerating capacity of the system, and produce better thermal conductivity and higher heat exchange efficiency, so HCFC-22 has better thermodynamic performance.

Compared with CFC-12 however, HCFC-22 refrigerant will increase the exhaust pressure and differential pressure, and pose higher mechanical stress on traditional CFC equipment components. Therefore the compressor needed to be redesigned and produced for HCFC-based systems. In addition, under the condition of fixed refrigeration capacity, the HCFC-22 circulation mass flow in the system is lower, and the flow rate is reduced, so the heat exchanger and pipes also needed to be specially designed.

HCFC-142b is often used as an important component of high-temperature refrigerants and various mixed refrigerants, and is mainly used in refrigeration systems in high-temperature environments, so some special-purpose unitary air conditioners have adopted HCFC-142b.

(2) HCFC-123

For centrifugal chillers, HCFC-123 has close to a normal boiling point and molecular weight to CFC-11, plus given only a small difference of cooling capacity per unit volume, it is an ideal transitional alternative. However, HCFC-123 has lower unit volume refrigeration capacity, and a slightly worse cycle performance than CFC-11, and may easily cause lower efficiency, reduced refrigeration capacity and increased power consumption. Therefore, for HCFC-123 refrigerant, it is necessary to redesign the compressor and adjust other parameters of the refrigeration system to compensate for the above deficiencies. In addition, due to the differences in physical properties, non-metallic parts (such as gaskets, sealing rings) need to be replaced.

To sum up, the new industrial and commercial refrigeration equipment should be redesigned, manufactured and installed to match with alternative HCFC refrigerants in use since CFC phase-out. Due to the limitation of production processes and equipment performance, the newly manufactured equipment cannot effectively use CFC-11 and CFC-12. If the refrigerant is replaced, the production line and related supporting product design need to be changed, which not only is costly, but also costs a lot of time. Therefore, there is next to no possibility of illegal use of

CFC-11 and CFC-12 refrigerants in the industrial and commercial refrigeration industry.

5.1.4 Other industries

5.1.4.1 Overview of the automotive air conditioning industry

CFC-12 had been widely used as the refrigerant of choice in China's automotive air conditioning industry. At the end of 2001, all the technical conversion work from CFC-12 to HFC-134a was completed. Since January 1, 2002, all newly produced automobiles stopped to install the automotive air conditioners with CFC-12 as refrigerant.

Although CFC-12 mobile air conditioners are no longer installed in newly produced automobiles, considering the high price of the corresponding substitutes and the maintenance needs of CFC-12 air conditioners installed on automobiles before 2002, there could theoretically be illegal use of CFC-12. In order to know the likelihood of illegal use of CFC-12 in mobile air conditioning, this section examines the servicing demand for CFC-12 in automotive air conditioners, and analyzes the risk of illegal use of CFC-12 from the perspectives of economic costs and technical difficulty.

(1) Estimation of CFC-12 refrigerant consumption

CFC-12 refrigerant consumed was mainly for servicing of CFC-12 automotive air conditioner in the existing vehicles. The calculation formula is as follows:

$$C_t = m_t \times a$$

In which: C_t is the consumption of maintenance refrigerant in the t-th year; m_t is the domestic automotive air conditioner maintenance quantity in the t-th year; *a* is the charging volume of refrigerant for maintenance of each automotive air conditioner.

The relevant parameters used for estimation of refrigerant consumption are shown in Table 5.1-20.

Table 5.1-20 Relative parameters in estimation of refrigerant consumed for maintenance of CFC-12 automotive air conditioner[1]

Vehicle type	Initial charge (kg)	Maintenance charge	Life (year)	Residual quantity upon scrap	Recovery rate[2]
Sedan car	0.8	30%	15	40%	70%
Truck	0.8	30%	10	40%	70%
Passenger car	4	30%	10	40%	70%

Note: 1. Source of parameters: *HFC-134a Demand and Emission Forecast for China's Automotive Air Conditioning Industry*;

2. According to the *Notice on the Recycling of CFC-12 Refrigerators in the Automobile Maintenance Industry* issued by the MEE in 2007, the estimated recovery rate is 70-90%, and here the lower value of 70% is adopted in calculation.

From 2008 to 2018, the number of vehicles equipped with CFC-12 air conditioner is shown in Table 5.1-21. According to the estimation based on vehicle life, by 2017, all the vehicles equipped with CFC-12 air conditioner had been scrapped and the inventory was zero.

Table 5.1-21 Number of vehicles equipped with CFC-12 mobile air conditioner from 2008 to 2018 (10k units)

Year	Sedan car	Truck	Passenger car	Total
2008	141.3	3.7	13.7	158.8
2009	125.0	2.2	8.6	135.8
2010	107.9	1.1	5.2	114.1
2011	87.5	0.0	0.0	87.5
2012	65.8	0.0	0.0	65.8
2013	41.1	0.0	0.0	41.1
2014	24.3	0.0	0.0	24.3
2015	13.0	0.0	0.0	13.0
2016	4.7	0.0	0.0	4.7
2017	0.0	0.0	0.0	0.0
2018	0.0	0.0	0.0	0.0

Note: Source of parameters: *Research on the Influence of Controlling and Managing HFCs-Opportunities and Challenges*

According to the above formula and relevant parameters, the refrigerant consumption of CFC-12 mobile air conditioner can be estimated, as shown in Table 5.1-22. It can be seen from the table that 397.9 tons of CFC-12 needed to be purchased from the national inventory of CFCs in 2008 for maintenance, and then the quantity decreased year by year. In 2016, the recovered amount of CFC-12 could meet the servicing demand of that year without outsourcing. According to the changes of CFC-12 inventory in ***5.6 Inventory and stock list of CFC-11 and CFC-12***, the national inventory of CFC-12 could meet the servicing needs of automotive air conditioning, and it also indicates that there is no use of CFC-12 from illegal sources in this industry.

Table 5.1-22 Consumption of refrigerant for CFC-12 automotive air conditioner maintenance from 2008 to 2016 Unit: tons

Year	Servicing amount required	Recovery amount	Outsourcing amount
2008	512.8	114.9	397.9
2009	408.4	97.5	310.9
2010	323.4	79.3	244.2
2011	210.1	83.9	126.2
2012	158.0	70.6	87.4
2013	98.6	55.4	43.1
2014	58.4	37.5	20.8
2015	31.2	25.4	5.8

2016	11.2	18.6	-7.4

(2) Analysis on the possibility of illegal use of CFC-12 in the automotive air conditioning industry

Since 2002, CFC-12 has been phased-out in the automotive air conditioning industry, and HFC-134a has long since been used as the alternative refrigerant. HFC-134ais a very effective and safe alternative refrigerant, however it is incompatible with the mineral refrigeration lubricating oil originally used in CFC-12 systems, so it was necessary to use a new type of refrigeration lubricating oil and change the system design of the mobile air conditioner. If CFC-12 is illegally used in newly designed HFC-134a automotive air conditioning system, it will cause irreversible damage to the compressor, so the possibility of illegal use of CFC-12 is low. The specific analysis is as follows:

HFC-134a and CFC-12 have similar thermodynamic properties and system structure, but use different refrigeration lubricating oils. Refrigeration lubricating oil is a kind of liquid lubricant with stable chemical properties, which can dissolve with refrigerant and can lubricate the compressor. After a refrigeration system runs stably, the distribution of refrigeration lubricating oil in the system is about 50% in the compressor, 20% in evaporator, and 10% in the condenser, storage tank and connecting pipes.

The refrigeration lubricating oil used in CFC-12 refrigeration system was a kind of mineral oil soluble with CFC-12, while HFC-134a is a kind of refrigerant with strong molecular polarity. HFC-134a is not miscible with mineral oil，so the mineral oil cannot play a lubricating role in the HFC-134aair conditioning system. Therefore, the refrigeration lubricating oil of HFC-134a is another special lubricating oil, such as polyalkylene glycol(PAG), polyester (POE). As PAG and POE refrigeration lubricating oil are not compatible with CFC-12, they cannot play the lubricating role when used with CFC-12 air-conditioning systems. The balance of the distribution of refrigeration lubricating oil will change adversely. In addition, due to the particularity of this lubricant, the requirements of HFC-134a air conditioning system for rubber materials are different from those of CFC-12 systems. Therefore, HFC-134a can only reach the desired working state in the system that is specially designed for it. For HFC-134a air conditioning system for automobiles, manufacturers will mark “HFC-134a” on compressors, condensers, evaporators, rubber pipes and filler equipment to prevent misuse.

If CFC-12 is used in the HFC-134a refrigeration system, the system pipeline must be cleaned with R113 cleaning agent first, otherwise the capillary tube will be blocked and the compressor will burn out. Secondly, the drying filter will have to be replaced. Third, if the refrigeration lubricating oil is not replaced, the system will not work well due to the incompatibility between the refrigeration lubricating oils used forHFC-134a and CFC-12, and the compressor will be damaged after running for a long time. If it is replaced with the refrigeration lubricating oil suitable for CFC-12, as mentioned above, the refrigeration lubricating oil will be distributed throughout the system, there will still be residual refrigeration lubricating oil of HFC-134a. The mixing of the two refrigeration lubricating oils in the system will weaken the lubrication effect and gradually damage the compressor. If CFC-12 is sold as HFC-134a at a low price for the HFC-134a automotive air conditioning system and used for refrigeration maintenance, because CFC-12 has been banned and cannot be obtained from normal channels, when HFC-134a refrigerant is added again later, it will be incompatible with the refrigeration lubricating oil, and the refrigeration lubricating oil taken away by CFC-12 refrigerant cannot return to the compressor. At this time, the compressor would be short of oil, and damaged after long-term operation due to dry friction. It is common knowledge for a professional mobile air conditioner service technician that HFC-134a refrigerant should not be mixed with mineral compressor oil of a CFC-12 system.

According to market research, the amount of refrigerant replenishment is very small every year, and the cost is extremely small as compared to the normal maintenance cost. Therefore, the automotive users will not be keen on counterfeit products on the cheap. For servicing companies, although using CFC-12 to counterfeit HFC-134a products can temporarily bring some benefits, this mode is unsustainable since it constantly causes harm to customers' vehicles.

To sum up, adding or replacing CFC-12 in HFC-134a automotive air conditioning system will cause serious problems in the air conditioning system, and even damage the compressor. The cost saved by using CFC-12 is far less than the damage for automotive users. Even if the servicing companies were to use the fake for the genuine, the illegal use of CFC-12 would not be sustainable.

5.1.4.2 Medical aerosol industry

The phase-out of CFCs in Chinese medicinal aerosols is divided into non-inhalation medicinal aerosols and metered dose inhalers (MDIs), and the use of CFCs for the two purposes was stopped in 2013 and 2016 respectively. However, the phase-out of CFC production in China was completed on July 1, 2007, so a special production line was reserved to meet CFCs demand for MDIs.

Since the production and consumption of CFCs for MDIs in 2010 and later years needed to be approved by the Parties to the MP and is subject to strict supervision, the newly produced CFCs are required to be sold only to MDI enterprises, and not for other purposes. Manufacturers of non-inhalation medicinal aerosols can purchase national reserves of CFCs through CFC storage enterprises/banks or distributors. According to the results of ***5.6 Inventory and stock list of CFC-11 and CFC-12***, the existing inventory could meet the CFC demand of the medical aerosol industry.

The supervision of the pharmaceutical industry is very strict. In 2009, the *Notice on Strengthening the Management of the Sale and Use of CFCs in the Medical Aerosol Industry* (Huanjingbianhan (2009) No. 72) was issued, requiring CFC production and sales enterprises and medical aerosol manufacturers to keep relevant evidence for reference. Therefore, illegal use of CFC-11 and CFC-12 in the industry is virtually impossible.

5.2 Evaluation of HCFC-22 production facilities

In this section, the possibility of conversion of HCFC-22 production lines to CFC-11 is analyzed and evaluated through systematic investigation of HCFC-22 production facilities.

HCFC-22 is the product with the largest output among HCFCs produced in China. Because of its excellent performance, it is used as a refrigerant and foaming agent in large quantities, and also used as the main raw material for the production of Polytetrafluoroethylene (PTFE). Based on the above demand, since 2000, the production capacity of HCFC-22 of China has increased rapidly, and the total production capacity has reached 757,000 tons in 2014. The *First Stage of HCFC Production Phase-out Management Plan* was implemented in 2013. Production line closure and quota reductions were conducted to implement the production phase-out of HCFC-22. At present, the goals of the first stage phase-out management plan have been successfully achieved. The S*econd Stage of HCFC Production Phase-out Management Plan* has started through a “bridging” allocation from the MLF but is pending formal approval. In 2018, China’s total capacity of HCFC-22 was 675,500 tons (excluding the capacity for newly established feedstock for self-usage).

According to the *Notice on Strict Control of New Construction, Reconstruction and Expansion of HCFCs Production Projects* (HuanBan[2008] No. 104) and the *Supplementary Notice on Strict Control of New Construction, Reconstruction and Expansion of HCFCs Production Projects* (HuanBanHan[2015] No. 644), new production facilities of HCFCs for controlled use such as refrigerants and foaming agents are prohibited across the country since 2008. New production facilities of HCFCs as special raw materials for chemical products should be constructed as supporting facilities in the same location as the downstream production facilities of the final chemical products. When the downstream production facilities are completed, put into operation and pass the EIA acceptance, the enterprise shall apply to the MEE for the construction of HCFC-22 production facilities with appropriate supporting capacity. After the MEE grants approval, the environmental protection department of the place where the enterprise is located shall accept, examine and approve the EIA Report (form) of the project in accordance with relevant regulations, and submit the approved project to the MEE for the record. On January 23, 2018, the above two notices were replaced by the *Notice on the Management of Construction Projects related to the Production and Use of Ozone Depleting Substances* (HuanDaQi [2018] No.

5), requiring that "ozone depleting substances produced only can be used as special raw materials for the enterprises' own downstream chemical products and shall not be sold externally". The construction of the new HCFC production project can start only after obtaining the EIA approval of the local environmental protection department.

According to the requirements of the *Notice on Strengthening the Management of Production, Sales and Use of HCFCs* (HuanHan [2013] No. 179), HCFC production enterprises shall submit data statements to the MEE quarterly and copy them to the provincial environmental protection authorities where the enterprises are located. As HCFC production enterprises belong to large chemical enterprises, local environmental protection departments will inspect such enterprises with a special focus. The inspection mainly covers the original records of transaction and use of raw materials and products, the relevant production process, and the conformity with the EIA documents. The inspection institutions and frequency can be arranged by the local environmental protection departments according to the actual situation of the regions.

From the perspective of production equipment and process flow, the production temperature and pressure level of HCFC-22 are higher than those of CFC-11, but their raw materials and process routes have not much difference – their reactors are both bubble type reactors, they both adopt the same catalyst $SbCl_5$ with no need for a new catalyst production unit, and they also have a similar post-treatment process. Therefore, from the perspective of production unit and process flow, an HCFC-22 production unit could be used to produce CFC-11 after appropriate modifications.

This section evaluates the operation status of HCFC-22 production unit by analyzing the output, unit consumption of production, product flow direction and market situation of China's HCFC-22 production industry, and discusses the possibility of illegal conversion of an HCFC-22 production unit to a CFC-11 unit.

Considering the time point of CFC-11 production phase-out, the targeted period of the evaluation is 2008-2018. During this period, there were 20 enterprises producing or once producing HCFC-22 in China, mainly distributed in Jiangsu, Zhejiang, Shandong, Sichuan and Fujian Provinces. Among them, 17 enterprises produced HCFC-22 products and sold them for controlled use or feedstock usage; and 3 enterprises produced for feedstock use only, which was used exclusively for downstream products and not for sale. Among the 17 HCFC-22 production enterprises, 12 are in normal operation, one enterprise has not operated since its completion, and four enterprises have closed their production lines; all 3feedstock usage production enterprises are in normal operation. The basic information of these enterprises is listed in Table 5.2-1. Through the survey on the production of the above 20 enterprises, the production data of enterprises that operate normally are basically collected, and only the data of one enterprise are not fully collected because of commercial confidentiality. For the closed enterprises, some data have been collected for two enterprises, while no data was collected for the other two due to their closing long before and staff departure.

Table 5.2-1Status of enterprises that currently produce or once produced HCFC-22

S/N	Enterprise name	ID	Production status	Product type	Information availability
1	Arkema (Changshu) Fluorochemical Co., Ltd.		Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
2	Changshu 3F Zhonghao New Chemical Materials Co., Ltd.	#15	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
3	Jiangsu Meilan Chemical Co., Ltd.	#17	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
4	Jinhua Yonghe Fluorochemical Co., Ltd.	#3	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
5	Linhai Limin Chemicals Co., Ltd.	#6	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
6	Shandong Dongyue Chemical Co., Ltd.	#20	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
7	Xingguo Xingfu Chemical Co., Ltd.	#28	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
8	Zhejiang Lanxi Juhua Fluorochemical Co., Ltd.	#8	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
9	Zhejiang Pengyou Chemical Co., Ltd.	#4	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
10	Zhejiang Quhua Fluorochemical Co., Ltd.	#1	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
11	Zhejiang Sanmei Chemical Co., Ltd.	#9	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Yes
12	Zhonghao Chenguang Research Institute of Chemical Industry	#25	Normal production	Sale of HCFC-22 products, for controlled or feedstock use	Section

S/N	Enterprise name	ID	Production status	Product type	Information availability
13	Fujian Sannong New Material Co., Ltd.		Normal production	feedstock use, not for sale	Yes
14	Zhejiang Jusheng Fluorochemical Co., Ltd.		Normal production	feedstock use, not for sale	Yes
15	Liaocheng Fuer New Material Technology Co., Ltd.		Normal production	feedstock use, not for sale	Yes
16	Jiangxi Yingguang Chemical Co., Ltd.		Not in production since long time ago	Sale of HCFC-22 products, for controlled or feedstock use	None
17	Zhejiang Yingpeng Chemical Co., Ltd.	#7	Production line closed	Sale of HCFC-22 products, for controlled or feedstock use	Section
18	Zhejiang Dongyang Chemical Co., Ltd.	#5	Production line closed	Sale of HCFC-22 products, for controlled or feedstock use	None
19	China Fluoro Chemical Technology Co., Ltd.	#21	Production line closed	Sale of HCFC-22 products, for controlled or feedstock use	None
20	Sichuan Honghe Fine Chemical Co., Ltd.	#26	Production line closed	Sale of HCFC-22 products, for controlled or feedstock use	Section

5.2.1 HCFC-22 production facilities and capacity

5.2.1.1 Introduction of HCFC-22 production facilities

(1) Introduction of the HCFC-22 production process

HCFC-22 is generated by the reaction of Chloroform (TCM) with AHF in the presence of $SbCl_5$. The reaction equation is as follows:

$$CHCl_3 + 2HF \xrightarrow{SbCl_5} CHF_2Cl + 2HCl \uparrow$$

At the same time, the following side reactions exist in the production process:

$$CHCl_3 + HF \longrightarrow CHFCl_2 + HCl \uparrow$$
$$CHCl_3 + 3HF \longrightarrow CHF_3 + 3HCl \uparrow$$

In the presence of catalyst, the raw material TCM and AHF are continuously added into the reactor under certain temperature and pressure to produce crude HCFC-22 gas products, and then continuously discharged out of the fluorination reactor. After deacidification and defluorination, the crude HCFC-22 gas product is compressed in a compressor, and the compressed gas liquefied into a crude product, which is then degassed, rectified (fractional distillation) and dried to obtain the final product HCFC-22.

(2) Introduction to HCFC-22 production facilities

HCFC-22 production facilities generally include raw material storage and a feeding system, fluorination reaction system, deacidification system, defluorination system and rectification system. The facilities of various HCFC-22 production enterprises are slightly different due to different process designs.

There are three HCFC-22 production enterprises that produce HCFC-22 for feedstock usage instead of sales, i.e. the HCFC-22 produced can only be used for internal downstream products. Their downstream products are Tetrafluoroethylene (TFE), which is prepared by dilution pyrolysis with HCFC-22 and superheated steam. The production facilities generally include cracking reaction system, cracked gas treatment system, a rectification system and a recovery system.

5.2.1.2 HCFC-22 capacity analysis

(1) HCFC-22 product manufacturer

There are 17 enterprises producing HCFC-22 products. Since 2013, the production capacity of HCFC-22 production enterprises for controlled use has not increased. In 2015, two HCFC-22 production enterprises, namely Zhejiang Yingpeng and Zhejiang Dongyang were closed as a whole, and their HCFC-22 production lines dismantled; in 2016, Linhai Limin and China Fluoro dismantled an idle HCFC-22 production line respectively; in 2017, Sichuan Honghe and China Fluoro dismantled an idle HCFC-22 production line by themselves respectively. By 2018, 12 enterprises are in normal production, and one enterprise has not produced since its establishment.

(2) HCFC-22 feedstock use production enterprises

According to the management requirements of the MEE on production facility construction projects based on HCFCs for feedstock use, from 2016 to 2018, three enterprises successively built new production plants of HCFC-22 for feedstock use in order to meet the production demand of the internal downstream product, TFE. The capacity of HCFC-22 was compatible with the capacity of TFE, HCFC-22 was transported to a downstream TFE facility by direct pipeline. These three facilities are “integrated” production facilities using HCFC-22 as feedstock.

5.2.2 Output and unit consumption of HCFC-22

5.2.2.1 Output of HCFC-22

(1) HCFC-22 production enterprises within the industry plan

The production and sales status of HCFC-22 production enterprises within the industry plan from 2013 to 2018 is shown in Table 5.2-2. From 2013 to 2018, the output of HCFC-22 for controlled use was constrained by production quotas and witnessed a significant downward trend. Since 2015, the output of HCFC-22 for feedstock use has increased year by year. Judging from the sales data, the sales and production of HCFC-22 were basically in balance, the sales of HCFC-22 for controlled uses were on the decline as a whole, and the HCFC-22 for feedstock use saw significant growth since 2015, which indicates that there is still a large space and strong market potential for development of HCFC-22 for feedstock usage.

Table 5.2-2 Production and sales of HCFC-22 at production enterprises within the industry plan (Unit: ton)

Year	Output		Domestic sales		Export	
	Controlled use	feedstock use	Controlled use	feedstock use	Controlled use	feedstock use
2013	288,493.01	327,407.94	195,002.02	308,025.35	93,490.99	19,382.59
2014	299,950.13	323,948.92	190,314.53	302,869.68	109,635.60	21,079.24
2015	243,888.95	291,040.90	154,387.58	270,697.60	89,501.37	20,343.30
2016	256,123.01	315,853.44	168,696.39	290,330.76	87,426.62	25,522.68
2017	244,479.21	348,568.26	172,982.66	320,590.60	71,496.55	27,977.66
2018	247,938.28	363,556.87	178,661.81	335,311.95	69,276.47	28244.92

(2) HCFC-22 feedstock use production enterprise

According to the survey data, the actual production of HCFC-22 in the three newly-built HCFC-22 feedstock usage production enterprises is consistent with the changing trend of downstream TFE production, with the quantities matched. In addition to maintaining necessary inventory of HCFC-22 to maintain the stable production of downstream TFE, the enterprises were not found to store a large amount of HCFC-22 or sell any HCFC-22 to the market.

5.2.2.2 Unit consumption of HCFC-22 as a raw material

In theory, if TCM reacts with AHF completely, 1.385 units of TCM and 0.46 units of AHF should be consumed per unit of HCFC-22. However, HFC-23 by-product in the reaction process is inevitable in actual production and accounts for 2.8-3.2% of the output. In addition, plus the dissolution of HCFC-22 in the water washing stage and the process loss of compressors, valves and other technological processes, 1 unit of HCFC-22 consumes about 1.44-1.45 units of TCM and 0.50 units of AHF. According to the collected data, the unit consumption of HCFC-22 production enterprises fluctuated around 0.5 from 2008 to 2018, with the maximum value of 0.56, 12% higher than the average level, the minimum value of 0.48, 4% lower than the average level. The unit consumption of TCM fluctuated around 1.45, with the maximum value of 1.52, about 5% higher than the average level, and the minimum value of 1.43, about 1% lower than the average level, but within the reasonable range of variation. Therefore, the unit consumption of raw materials in HCFC-22 production enterprises conforms to the normal reaction law of TCM and AHF.

For production enterprises of HCFC-22 for feedstock usage, the unit consumption of AHF is 0.49-0.56, with the maximum value of 0.56, 12% higher than the average level. The minimum value is 0.49, 2% lower than the average level. The unit consumption of TCM is between 1.39-1.53, with the maximum value of 1.53 – about 5.5% higher than the average level, and the minimum value of 1.39 is about 4% lower than the average level, but within the reasonable range of variation. Through analysis, the reason why the unit consumption of raw materials is slightly higher is due to the short production years of the three enterprises, and the unit consumption in the initial commissioning stage of the device is far higher than the normal production level, which has a great impact on the average unit consumption level.

Relevant research shows that the unit consumption of TFE can reach about 1.90[3], and the unit consumption of TFE of the three feedstock usage production enterprises is between 1.84 and 1.94. Therefore, it can be assumed that the TFE unit consumption of the three enterprises is within a reasonable range.[3] In conclusion, the raw material consumption of HCFC-22 feedstock usage production enterprises conforms to the reaction law of TCM and AHF, HCFC-22 and superheated steam.

5.2.3 Operation evaluation of HCFC-22 production facilities

5.2.3.1 Analysis on the operating rate (production/capacity) of HCFC-22 production facilities

(1) HCFC-22 producer

According to the collected data, among the current operating enterprises, except for some that have had their production lines idle for a long time and some that had abnormal production due to accidents, the average operating rate of enterprises reached more than 80%, and that of some enterprises even exceeded 100%. Because the chemical plant needs to be shut down for maintenance every year, judging the general production level of chemical enterprises, they

[3] Xie Xiaogang, Tan Jianming, Li Feilu. Energy saving and consumption reduction in tetrafluoroethylene production [J]. Chemical production and technology, 2014, 021 (001): 25-27

basically operate at full load. It also shows that these enterprises have relatively stable marketing channels for their HCFC-22 for controlled usage and feedstock usage.

In addition, for enterprises that shut down their production lines, Sichuan Honghe had a high operating rate from 2008 to 2012 and basically produced at full capacity. In 2014, due to operation difficulty, its business volume decreased, and its operating rate gradually dropped below 50%. In 2017, the enterprise went bankrupt and its HCFC-22 production line was closed and dismantled. Yingpeng Chemical maintained its operating rate over 70% from 2008 to 2014, and its production line was closed in 2015. Zhejiang Dongyang closed its production line in 2015; China Fluoro closed one production line in 2016 and 2017 respectively, and no longer produces HCFC-22.

(2) HCFC-22 feedstock usage production enterprise

From 2016 to 2018, among the three HCFC-22 feedstock use producers, the operating rate of Liaocheng Fuer was over 95%; Zhejiang Jusheng was put into trial operation in 2017 and achieved full-capacity production in 2018; in 2016-2017, the operating rate of Fujian Sannong was more than 60%. In 2018, due to the expansion of production capacity, the operating rate was only 55%. Accordingly, the operating rate of TFE plants was compatible with HCFC-22 produced, with a consistent rates of change/fluctuation.

5.2.3.2 Operation evaluation of HCFC-22 production facilities

As mentioned above, for the conversion of HCFC-22 production facilities to CFC-11, from the perspective of equipment and process technology, the modification cost of HCFC-22 production equipment, waste treatment and utility facilities is not high, and raw materials can be directly replaced for CFC-11 production with a little or even no modification of the plant. Therefore, in theory, the production facilities of HCFC-22 can be converted to CFC-11from the perspective of the production plant and process flow. However, there are many impact factors in the production of chemical enterprises, the possibility of illegal conversion of HCFC-22 production facilities to CFC-11 in reality must be analyzed from the aspects of production plant operation, capacity load, market demand, raw material procurement and government supervision.

(1) Operation of HCFC-22 production plant

- Analysis from perspective of operating rate

According to the previous analysis of the operating rate, most enterprises' facilities had an operating rate higher than 80% in most years, with little possibility of switching to other products. For some enterprises with low operating rate, such as Xingguo Xingfu, due to the impact of safety accidents from 2017 to 2018, according to the local government's requirements for accident handling and rectification, most of them were in the state of closure, with extremely low operating rates and nearly no possibility of switching to other products.

For the enterprises with closed production lines, their operating rates were very high during the normal production period, basically at full load, and these enterprises had only one production line, with nearly no possibility of switching to other products.

- Analysis from perspective of unit consumption of products

In the production process of HCFC-22, the unit consumption of AHF fluctuated around 0.5, and the unit consumption of TCM fluctuated around 1.45, both of which were within the reasonable range and in line with the normal reaction law of TCM and AHF. The unit consumption of TFE of the three feedstock usage production enterprises ranged from 1.84 to 1.94, which also conforms to the reaction law of HCFC-22 and superheated steam. Therefore, the production of HCFC-22 in China is at a normal level and there is little possibility of switching to other products.

- Analysis from the perspective of plant operations

Chemical production needs continuous operation of the plant. The more continuous the operation time, the better the stability of the equipment and the better the product quality. The HCFC-22 production facilities of the enterprises have been running continuously since start-up, for 24 hours a day without interruption, and production has stopped only during equipment maintenance and holidays. For enterprises with more than one production line, the strategy of rotating maintenance has been adopted to ensure smooth production. For enterprises with only one production line, the only way is to stop the production for maintenance.

If a plant were to convert to CFC-11 production halfway, the plant would need to stop for technical transformation, cleaning and replacement. After a period of operation, it would need to switch back to HCFC-22, and then the plant would also need to stop for technical transformation, cleaning and replacement, which would greatly damage the production facilities. This not only affects the stability of the equipment, but also seriously affects the quality of the product. Therefore, for normal producers, there is no incentive for switching to CFC-11. For enterprises with closed production lines, after closure the key production equipment (reactor) was all dismantled (and verified as such), so there is no possibility of starting CFC-11 production.

(2) Time cost

If an HCFC-22 production facility is converted to CFC-11, the technical transformation, cleaning and raw material conversion of the system needs time. If the purity requirement of CFC-11 is not high, it is preliminarily estimated that the technical transformation can be completed in 2-4 weeks. However, when CFC-11 is converted back to HCFC-22 production, due to the high purity requirements, the system cleaning is not only very difficult but also takes more time, so the time cost of production conversion and reconversion is very high. Moreover, the general rectification system is shared by multiple production lines, so it is necessary to stop the production of many lines in the plant area to do the conversion, which adds to the time cost of CFC-11 conversion. There is virtually no possibility of conversion.

(3) Market demand and capacity load

As one of the newer chemical materials, fluorinated chemical products are characterized by many varieties, excellent performance, wide applications, high performance and high added value. Since 2008, the demand for fluorochemical products in China and other countries around the world has witnessed an increase. The fluorination industry has become one of the sub-industries with the most rapid development, the most technological prospects and most development advantages among China's chemical industries.

HCFC-22 can be used not only as a refrigerant, foaming agent and for other controlled uses, but also as the main raw material for PTFE production and therefore, it has a broad market. Moreover, the added value of HCFC-22 products is higher than that of CFC-11, and the producers have considerable profit margins. In particular, due to the existence of the quota system, the industrial competition make-up has been solidified, and the monopoly positions of existing enterprises have been formed. Generally, the production enterprises will make great efforts to use their position to carry out production and sales and obtain considerable profits, and will not illegally engage in high-risk CFC-11 production.

In addition, as mentioned above, the average operating rate of HCFC-22 producers in normal production reaches more than 80%, and even some enterprises are basically producing at full capacity. In particular, the HCFC-22 production enterprises are of very large scale and have strict management standards. The HCFC-22 production plants are also of large scale, so it would take a long time for technical transformation, system cleaning and conversion in order to produce CFC-11, and would seriously affect the normal production orders of these producers. Therefore, under the current circumstances, there is no determinable reason for switching to any other substance. In particular, the profit from sales of CFC-11 would be insufficient to make up for the losses of HCFC production, so there is no economic driver for enterprises to switch to other products.

(4) Raw material purchase

As the main raw material for CFC-11 production, a lot of CTC would be needed for a large-scale plant conversion to CFC. As CTC production, sales and use are strictly controlled by the government, there are too many exposure points in the process to allow large-scale illegal procurement and use to occur. A large number of personnel are also involved in raw material procurement, product sales, workshop production, storage, and transportation making the procurement or use of these raw materials very difficult.

(5) Strict supervision

The World Bank conducts a comprehensive inspection of HCFC production plants (for consumption) every year. According to the verification of raw material supply, plant startup and shutdown time, equipment load, and HCFC production, it is confirmed that there is no conversion of HCFC-22 production facilities to CFC-11 at these producers.

To sum up, in theory, HCFC-22 production plants can be converted to CFC-11. However, due to the large size of current HCFC-22 producers, strict management standards, the large scale of HCFC-22 production facilities, operational conditions of the production units, cost from lost time, market demand and the production capacity load, raw material procurement and strict regulatory measures, the benefits of conversion cannot make up for the losses, and the risk is huge. There is neither economic driver, nor subjective or objective conditions for the producers to switch to CFC-11.

5.3 Analysis and assessment of CTC market information

The possibility of CTC illegal outflow is analyzed in this section through investigation of methane chloride manufacturers and enterprises with CTC feedstock use.

CTC is an ozone depleting substance with ODP of 1.1. It is mainly used as a processing agent and cleaning agent, or as the raw material for CFC-11 and CFC-12. It is also the chemical material to produce hundreds of non-ODS chemical products. China has fully phased-out production and consumption of CTC-controlled purposes since 2010. At present, CTC is only produced as the byproduct during methane chloride production. A little of CTC output is used for exempted additives and laboratory analysis, but other CTC byproduct must be used to produce non-ODS products as raw material or incinerated. For feedstock usage, CTC is mainly converted and disposed as the byproduct by methane chloride manufacturers through in-house CTC conversion devices, or is used as chemical raw material by other enterprises to produce other chemical products.

CTC is the main ingredient of CFC-11. Therefore, the management and control of CTC production and conversion process plays a key role in restricting illegal production of CFC-11. The CTC byproduct yield of methane chloride in China is about 5%. Since the total output of methane chloride is large, CTC byproduct output is also large. From the economic analysis of conversion, the economic efficiency of CTC conversion is found to better than that of incineration but far lower than that of sales as products. Thus, there is a market driver for enterprises to illegally trade in CTC.

In this section, data analysis for CTC generation, conversion and sales of methane chloride manufacturers is carried out, and the possibility of CTC illegal outflow is discussed; moreover, the material balancing calculation is applied to CTC use processes of enterprises using CTC as raw material so as to discuss reasonable CTC use and evaluate risks of CTC illegal outflow.

5.3.1 CTC production, conversion and disposal

In view of the timing of CFC-11 and CTC production and phase-out, this survey selected the time period of 2008-2018. During that period, there were twenty enterprises which were producing or once produced methane chloride in China, mainly distributed in Jiangsu, Zhejiang, Shandong, Sichuan, Jiangxi, Guangxi and Guangdong. At present, 16 enterprises are still producing the substance, and 4 have shut down the production line. The basic information of those enterprises can be seen in Table 5.3-1. Due to a time limit for data retention, full data of some enterprises during the investigated period could not be collected; data of the enterprises closure was also not collected due to reasons such as early shutdown or personnel changes.

Table 5.3- 1 Enterprises producing or once producing methane chloride

S/N		Production Status	Information availability
1	Shandong Dongyue Fluorosilicone Materials Co., Ltd.	Normal production	Yes
2	Shandong Jinling Chemical Co., Ltd.	Normal production	Yes
3	Shandong Jinling New Material Co., Ltd.	Normal production	Yes
4	Liaocheng Luxi Chloromethane Chemical Co., Ltd.	Normal production	Yes
5	Dongying Jinmao Aluminum High Technology Co., Ltd.	Normal production	Yes
6	Zhejiang Quhua Fluorochemical Co. Ltd.	Normal production	Yes
7	Ningbo Juhua Chemical & Science Co., Ltd.	Normal production	Yes
8	Jiangsu Meilan Chemical Co., Ltd.	Normal production	Yes
9	Jiangsu Lee & Man Chemical Company Limited	Normal production	Yes
10	Luzhou Xinfu Chemical Co., Ltd.	Normal production	Yes
11	Chongqing Tianyuan Chemical Co., Ltd.	Normal production	Yes
12	Jiangxi Lee & Man Chemical Company Limited	Normal production	Yes
13	Guangdong Shaoguan Ruyuan Dongyangguang Fluorine Co., Ltd.	Normal production	Yes
14	Chongqing Haizhou Chemical Co., Ltd.	Normal production	Yes
15	Guangxi Tiandong Jinyi Technology Co., Ltd.	Normal production	Yes
16	Jiangxi Shilei Fluorine Chemical Co., Ltd.	Normal production	Yes
17	Sichuan Honghe Fine Chemical Co., Ltd.	Production line closed	None
18	Shandong Haihua Chlorine & Alkali Resin Co., Ltd.	Production line closed	None
19	Luzhou North Chemical Industries Co., Ltd.	Production line closed	None
20	Wuxi Greenapple Chemical Industry Co., Ltd.	Production line closed	None

5.3.1.1 Production and reaction principles of methane chloride

At present, the production of methane chloride mainly utilizes the methanolhydro-chlorination process, which is divided into two steps, specifically as follow:

1) Methanol reacts with hydrogen chloride to generate chloromethane

$$CH_3OH + HCl \rightarrow CH_3Cl + H_2O$$

2) Chloromethane reacts with Cl_2 to generate dichloromethane and trichloromethane.

$$CH_3Cl + Cl_2 \rightarrow CH_2Cl_2 + HCl$$

$$CH_2Cl_2 + Cl_2 \rightarrow CHCl_3 + HCl$$

(Side reaction)

CTC is the byproduct of methane chloride production. The CTC byproduct yield rate may be controlled by adjusting reaction conditions and the proportion of dichloromethane and trichloromethane.

5.3.1.2 Production process of methane chloride

The production process of methane chloride mainly contains hydro-chlorination and chlorination. First of all, the gaseous methanol and hydrogen chloride gas are sent to the hydro-chlorination reaction unit with certain proportion, and generates chloromethane with the effect of a catalyst. The pure chloromethane is acquired after washing, alkali washing, drying, compression and condensation of gas discharged from the reactor. On one hand, it can be sold as a product by putting it in a storage cylinder and on the other hand it can be part of the next stage reaction in the chlorine reactor. At present, the methane chloride manufacturers have adopted gas-solid catalysis method while some have adopted gas-liquid catalysis method.

The pure chloromethane generated from hydrochlorination reactor generates chlorination with fresh chlorine in the chlorination reactor unit. The liquid methane chloride mixture is acquired after the gas output passes through rapid cooling circulating system, and then it enters the distillation unit. The finished products of dichloromethane and trichloromethane and coarse CTC can be generated through dichloromethane rectifying tower and trichloromethane distillation tower. For enterprises without qualifications for CTC sales, the coarse CTC is usually sent to an internal CTC converting device of the enterprise for disposal. For enterprises with the qualification for CTC sales, some coarse CTC enters into a CTC purification unit to become a CTC finished product. The residue on the bottom of tower is collected for further treatment.

5.3.1.3 Overall CTC production, conversion and sales situations

According to literature research and investigation of enterprises, there were a total 48 methane chloride production lines in 2018 in China with aggregate productivity of 2.838 million ton and average productivity of 59,100t/a per facility. They are characterized by a high degree of automation, continuity and are large in scale. The capacity of methane chloride in China has increased from 997,000t in 2008 to 2.838million ton in 2018 with annual average growth rate of 10.12%; the output[1]has increased from 897,000t in 2008 to 2.733 million tons in 2018, with an annual average growth rate of 10.62%. See Table 5.3-2.

Table 5.3-2 Overall CTC production, conversion and sales situation during 2008-2018 (Unit: ton)

Year	Methane chloride output	CTC output	CTC byproduct rate	CTC conversion and sales	Balance
2008	996,662.64	42,818.20	4.30%	42,631.69	186.50
2009	1,002,970.94	50,762.14	5.06%	50,092.73	669.41
2010	1,153,933.91	59,464.24	5.15%	58,151.85	1,312.39
2011	627,556.31	32,077.16	5.11%	31,309.85	767.32
2012	1,010,203.98	53,026.23	5.25%	51,932.03	1,094.20
2013	1,108,992.37	61,092.29	5.51%	60,414.71	677.57
2014	1,361,058.11	78,936.91	5.80%	80,134.00	-1,197.09
2015	2,146,412.34	96,558.08	4.50%	95,483.05	1,075.03
2016	2,272,657.91	105,033.29	4.62%	103,750.63	1,282.66
2017	2,586,664.38	122,268.85	4.73%	122,048.77	220.08
2018	2,733,319.52	139,119.92	5.09%	139,054.35	65.58

During 2008-2018, the CTC output in China has grown to 139,119.92t from 42,818.20t, with an annual average growth rate of 12.51%, which is consistent with the growth of methane chloride output. The byproduct rate[2] is 4.30%-5.80%, with an average of 5.01%. It is at a favorable level internationally.

CTC disposal at methane chloride manufacturers involves internal conversion and external sales. The total capacity of equipped CTC conversion devices in the manufacturing industry in 2018 is 246,500t for 7 types of converted products, which is higher than the CTC byproduct output (139,100t in 2018), shows enough CTC conversion capacity of methane chloride manufacturers. The on-site supervisors will check the liquid level meter and flow meter set for the CTC production, storage, conversion and other pathways, and verify the conversion volume of CTC. There are three methane chloride manufacturers with CTC sales qualifications, and are registered with the MEE every year. The CTC can only be sold to enterprises with CTC consumption quotas for feedstock use or exempted purposes. The CTC conversion and sales

[1] The annual output of methane chloride refers to the sum of dichloromethane and trichloromethane output.
[2] CTC byproduct rate = CTC output/ (dichloromethane output + trichloromethane output + CTC output) ×100%.

volume has increased from 42,631.69t to 139,054.35t during 2008-2018.

During that period, the balance between domestic "CTC byproduct output" and "CTC conversion and sales volume" is -1,197.09~1,312.39, largely within the production-adjusted inventory and statistical error. Results show CTC by product output has kept balance with conversion and sales, and there is no illegal outflow of CTC as feedstock use.

5.3.1.4 Summary of CTC byproduct situation of methane chloride manufacturers

The 16 methane chloride manufacturers follow normal production in China, and the CTC byproduct rate during methane chloride production at most manufacturers is within the normal levels. Chongqing Huasheng increased trichloromethane productivity in order to use the excessive chlorine productivity of its upstream chlorine-alkali factory, resulting in a higher CTC byproduct rate. Although the CTC production, sales and conversion at most enterprises cannot be kept in exact balance, the difference is usually less than 3% of the CTC byproduct rate. Specific analysis is as follows:

(1) The different value belongs to regular production-adjustments of the inventory. For instance, during CTC conversion, the CTC consumption rate of the downstream production process is unnecessarily fully consistent with the CTC generation rate during methane chloride production. When the consumption rate is small, the unconsumed CTC byproduct will be stored in the workshop temporarily, i.e., will be workshop inventory. For enterprises that sell CTC, the unsold CTC byproducts will be stored in the warehouse. From this perspective, the CTC byproduct output, conversion and sales volume are largely kept in balance.

(2) The methane chloride manufacturers usually keep CTC byproduct data for only three years. In this survey, the time period is from 2008 to 2018 – a large time span. Thus, some enterprises failed to provide data for the entire period but only provided data in recent years. The older data, such as historical production data in the past three or more years may not be sufficiently accurate so as to cause an incomplete balance between CTC production, sales and conversion.

(3) The statistical standards for CTC byproducts data of methane chloride manufacturers may be different. The statistical data of enterprises is divided into calendar year data and financial year data, which should not overlap. If some data is from the financial system, the data statistics may be inconsistent and show some error, i.e., CTC production, sales and conversion might also not balance completely.

5.3.2 CTC applications for feedstock use

During 2011-18 after CTC consumption phase-out, there were 34 enterprises which were producing or once produced products with CTC for feedstock use in China, mainly distributed in

Jiangsu, Zhejiang, Shandong, Jiangxi, Hebei and Shanghai. The production situation of the 34 enterprises was surveyed, and 16 enterprises replied, involving 11 product varieties. Description of the enterprises can be seen in Table 5.3-3.

Among the 16 enterprises, HFC-245fa manufacturers are 4, the most; triphenylmethyl chloride manufacturers and 2,4-dichloro-5-fluorobenzoyl chloride manufacturers are two each; and other 8 enterprises respectively produce one kind of product. In accordance with analysis on survey documents, the purchase amount, consumption amount and inventory of CTC every year could largely keep balance every year in aforesaid enterprises, and the raw material consumption of the product is within the reasonable and normal range, showing legal and complying CTC application and no illegal outflow of CTC feedstock usage in those enterprises.

Table 5.3-3 Description of 16 manufacturers with CTC feedstock use

S/N	Enterprise Name	Product
1	Sinochem Honeywell New Material Co., Ltd.	HFC-245fa
2	Zibo Aohong Chemical Technology Co., Ltd.	HFC-245fa
3	Cangzhou Lingang Heji Chemical Co., Ltd.	HFC-245fa
4	Zhejiang Quzhou Juxin Fluorine Chemical Co., Ltd.	HFC-245fa
5	Zhejiang Benli Technology Co., Ltd.	2,4-dichloro-5-fluorobenzoyl chloride
6	Changzhou Feiyu Chemical Co., Ltd.	2,4-dichloro-5-fluorobenzoyl chloride
7	Qing Dao XueJie Chemicals Co., Ltd.	Triphenylmethyl chloride
8	Jangxi Yuankang Silicon Industry Technology Co., Ltd.	Triphenylmethyl chloride
9	Jiangsu Youth Chemical Industry Co., Ltd.	Tetrachloro ester
10	Weihai New Era Chemical Co., Ltd.	Tetrachloropropane
11	Ningbo Juhua Chemical & Science Co., Ltd.	PCE
12	Shanghai institute of Organic Chemistry, Chinese Academy of Sciences	Chlorofluorocarbon oil
13	North China Aluminum Co., Ltd.	Light gauge foil
14	Jiangsu Lianhe Chemical Technology Co., Ltd.	LT350
15	Zhejiang Kangyuan Chemical Co., Ltd.	HFC-236fa
16	Hebei Veyong Bio-Chemical Co., Ltd.	Dimethylphosphine oxide

5.3.2.1 HFC-245fa

(1) Reaction process

CTC and vinyl chloride firstly generate an additive reaction under a catalyst effect and produce pentachloropropane, and then get pure pentachloropropane after desolventizing and double distillation; then in the fluorination section, pentachloropropane reacts with HF and generates HFC-245fa. According to the law of conservation of mass, per unit HFC-245fa should consume 1.15 unit of CTC theoretically. However, for chemical reactions, it is impossible to realize a 100% reaction. In addition to process losses, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption. Moreover, aforesaid reaction is a two-step reaction, and different output proportions may change per unit of consumption of HFC-245fa.

(2) Analysis on HFC-245fa manufacturers

Among aforesaid 16 enterprises using CTC for feedstock, four produce HFC-245fa. During 2014-2018, total CTC consumption is 51,824.26t. According to inventories of all enterprises in this industry, the average CTC inventory is about 7% of annual CTC consumption, belonging to a reasonable feedstock usage inventory level for chemical production. The per unit consumption of HFC-245fa production in most enterprises is 1.28-1.77, within a normal range. In several enterprises, the HFC-245fa production line was in commissioning or debugging stages with unstable product quality and unsatisfactory sales volumes. The HFC-245fa output was low, and the main device is in low load operation so that CTC per unit consumption is as high as about 3.

5.3.2.2 2,4-dichloro-5-fluorobenzoyl chloride

(1) Reaction process

As catalyzed by $AlCl_3$, CTC and 2,4-dichlor fluorbenzene generate a substitution reaction and produce 2,4-dichloro-5-fluorine - (trichloromethyl) benzene (trichloride for short); after quenching, washing and desolventizing, 2,4-dichloro-5-fluorobenzoyl chloride is produced through the hydrolysis reaction catalyzed by $FeCl_3$. According to the law of conservation of mass, per unit 2,4-dichloro-5-fluorobenzoyl chloride should consume 0.68 unit of CTC theoretically. However, for chemical reactions, it is impossible to realize a 100% reaction. In addition to process loss, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption.

(2) Analysis on 2,4-dichloro-5-fluorobenzoyl chloride manufacturers

Among aforesaid 16 enterprises using CTC as feedstock use, two produce 2,4-dichloro-5-fluorobenzoyl chloride. During 2015-2018, total CTC consumption was 11744.15t. According to the inventory situation, the industry average CTC inventory is slightly high, about 20% of annual CTC consumption, but still belonging to a reasonable feedstock inventory size for chemical production. The per unit consumption of 2,4-dichloro-5-fluorobenzoyl chloride production in the two enterprises is 0.70-0.77, within a normal range.

5.3.2.3 Triphenylmethyl chloride,

(1) Reaction process

As catalyzed by $AlCl_3$, benzene and CTC carry out an additive reaction, and the reaction product enters the hydrolysis section to produce triphenylmethyl chloride and a little triphenylcarbinol. It then enters the chlorination section after desolventizing, and the finished product of triphenylmethyl chloride is generated after refining. According to the law of conservation of mass, per unit triphenylmethyl chloride should consume 0.55 unit of CTC theoretically. However, for chemical reactions, it is impossible to realize a 100% reaction. In addition to process loss, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption.

(2) Analysis on triphenylmethyl chloride manufacturers

Among aforesaid 16 enterprises using CTC as feedstock, two produce triphenylmethyl chloride. During 2011-2018, total CTC consumption was 2713.78t. According to the inventory situation, the industrial average CTC inventory was about 11% of annual CTC consumption, belonging to a normal feedstock inventory level for chemical production. The per unit consumption of triphenylmethyl chloride production in the two enterprises is 0.61-0.87, within a normal range.

5.3.2.4 Tetrachloro ester

(1) Reaction process

CTC first reacts with 3,3-dimethyl-4-pentenoic acid methyl ester in the synthesis section to generate tetrachloro ester, and then the final tetrachloro ester product is obtained after acid pickling and desolventizing. According to the law of conservation of mass, per unit tetrachloro ester should consume 0.55 unit of CTC theoretically. However, for chemical reactions, it is impossible to realize 100% reactions. In addition to process loss, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption.

(2) Analysis on tetrachloro ester manufacturers

Among aforesaid 16 enterprises using CTC as feedstock, one produces tetrachloro ester. During 2011-2018, total CTC consumption in the enterprise was 13,622.50t. According to the inventory situation, the industrial average CTC inventory was about 7% of annual CTC consumption, belonging to a reasonable feedstock inventory level for chemical production. The per unit consumption of tetrachloro ester production in the enterprise was 0.56-0.59, within a normal range.

5.3.2.5 Tetrachloroethane

(1) Reaction process

Ethylene and excess CTC are put into the polymerizer to generate tetrachloropropane and a little high-boiling residue byproduct. The tetrachloropropane is separated according to the fractionation method. According to the chemical mass balance analysis, per unit tetrachloropropane should consume 0.85 unit of CTC theoretically. However, for chemical reactions, it is impossible to realize 100% reactions. In addition to process loss, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption.

(2) Analysis of tetrachloropropane manufacturers

Among aforesaid 16 enterprises using CTC as feedstock, one produces tetrachloropropane. During 2011-2018, total CTC consumption at the enterprise was 6473.55t. According to the inventory situations, the industrial average CTC inventory was about 12% of annual CTC consumption, belonging to a reasonable feedstock inventory level for chemical production. The per unit consumption of tetrachloropropane production at the enterprise is 0.83-1.01, within a normal range.

5.3.2.6 Perchloroethylene (PCE)

(1) Reaction process

Inlet CTC, HC and chlorine into the reactor to produce PCE and HCl after reaction under 600°C; the reaction products contain a little hexachloroethane byproduct, and non-reacted CTC and Cl_2. Then, the reaction products are sent to the quench tower; the coarse PCE, mainly PCE and some CTC, is collected from the quenching tower, and then enters the light component distillation tower to remove CTC, and at last enters the PCE refining tower to obtain the finished PCE product. According to the law of conservation of mass, per unit PCE should theoretically consume 0.46 unit of CTC. However, for chemical reactions, it is impossible to realize 100% reactions. In addition to process loss, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption. However, since the reaction temperature is controlled and reaction speed is adjusted by adding HC in the industry, the per unit product consumption will be lowered if per unit consumption is only calculated by CTC added.

(2) Analysis of PCE manufacturers

Among aforesaid 16 enterprises using CTC as feedstock, one produces PCE. During 2013-2018, total CTC consumption at the enterprise was 77,815.17t. According to inventory of all enterprises, the industrial average CTC inventory is about 2% of annual CTC consumption, belonging to a reasonable feedstock inventory level for chemical production. The per unit consumption of PCE production at the enterprise is 0.39-0.52 and floating around 0.46, within a normal range.

5.3.2.7 Chlorofluorocarbon oil

Among aforesaid 16 enterprises using CTC as feedstock, one scientific research institution produces chlorofluorocarbon oil. For confidentiality reasons, the institution failed to disclose technical information on production. The annual average CTC consumption is only 9.8t and for laboratory devices. Thus, the reaction principle and product per unit consumption will not be discussed here. During 2012-2018, total CTC consumption at the institution was 68.77t. According to the inventory situation, the average CTC inventory was about 30% of annual CTC consumption; the per unit consumption of chlorofluorocarbon oil production is about 8.61-8.92, and relatively stable.

5.3.2.8 Light gauge foil

(1) Reaction process

During production of light gauge foil, CTC is mainly used to remove the tiny bubbles generated by traces of H_2 in liquid aluminum. The aluminum ingot is melted in the furnace, and inlet CTC steam (Ar is the carrier gas); the black carbon generated by CTC splitting will be removed as scum; the aluminum liquid coming from the furnace will enter the holding furnace and be sent to rolling machine to produce light gauge foil after heat preservation for a while. During heat preservation, Ar gas containing CTC will still enter the furnace, and scum formed will be separated and removed when it is discharged.

(2) Analysis on light gauge foil manufacturers

Among aforesaid 16 enterprises using CTC as feedstock, one produces light gauge foil. Since CTC only plays the role of H_2 removal during light gauge foil production rather than actually participating in the reaction, per unit consumption of the product will not be analyzed here. During 2011-2018, total CTC consumption in the enterprise was 345.07t. According to the inventory situation, the average CTC inventory is about 41% of annual CTC consumption. The enterprise consumes very little CTC every year, while the CTC purchase amount is unbalanced. Therefore, the CTC inventory is large.

5.3.2.9 LT350

(1) Reaction process

CTC and methyl isobutyl ketone solvent are put into the reaction still, and cyclopentadiene is dripped to initiate the reaction. Non-reacted CTC is separated from the reaction products through distillation column I, and applied circularly; then gas MBIK is recovered and applied in the distillation column II after filter-pressing and the washing sections. Meanwhile, liquid LT350 product is acquired. According to the law of conservation of mass, per unit LT350 should theoretically consume 0.71 unit of CTC. However for chemical reactions, it is impossible to realize 100% reactions. In addition to process loss, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption.

(2) Analysis on LT350 manufacturer

Among aforesaid 16 enterprises using CTC as feedstock, one produces LT350. Since the enterprise failed to provide CTC inventory data from 2014 to 2018, the study was unable to analyze the CTC inventory balance. According to data provided, from 2014 to 2018, the total CTC consumption of the enterprise was 2128.56t, and per unit consumption of LT350 production was 0.71-0.84, within normal range.

5.3.2.10 HFC-236fa

(1) Reaction process

Vinylidene chloride and excess CTC first generate a telomeric reaction and produce Hexachloropropane. Coarse HFC-236fa is produced through the reaction of AHF and Hexachloropropane, which goes through the process of desolventizing and the double distillation. The finished product of HFC-236fa comes after rectification. According to the law of conservation of mass, the per unit HFC-236fa should consume 1.01 unit of CTC theoretically. However, for chemical reactions, it is impossible to realize a 100% reaction. In addition to process loss, side reaction consumption and high-boiling residues, the actual per unit consumption during production is far higher than the theoretical per unit consumption.

(2) Analysis of HFC-236fa manufacturers

Among aforesaid 16 enterprises using CTC as feedstock, one produces HFC-236fa. During 2015-2018, total CTC consumption at the enterprise was 1992.33t. According to the inventory situation, the industrial average CTC inventory was about 5% of annual CTC consumption, belonging to a normal feedstock inventory level for chemical production. The per unit consumption of HFC-236fa production at the enterprise is 1.29-1.94, within a normal range.

5.3.2.11 Dimethylphosphine oxide

(1) Reaction process

During the reaction process of CH_4 and PCl_3 to synthesize CH_3PCl_2, CTC is the initiator of a free radical reaction, and under high temperature, CTC reacts with CH_4 to convert to non-ODS substances such as carbon and dichlormethane.

(2) Analysis on dimethylphosphine oxide manufacturer

Among aforesaid 16 enterprises using CTC as feedstock, one produces dimethylphosphine oxide. During 2017-2018, total CTC consumption in the enterprise was 58.50t. According to the inventory situation, the CTC inventory is 100% of annual CTC consumption in 2017, while 8% in 2018. The reason is the enterprise put the production device into commissioning from 2017 and the production line was still in the debugging stage with low operation load, resulting in a high CTC inventory. After 2018 when the production line was put into normal operation, CTC inventory reached a reasonable feedstock inventory level of chemical production. Since CTC only plays the role of triggering the free radical reaction during dimethylphosphine oxide production rather than actually participating in the reaction, it is unnecessary to analyze the per unit consumption of the product.

5.3.3 Regulatory policies regarding CTC

China started phasing out CTC production and chemical auxiliaries in 2003 and has realized comprehensive phase-out of CTC production and application for controlled purposes except for special purposes since 2010. During that period, in order to promote the implementation of phase-out activities as per industrial plans, and normalize CTC supervision, China issued a series of measures and gradually established and improved the CTC management mechanism, as shown in Table 5.3-4.

Table 5.3-4 Regulation and policies regarding CTC

Time of Issuance	Name
2003	Notice on Strictly Controlling New (Expanded) CTC Production Projects (HuanBan [2003] No.28)
2003	Notice on Implementation of CTC Consumption Quota License Management
2003	Management Measures for On-site Supervision of CTC Manufacturers (HuanJingHan [2003] No.21)
2005	Notice on Implementation of CTC Production Quota License, Consumption Quota License and Sales Registration Management (HuanHan [2005] No.289)
2006	Supplementary Notice on Strictly Controlling New (Expanded) CTC Production Projects
2009	Bulletin on Restriction of CTC Production, Procurement and Application (Ministry of Environmental Protection [2009] No.68)
2018	Notice on Management of Ozone-Depleting Substances Production and Consumption Construction Project (HuanDaQi [2018] No.5)

5.3.3.1 Supervision of CTC production

(1) Preapproval of construction projects

According to Article 3 in the *Notice on Strictly Controlling New (Expanded) CTC Production Projects* (HuanBan[2003] No.28) issued by the former State Environmental Protection Administration, the project owner shall make a written commitment about the disposal method of CTC byproduct device (production line) construction project to the State Environmental Protection Administration before submitting to each level of environmental protection department for approval. The FECO and MEE shall take charge of the application acceptance, form examination and organize experts to carry out a technical review. Before 2018, this measure played an important role in the compliance with the MP, and also normalized industrial orderliness. In order to streamline the administration and delegate powers to lower levels, while normalizing administrative approval matters, the Atmosphere Division of the former Ministry of Environmental Protection released the *Notice on Management of Ozone-Depleting Substances Production and Consumption Construction Project* (HuanDaQi[2018] No.5) to cancel preapproval matters of CTC byproduct construction projects. It clearly proposes however management requirements for CTC byproduct construction projects, i.e. they"should build CTC disposal facilities for all new, reconstructed or expanded construction project which has CTC as byproduct".

(2) Online flow monitoring of CTC manufacturers

All of the 16 normal production enterprises have installed CTC online flow and liquid level monitoring systems. The online real-time flow monitoring system mainly applies real-time monitoring on CTC flow and liquid level in the steps of CTC production, storage, conversion or sales. The system, with flow meter as the front-end data acquisition unit, realizes remote data transmission by means of wireless data communication. After the data is sent to the server in the monitoring center, it is convenient for the management or operations personnel to check the real time data at any time.

In the CTC production process, the flow meter mainly monitors the flow of coarse CTC entering CTC rectification system and the flow of CTC from monitor tank to the receiving tank; and simultaneously monitors the liquid level of heavy ends after TCM rectification, and the coarse CTC storage tank and CTC checking tank.

In the CTC storage process, enterprises with CTC sales qualifications will install flow meters for sales to the receiving tank to monitor CTC sales volume. Moreover, they will install the flow meter for conversion to monitor CTC conversion amounts. Meanwhile, they will simultaneously monitor liquid levels in the receiving tank.

In the CTC conversion process, the flow meters are installed to the inlet and outlet of the reactor to monitor CTC amounts entering the reactor and the product amounts produced.

In the CTC residual disposal process, although no flow meter is installed, enterprises will monitor the change in liquid levels.

(3) On-site supervision at CTC manufacturers

The *Management Measures for On-site Supervision of CTC Manufacturers* (HuanJingHan[2003] No.21) issued by the former State Environmental Protection Administration requires "implementing on-site production supervision in chemical manufacturers who have CTC production quota license". Although the CTC production quota license management has been cancelled, on-site production supervision is still applied to methane chloride manufacturers which have CTC byproducts. The onsite inspectors mainly consist of technical or management personnel of other methane chloride manufacturers, experts assigned by the MEE or staff of local environmental protection organs. The onsite inspectors shall check the CTC production situation at the production site, record changes in CTC and rectification residue production, sales and inventory, and report on the production situation of enterprises under supervision to the law enforcement bureau of the MEE.

5.3.3.2 Supervision of CTC sales and applications

(1) Consumption quota for exempted purposes

The MEE will apply quota license management to exempted CTC for laboratory analysis or auxiliary purposes. In recent years, the number of enterprises with such applications is 8. From 2013 to 2018, the CTC consumption quota of 289t-395t was issued to these 8 enterprises, seen in Table 5.3-5.

Table 5.3-5 Quota issued to enterprises for exempted CTC purposes during 2013-2018 (unit: ton)

No.	Enterprise Name	2013	2014	2015	2016	2017	2018
1	Rionlon Bohua (Tianjin) Pharmaceutical & Chemical Co. Ltd.	41	41	41	41	41	41
2	Tianjin Kemiou Chemical Reagent Co., Ltd.	20	20	20	20	20	20
3	Guangdong Guanghua Sci-Tech Co., Ltd.	11	11	11	11	11	11
4	Chinasun Specialty Products Co., Ltd.	40	40	40	40	40	40
5	Tianjin Aoran Fine Chemical Research Institute	40	40	40	40	40	40
6	Xilong Chemical Co., Ltd.	18	18	18	18	33	33
7	Nanjing Chemical Reagent Co., Ltd.	30	30	30	30	30	30
8	CNPC Jilin Petroleum	89	180	180	180	180	180

(2) Registration for use and sales as feedstock usage

The MEE shall apply annual registration management to enterprises using and selling CTC as feedstock. For the enterprises using CTC as feedstock, its use should be announced and its usage controlled, but MEE will not restrict the amount of usage. In 2018, there were in total 23 enterprises using CTC as feedstock to produce non-ODS chemicals such as PCE, tetrachloroethane, HFC-245fa, HFC-236fa and triphenylmethyl chloride, and pesticide and medical intermediates such as 2,4-dichloro-5-fluorobenzoyl chloride, dimethylphosphine oxide and DV chrysanthemoyl chloride.

In recent years, the number of registered CTC selling enterprises remains stable, and numbers at 7 in 2018 including 3 methane chloride manufacturers, 1 CTC rectifying enterprise and 3 CTC dealers. Aforesaid enterprises are only allowed to sell CTC to enterprises with CTC consumption quota or enterprises registered as CTC feedstock users..

5.3.3.3 Supervision and management measures analysis

The MEE is responsible for registration and documentation of the enterprises for sales and use, as well as supervision and management of CTC production, conversion and sales through the CTC online flow monitoring system and on-site supervision. Local governmental ecology and environmental departments are responsible for the EIA examination and approval of CTC construction projects and the consumption enterprises, as well as routine supervision and management of the production activities of relevant enterprises. The cooperation between national and local governmental ecology and environmental departments covers all aspects of CTC-related enterprises which can effectively prevent illegal outflows of CTC.

In addition, in accordance with RAODS, CTC byproduct enterprises, sales enterprises and consuming enterprises shall all report corresponding data regarding CTC production, sales, disposal, procurement, use and storage to the MEE as required. The FECO, MEE will periodically carry out a survey on CTC feedstock use, and take samples from enterprises using CTC as feedstock with a certain ratio for field investigation; checking whether sales information of CTC manufacturers is authentic and whether enterprises using CTC as feedstock use resold CTC by checking CTC procurement and consumption records. Data submission and the enterprise data verification system play an important role in preventing illegal outflows of CTC.

5.4 Inventory and stock list of CFC-11 and CFC-12

CFCs were phased-out on July 1, 2007 in China. However, one CFC producer was left to meet CFC demand for MDIs. At the same time, China reserved 500t CFC-11 and 3000t CFC-12, and some enterprises also reserved certain CFCs to meet CFC consumption demands of non-inhalation medical aerosols and the refrigeration servicing sector in 2008 and later years. This section sorts out list data of CFC-11 and CFC-12 investigated and collected, prepared stock list and evaluated the justification for stock changes.

5.4.1 CFC-11 and CFC-12 inventory and stock list preparation

The national stock of CFCs was respectively stored in Zhejiang Quhua, Changshu 3F, Jiangsu Meilan and Zhejiang Dongyang. Moreover, Zhejiang Quhua reserved one CFC production line to meet production demands of MDIs. This production line was shut down in 2015. Relevant connection pipelines of the feeding system were removed, and the chemical reaction system and rectification system devices have been used in the production process of HCFC-22. This production line is subject to the management of HCFC-22 production enterprises. According to investigation results of CFCs production, sales, export and incineration data during 2008-2018, the stock list of CFC-11 and CFC-12 is prepared, as shown in Table 5.4-1 and Table 5.4-2.

5.4.2 Analysis on stock changes of CFC-11 and CFC-12

For CFC-11, the CFC-11 newly produced by Zhejiang Quhua could only be purchased and used by MDI manufacturers. Except for domestic MDI demand, it could also be exported for MDI purposes. During 2008-2018, a total 986.72t was produced. The CFC-11 inventory contained 500t of national inventory and 223.2t of enterprise inventory. During 2008-2018, a total 1080.14t was sold domestically, 426.03t was exported and 199.9t was incinerated. Moreover, 2.15t was lost due to damaged packaging. By the end of 2018, the remaining CFC-11 inventory was only 1.07t.

For CFC-12, the CFC-12 newly produced by Zhejiang Quhua could only be purchased and used by MDIs manufacturers; except for domestic MDI demand, it shall be exported for MDI purposes only. During 2008-2018, a total 2887.5t was produced. The CFC-12 inventory contains 3000t in the national inventory and 1275.79t in the enterprise inventory. During 2008-2018, a total4562.32t was sold domestically, 1954.91t was exported and 3.76t was lost due to damaged packaging. By the end of 2018, the remaining CFC-12 inventory was only 642.3t.

In summary, newly produced CFCs and inventory met demands of medical aerosol and refrigeration servicing, and data of production, consumption and export matched. The CFC production line was shut down in 2015, and the consuming enterprise (MDI manufacturer) stopped using CFCs. It was also no longer exported. Some CFC inventory was incinerated since it was contaminated, and the remaining is stored properly in the storage enterprises under a strict account management system for subsequent sudden consumption demands. Therefore, from the CFC stock list, the risk of illegal CFCs inventory outflow is low.

5.4.3 CFCs inventory management

Zhejiang Quhua needs to submit CFCs production quota application to the MEE every year for new CFCs production for essential use, and organizes production according to the production quota issued by the MEE. The sales of newly produced CFCs shall adopt "sales registration management" method only for the purpose of MDIs production. Zhejiang Quhua will directly sell CFCs to MDIs manufacturers, and the manufacturers shall guarantee to apply it to MDIs production. The manufacturers and users shall reserve relevant evidences for future reference. The CFC inventory can only be used for the non-inhaled medical aerosol and for servicing and must abide withthe account management system.

The account management system in itself is systematic and rational for inventory sales management, but the supervision department of government should strengthen monitoring of the implementation of the account management system.

Table 5.4- 1 CFC-11 inventory use situations

Name	Types	Closing inventory in 2007	Production during 2008-2018	Sales during 2008-2018			Breakage amount	Incineration amount	Closing inventory in 2008
				Domestic sales	Export volume	Subtotal			
Total	National reserve	500	0	400	0	400	0	100	0
	Enterprises' reserve	223.2	986.72	680.14	426.03	1106.17	2.15	99.9	1.7
	Total	723.2	986.72	1080.14	426.03	1506.17	2.15	199.9	1.7

Table 5.4- 2 CFC-12 inventory use situations

Name	Types	Closing inventory in 2007	Production during 2008-2018	Sales during 2008-2018			Breakage amount	Closing inventory in 2008
				Domestic sales	Export volume	Subtotal		
Total	National reserve	3000	0	2310.71	312.47	2623.18	2.15	374.67
	Enterprises' reserve	1275.79	2887.5	2251.61	1642.44	3894.05	1.61	267.63
	Total	4275.79	2887.5	4562.32	1954.91	6517.23	3.76	642.3

6. Assessment Conclusions and Recommendations

6.1 Summary of the Review of China's ODS Regulatory and Policy Framework

Since becoming a Party to the MP, China has established and implemented over a hundred laws, regulations and policies at both the national and local levels in accordance with the MP. Requirements and management principles for ODS phase-out are laid out in the APPL. The management and supervision of all aspects of the ODS lifecycle is detailed in RAODS. Furthermore the NP formulates the objectives, technical route to achieve objectives and the action plan for ODS phase-out in China and is reflective of the ODS phase-out plans under the MLF.

Together these law and regulations, policies and measures set forth specific and detailed requirements on new construction of ODS production and manufacturing facilities, ODS production, sales and use in various applications, import/export, recovery, reutilization, destruction, and substitute development, and management and supervision of MP implementation. Through key policy measures including maintaining a controlled substances list and catalogue, rules on new and expansion of production and manufacturing facilities, a quota and licensing system, gradual industrial conversion, promotion of ODS substitutes, and ODS bans, China has phased out the production and consumption of CFCs, Halons, CTC, TCA and MBr for controlled purposes, exceeded the HCFCs phase-out tasks for the first phase, completed the implementation goals required by the MP as scheduled, and gradually ceased essential use and critical use exemption. Till now, China has phased out some 280,000 tons of ODS, accounting for more than half of the ODS phased out by developing countries.

Similarly, China's ODS regulatory and policy framework has established and put a mechanism into place to continuously improve ODS supervision and management at both the national and local levels. Oversight, supervision and management rely on certain mandated institutions. The NLGPOL consists of the MEE, other national ministries and commissions, and contains specialized entities for ensuring MP compliance, including the I/E Office, the Coordination Group for MP Compliance within MEE and its offices, and the PMO of MEE. Institutions for ODS supervision and management at the local level are comprised of ecological and environment departments of the provincial, municipal and county government. The Coordination Group Office takes charge of routine work related to MP compliance. In the top-down supervision and management system of China, the national level is primarily responsible for policy formulation, developing overall plans, decision-making and conducting supervision and management over implementation of policies at local levels. The local level ecological and environmental departments of the provincial, municipal and county government execute national policies and plans, conduct on site supervision and inspection, and enforce the law. Supervision and management are carried out mainly on ODS-related project, licensing system for import and export, production and consumption quota system, ODS phase-out activities and data report.

The study found that the Chinese government, both at the national and local levels, has well incorporated supervision and management of ODS production and use into their conventional environmental supervision and law enforcement system; with routine environmental supervision according to law. Of note is the organization of special ODS supervision and law enforcement actions according to compliance progress determined by both national and local level authorities. The guiding principle of supervision and management is regular supervision of the market and industry in order to prevent and mitigate any nonconformance with rules and regulations.

It is because of an effective regulatory and policy framework and particularly through special campaigns and law enforcement that some illegal CFC-11 production and consumption has been identified and prosecuted over the period of study, namely in the rigid PU foam industry. This however can be characterized as small - in scale, of short duration and occurring in more remote areas where routine supervision and management capacity is weaker. Several cases that highlight these findings are included in the report.

Because of these select cases, the study finds room for further improvement of the ODS regulatory, policy and management framework, but more specifically related to the latter element entailing more comprehensive or consistent supervision throughout the country to prevent and detect breaches, and enforcement to discourage additional breaches from occurring. The study found that a sustainable compliance mechanism after initial phase-out goals have been achieved is needed along with better delineation of compliance responsibilities at different levels of government. Punitive penal policies require strengthening while incentive policies should be formulated to foster innovation in alternative technologies and processes, and rules detailed that promote substitute technologies. Increased information is central to preventing and detecting illegal actions and hence actions to prevent data gaps in the established national ODS phase-out and compliance information system are needed, particularly along the divide between MEE-EEB jurisdictions. Relatedly, capacity building of local government to build or enhance ODS monitoring capacity, including in strategically determined locations is needed.

6.2 Summary of the Market Survey and Data Assessment

After CFC-11 was phased-out in 2007 in the PU foam sector, the industry had successfully adopted substitute technologies, primarily HCFC-141b, HC, HFCs, water and methyl formate. Using 2008-2018data acquired through the market survey, the study carried out a mass-balance analysis of raw materials linked to rigid PU foam manufacturing. The results suggest that widespread production and consumption of CFC-11 during this period is unlikely. Based on the balance conditions between the market survey amounts of foaming agent and that derived from polymeric MDI market data, a foaming agent shortage might have occurred during 2008-2010 subsequent to the CFC-11 phase-out. As a consequence, there could have been illegal CFC-11 use to fill the shortage but considering that the market often stockpiles upon an impending ban, the gap could have equally been met in full, or partially by CFC-11 stocks existing after 2007.

In the household refrigeration industry, the key to sustainable phase-out of the main refrigerant of CFC-12 was a commercially viable substitute for refrigerators and freezers. According to materials and data for the period 2008-2018acquired through market survey, the study carried out an economic analysis on alternative technologies and estimated consumption amounts of these various refrigerants. Results show the refrigerants available on the market could completely meet industrial requirements therefore reducing the possibility for illegal use of CFC-12.

In order to replace CFC-11 and CFC-12 refrigerant in the industrial and commercial refrigeration industry, the new equipment has to be specially designed to accommodate the substitute refrigerant. These changes to the production process and equipment are prohibitive for reconversion to CFCs, leaving a possible small amount of CFC-11/CFC-12 refrigerant needed for maintenance of old, installed units. This small amount alone would make it highly unlikely there is any significant demand for CFCs in this sector.

For mobile air conditioning, newly produced vehicles cannot be installed with units based onCFC-12 refrigerant due to the long-established industry standard around the world based on HFC-134a. The economic analysis of refrigerant technology in mobile air conditioning systems and analysis and calculation of the potential inventory CFC-12 indicate that the possibility of illegal use of CFC-12 in auto repair field is low. For pharmaceutical aerosols, newly produced and inventoried medical-grade CFCs could meet this industrial demand. Moreover, the regulation of the pharmaceutical industry is strict, and virtually impossible to use CFCs illegally.

Theoretically speaking, HCFC-22 production can be converted to produce CFC-11 or CFC-12, but according to analysis and assessment of information and data including on the configuration of HCFC-22 production facilities, product capacity, raw material consumption, and the rate of operation during 2008-2018, the loss outweighs the gain for production line conversion. There is no economic driver for an enterprise to produce CFC-11 or CFC-12, nor subjective and objective conditions for production conversion.

CTC is the inevitable byproduct of methane chloride production. CTC generated may be sold legally as raw material, sold for exempted use purposes, used by methane chloride manufacturers directly as raw material, converted to a non-ozone depleting substance, or incinerated as residue product containing CTC. The study determined that over the period of review, CTC output has been largely balanced with its consumption as a raw material for non-ODS uses, for converting to a non-ODS, and with its sales volume as a legal raw material.

As CFCs were phased-out in 2007 and in order to meet immediate CFC demand of the pharmaceutical non-inhaled aerosol industry as well as the refrigeration servicing sector, China legally dedicated one CFC production line. It stored 500t CFC-11 and 3000t CFC-12. In total, this dedicated line produced 986.72t of CFC-11 and 2,887.5t of CFC-12 and was shut down completely by 2015. The data on CFC-11 and CFC-12 production, consumption and export from 2008 to 2018 largely reconciled. In 2018, a total 1.7t of CFC-11 and 642.3t of CFC-12 was left in stocks. As the account management system is scientific and rational for the inventory sales management, the risk of CFC illegal outflow is low.

6.3 Conclusions and Recommendations

Based on the review, analysis and evaluation of the laws and regulations, supervision and administrative system, and the qualitative and quantitative market information obtained from the market survey, the study concludes that widespread production and consumption of CFC-11 in the rigid PU foam sector during 2008-2018 was highly unlikely in China. This achievement is testament to the effectiveness of laws, regulations, systems and policies established and implemented. These include a supervision and management system that extends from the national level to the local level, the quota and licensing system, introduction of targeted policies and management measures, industrial conversions, and data reporting.

According to the mass-balance estimates using data acquired from the market survey, however, during a short time immediately after CFC-11 phase-out, there appears to have been a shortfall of CFC-alternatives for foam blowing. Therefore, one conclusion could be that CFC-11 use as a foaming agent might have existed to fill this shortage, which might be from illegal CFC-11 or stocks built by the private sector during the final years of CFC-11 consumption. More recently, isolated cases of limited illegal production and use of CFC-11 were found through the campaign led by MEE. The study examined circumstances that might have influenced this outcome and draws several conclusions and puts forward related recommendations as follow for reference:

- ***Complement and enhance legal provisions on sustainable compliance with the MP in the established ODS regulatory and policy framework and accelerate the revision of RAODS***. Over the years of implementation, it was found that there are some short comings relevant to the provisions of the RAODS, including the challenges in dealing with already banned ODS. Specific regulatory or policy measures could help sustain bans. In addition, improved rules and policies that can ensure timely detection of illegal production, import/export, and consumption are necessary given that illegal actors fall outside the normal regulatory purview of authorities.

- ***Further clarify the roles and responsibilities of each relevant actor for sustainable compliance with the MP, strengthen the efforts and frequency of routine ODS law enforcement at the local levels, and increase the penalties for violations of the law***. The study found there is a lack of coordinated and consistent revisions to RAODS and implementing rules when other relevant laws are revised. This includes not comparing the similarities and differences between ODS emissions and the discharge of other common environmental pollutants which would facilitate and streamline the work of local officials during site inspections. Most notably the study revealed that penalties for violations are not always consistent with the costs of violations, and not enough to deter illegal action and potential economic gains.

- ***Improve incentives for innovation and development of alternative technologies and substitutes.*** There should be practical and specific incentive policies for each sector to further encourage and support the research, development and application of substitutes through market mechanisms as this may address the perception in the market that alternatives are higher in price or lead to poor product quality. These policies could include technical standards and economic instruments. In many cases, although the cost of developing, promoting and applying new technologies and products is fairly high, it is still a better choice than the social and environment costs of older technologies and the need to mobilize government and social resources for strict inspection, testing, and supervision and enforcement.

- ***Improve the national information management system for ODS phase-out and compliance with the MP, strengthen coordination, information communication and knowledge sharing between the MEE and local ecological environment departments.*** Currently there exists an overall on-line HCFCs information management system in China with functions including the management of HCFCs quota application, registration application and data reporting. Some provinces and municipalities established their own on-line registration system for registration management and data reporting. A more sophisticated information management system should be updated based on existing HCFCs information management system aiming to consolidate all local systems into an overall system, extend the scope to all ODS, get a picture of the overall situation of ODS production, sales and consumption in the country and promote information sharing between MEE and local EEBs. The assessment found capacity building efforts of local government requires strengthening in order to ensure and sustain future MP implementation.

Enhance capacity for ODS detection and analysis, and strengthen and expand technical

training on rapid detection equipment. Prior to 2018 there was a lack of necessary ODS testing equipment and monitoring personnel, in particular, basic environmental law enforcement agencies were not equipped with necessary testing equipment. Equipment is being provided but more is needed, as is standardized ODS sampling and testing.

Annex 1 Calculation and analysis of rigid PU foam production and consumption balance model

(1) Rigid PU foam production and consumption balance model

1) Modeling

Make i represent various foaming agents, i=1-7 respectively represents HCFC-141b, HC, HFC, HFO, water and methyl formate; j refers to various industries, and j=1-9 respectively represents refrigerator, freezer, water heater, pipe thermal insulating, spraying, plates, cold closet, filler, automobile and other industry.

The definition of matrix is as follows:

A (7×9): a_{ij}= Use amount of the i foaming agent in the j sub-industry

$$A = \begin{pmatrix} a11 & \cdots & a19 \\ \vdots & \ddots & \vdots \\ a71 & \cdots & a79 \end{pmatrix}$$

B (7×9): b_{ij}= the use amount of black material, i.e., polymeric MDI, in the i foaming agent and the j sub-industry

$$B = \begin{pmatrix} b11 & \cdots & b19 \\ \vdots & \ddots & \vdots \\ b71 & \cdots & b79 \end{pmatrix}$$

D (7×9): d_{ij}= the use amount of white material in the i foaming agent and the j sub-industry

$$D = \begin{pmatrix} d11 & \cdots & d19 \\ \vdots & \ddots & \vdots \\ d71 & \cdots & d79 \end{pmatrix}$$

T (7×7): t_i= total annual consumption amount of various foaming agents, diagonal matrix.

$$T = \begin{pmatrix} t1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & t7 \end{pmatrix}$$

M (9×9): m_j= total annual consumption amount of black material, i.e., polymeric MDI, in various sub-industries, diagonal matrix.

$$M = \begin{pmatrix} m1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & m7 \end{pmatrix}$$

H (7×9): h_{ij}= black material mass/white material mass =b_{ij}/d_{ij}.

$$H = \begin{pmatrix} h11 & \cdots & h19 \\ \vdots & \ddots & \vdots \\ h71 & \cdots & h79 \end{pmatrix}$$

H_t(7×9): replace every element in H matrix with its reciprocal

$$H_t = \begin{pmatrix} 1/h11 & \cdots & 1/h19 \\ \vdots & \ddots & \vdots \\ 1/h71 & \cdots & 1/h79 \end{pmatrix}$$

R (7×9): r_{ij}=foaming agent mass/white material mass=a_{ij}/d_{ij}.

$$R = \begin{pmatrix} r11 & \cdots & r19 \\ \vdots & \ddots & \vdots \\ r71 & \cdots & r79 \end{pmatrix}$$

R_t (7×9): replace every element in R matrix with its reciprocal

$$R_t = \begin{pmatrix} 1/r11 & \cdots & 1/r19 \\ \vdots & \ddots & \vdots \\ 1/r71 & \cdots & 1/r79 \end{pmatrix}$$

E (7×9): $e_{ij}=a_{ij}/t_i$, $\sum_{k=1}^{9} e_{ik} = 1$, k=1-9 represents every each sub-industry.

$$E = \begin{pmatrix} e11 & \cdots & e19 \\ \vdots & \ddots & \vdots \\ e71 & \cdots & e79 \end{pmatrix}$$

P (7×9): $p_{ij}=b_{ij}/m_j$, $\sum_{k=1}^{7} p_{kj} =1$, k=1-7 represents each foaming agents.

$$P = \begin{pmatrix} p11 & \cdots & p19 \\ \vdots & \ddots & \vdots \\ p71 & \cdots & p79 \end{pmatrix}$$

According to aforesaid definitions, the following relations can be derived:

$a_{ij}=e_{ij}\times t_i$

$b_{ij}=p_{ij}\times m_j$

$a_{ij}=r_{ij}\times d_{ij}$

$b_{ij}=h_{ij}\times h_{ij}$

$a_{ij}= (r_{ij}/h_{ij})\times b_{ij}$

$b_{ij}=(h_{ij}/r_{ij})\times a_{ij}$

$\sum_{k=1}^{9} e_{ik} = 1$, k=1-9

$\sum_{k=1}^{7} p_{kj}$ =1, k=1-7

Thus, aforesaid matrixes show the following relations:

$A=E\cdot T$

$B=P\cdot M$

$A=R\circ H_t\circ B$

$B=H\circ R_t\circ A$

In aforesaid formulas, the symbol ◦ means Hadamard product of the matrix and symbol · refers to the common product of matrix.

The annual consumption data of various foaming agents are acquired through market survey so as to obtain the data of matrix T.

The annual consumption data of black material (polymeric MDI) in various industries including refrigerator, freezer, water heater, pipe thermal insulating, spraying, plates, cold closet, filler, automobile and other industry are acquired through market survey so as to obtain the data of matrix M.

The distribution proportion of various foaming agents in different industries can be obtained through industrial process analysis, professional judgment and the market survey, so as to get data of matrix E.

The proportion of black material and white material in different sub-industries can be estimated through industrial process analysis, expert judgment and the market survey, so as to get data of matrix H.

The proportion of foaming agents in various white materials can be estimated through industrial process analysis, expert judgment and the market survey, so as to get data of matrix R.

2) Material balancing calculation of rigid PU foam

(a) First, use the ratio of black and white materials, the proportion of foaming agents in white materials, the use ratio range of various foaming agents in various industry sub-sectors, and the proportions of various foaming agents' consumption amount to estimate the proportion of the black material in various sub-industries and various foaming agents.. The calculation process is as follows:

$B_g=H\circ R_t\circ (E_{professional}\cdot T_{statistic})$

In aforesaid formula, B_g is the matrix of black material consumption in each foaming agent field and each industry.

$$m_{jcalculated}=\sum_{k=1}^{7} b_{kj}$$

In the formula, $m_{jcalculated}$is the calculated value of the black material in the j industry, j=1-9.

$P_{calculated}=B_g\cdot M_{calculated}^{-1}$

In the formula, $P_{calculated}$is the proportion matrix of black material in various foaming agent fields and in different industries.

(b) Then, the consumption of various foaming agents in each sub-industry and total consumption of various foaming agents are calculated according to statistical data of black materials from the market survey and the proportion relationship acquired from (a). The calculation process is as follows:

$A_{calculated}=R\circ H_t\circ (P_{calculated}\cdot M_{statistic})$

In aforesaid formula, $A_{calculated}$ is the matrix of various foaming agents in different sub-industries acquired through calculation.

$$t_{icalculated}=\sum_{k=1}^{9} a_{ik}$$

In the formula, $t_{icalculated}$is the calculated value of total consumption of the foaming agent, i=1-7.

(c) Compare the total amount of various foaming agents every year acquired from calculation and total consumption amount acquired from market statistics.

If $t_{icalculated} \leq t_{istatistic}$, the supply of normal foaming agent in the market is sufficient and could meet demands of rigid PU foam products. There is no large amount illegal CFCs foaming agents in the market.

If $t_{icalculated} > t_{istatistic}$, the supply of normal foaming agents in the market is insufficient and could not meet demands of rigid PU foam products. There probably are some illegal CFCs foaming agents in the market which would be used in rigid PU foam products.

(d) The approximate amount of illegal CFCs foaming agents is estimated through the difference between calculated value and market statistic value.

$t_{idifference} = t_{istatistical} - t_{icalculated}$

In the formula, $t_{idifference}$ is the difference value between statistic value and calculated value. Thus, the possible approximate amount of illegal CFCs foaming agents could be estimated.

3) Distribution proportion adjustment

The initial assigned value of the distribution proportion e_{ij}(i-1-7, j=1-9) of the foaming agent in each sub-industry was estimated by 14 experts of rigid PU foam industry. However, the professional estimated value is a variation range. In order to get comprehensive rational distribution proportion, the initial apportioning value was adjusted through mathematical optimization so as to reasonably reflect the distribution proportion with the presumption of innocence condition.

According to aforesaid calculation relationship, the following formula can be deduced:

$$p_{icalculated} = \frac{b_{ijcalculated}}{m_{jcalculated}} = \frac{h_{ij} \times a_{ijcalculated}}{r_{ij} \times m_{jcalculated}} = \frac{h_{ij} \times t_{istatistic} \times e_{ijproportional}}{r_{ij} \times m_{jcalculated}}$$

In the formula,

$$m_{jcalculated} = \sum_{q=1}^{7} b_{qjcalculated} = \sum_{q=1}^{7} \frac{h_{qj} \times t_{qstatistic} \times e_{qjproportional}}{r_{qj}}$$

Then,

$$e_{ijcalculated} = \frac{r_{ij} \times b_{ijcalculated}}{h_{ij}} = \frac{r_{ij} \times p_{ijcalculated} \times m_{jstatistic}}{h_{ij}} = \frac{t_{istatistic} \times m_{jstatistic} \times e_{ijproportional}}{m_{jcalculated}}$$

$$t_{i\,\text{calculated}} = \sum_{k=1}^{9} t_{ik\,\text{calculated}} = \sum_{k=1}^{9} \frac{t_{i\,\text{statistic}} \times m_{k\,\text{statistic}} \times e_{ik\,\text{professional}}}{m_{k\,\text{calculated}}}$$

According to aforesaid formula,

$$t_{i\,\text{difference}} = t_{i\,\text{statistic}} - t_{i\,\text{calculated}}$$

$$t_{i\,\text{Difference}} = t_{i\,\text{Statistic}} \times \left(1 - \sum_{k=1}^{9} \frac{m_{k\,\text{Statistic}} \times e_{ik\,\text{Professional}}}{\sum_{q=1}^{7} \frac{h_{qk} \times t_{q\,\text{Statistic}} \times e_{qk\,\text{Professional}}}{r_{qk}}}\right)$$

In the formula, i=1-7

$$\sum_{k=1}^{9} e_{ik\,\text{professional}} = 1$$

In the formula, i=1-7

It can be abstracted to the following mathematical calculation process.

The objective is the distribution situations when the $t_{i\text{difference}}$(i=1-7) is the minimum value under the professional constraint condition, i.e.,

(i) Objective function

Min($t_{1\text{difference}}$)

Min($t_{2\text{difference}}$)

.

.

.

Min($t_{7\text{difference}}$)

(ii) General constraint condition

$$\sum_{k=1}^{9} e_{1k} = 1$$

.

.

.

$$\sum_{k=1}^{9} e_{7k} = 1$$

(iii) Professional constraint condition

$$e_{ij,\text{Minimum professional judgment}} \leq e_{ij} \leq e_{ij,\text{Maximum professional judgment}}$$

In the formula, $i = 1,\Lambda,7, j = 1\Lambda 9$

Solve the assigned value of e_{ij}(i-1-7,j=1-9) under aforesaid conditions.

Aforesaid problem is a multivariate (63 variables) mathematical optimization problem with multiple objectives (7 objectives) and multiple constraints (133 constraint conditions), which could be proved that the mathematical problem has the theoretical optimal solution under constraint (ii); the theoretical optimal solution does not exist with constraint condition (iii). Therefore, the local optimal conditions near the initial assigned value (vector set) can be found as the most reasonable assigned value. Aforesaid mathematical optimization process is calculated through computer programming application.

(2) Statistical table of polymeric MDI consumption in each sub-industry in China

Table Annex1-1 Statistical table of Polymeric MDI consumption in each sub-industry in China

Time		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Polymeric MDI consumption in sub-industry (ten thousand ton)	Refrigerator and freezer	21.9	24.9	30.9	33.3	35.9	43.6	43.1	42.8	41.7	46.4	49.1
	Water heater	3.4	4.3	4.7	5.5	5.7	6.0	5.6	5.6	5.6	5.8	6.2
	Insulating layer of pipe	4.5	4.8	5.3	5.6	6.2	9.1	8.4	7.5	7.5	8.2	8.6
	Spray coating of building	4.6	5.0	6.6	6.7	6.2	7.2	7.2	6.6	5.6	6.0	6.9
	Insulation plates for building	4.1	4.4	4.8	4.6	4.5	7.1	7.3	6.1	6.1	6.2	7.3
	Filler	2.6	2.9	3.6	6.0	4.5	5.3	5.4	5.2	4.8	4.7	5.3
	Cold closet	3.2	3.7	3.7	5.3	5.0	4.1	4.5	4.7	4.4	5.1	5.4
	Automobile	3.2	4.9	6.8	6.8	7.2	8.7	9.1	9.4	10.2	14.5	15.2
	Others	1.9	2.2	2.4	2.1	2.2	2.5	2.1	2.3	2.0	2.5	2.8
	Subtotal of Polymeric MDI consumption in rigid PU foam industry	49.4	57.1	68.8	75.9	77.4	93.6	92.7	90.2	87.9	99.4	106.8
	Molded high-resilient flexible foam	2.6	3.5	4.3	3.8	3.8	4.6	4.7	4.8	4.8	4.9	5.1
	Adhesive and sealant	3.0	3.4	3.8	6.1	7.8	10.3	9.2	9.5	9.7	10.8	12.0
Total Polymeric MDI consumption (ten thousand ton)		55.0	64.0	76.9	85.8	89.0	108.5	106.6	104.5	102.4	115.1	123.9

(3) Distribution proportion of various foaming agents in different sub-industries during 2008-2018

Table Annex1-2Distribution proportion of various foaming agents in different sub-industries in 2008

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.20	0.19	0.14	0.21	0.10	0.01	0.05	0.01	0.08	1
HC	0.43	0.03	0.01	0.00	0.13	0.25	0.01	0.12	0.02	1
HFC	0.60	0.16	0.00	0.00	0.01	0.11	0.00	0.02	0.10	1
HFO	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1
Water	0.03	0.08	0.43	0.00	0.01	0.01	0.13	0.24	0.08	1
Methyl formate	0.10	0.38	0.11	0.30	0.11	0.00	0.00	0.00	0.00	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.02	0.01	0.01	1

Table Annex1-3Distribution proportion of various foaming agents in different sub-industries in 2009

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.21	0.19	0.08	0.21	0.10	0.01	0.05	0.07	0.08	1
HC	0.60	0.01	0.01	0.00	0.03	0.17	0.00	0.09	0.08	1
HFC	0.84	0.02	0.00	0.00	0.00	0.09	0.00	0.00	0.04	1
HFO	0.69	0.17	0.00	0.00	0.01	0.01	0.00	0.10	0.03	1
Water	0.03	0.11	0.29	0.00	0.06	0.01	0.19	0.21	0.10	1
Methyl formate	0.20	0.29	0.11	0.30	0.10	0.00	0.00	0.00	0.00	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-4Distribution proportion of various foaming agents in different sub-industries in 2010

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.22	0.14	0.05	0.20	0.15	0.06	0.05	0.06	0.07	1
HC	0.40	0.11	0.01	0.00	0.19	0.20	0.01	0.06	0.02	1

HFC	0.58	0.20	0.00	0.00	0.00	0.10	0.00	0.05	0.07	1
HFO	0.75	0.00	0.00	0.00	0.01	0.00	0.00	0.15	0.09	1
Water	0.03	0.08	0.38	0.00	0.00	0.01	0.15	0.25	0.10	1
Methyl formate	0.10	0.10	0.30	0.30	0.20	0.00	0.00	0.00	0.00	1
Others	0.01	0.19	0.29	0.35	0.10	0.01	0.02	0.01	0.01	1

Table Annex1-5Distribution proportion of various foaming agents in different sub-industries in 2011

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.29	0.10	0.10	0.20	0.10	0.04	0.07	0.02	0.07	1
HC	0.59	0.03	0.02	0.00	0.08	0.10	0.01	0.14	0.02	1
HFC	0.53	0.05	0.00	0.00	0.13	0.15	0.00	0.04	0.10	1
HFO	0.92	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.04	1
水 Water	0.02	0.08	0.35	0.03	0.00	0.06	0.16	0.25	0.06	1
Methyl formate	0.20	0.14	0.19	0.30	0.17	0.00	0.00	0.00	0.00	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-6Distribution proportion of various foaming agents in different sub-industries in 2012

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.35	0.10	0.10	0.21	0.06	0.02	0.06	0.05	0.05	1
HC	0.52	0.01	0.03	0.00	0.19	0.10	0.00	0.08	0.07	1
HFC	0.41	0.28	0.00	0.00	0.01	0.10	0.00	0.13	0.07	1
HFO	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1
Water	0.02	0.08	0.34	0.02	0.02	0.06	0.13	0.22	0.10	1
Methyl formate	0.16	0.10	0.25	0.26	0.01	0.01	0.10	0.10	0.02	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-7Distribution proportion of various foaming agents in different sub-industries in 2013

Foaming agent	Refrigerator	Water heater	Pipe thermal insulati	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total

	and freezer	r	on							
HCFC-141b	0.16	0.20	0.06	0.20	0.10	0.01	0.08	0.07	0.11	1
HC	0.62	0.01	0.01	0.00	0.12	0.10	0.00	0.12	0.02	1
HFC	0.59	0.12	0.00	0.00	0.06	0.10	0.00	0.03	0.10	1
HFO	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1
Water	0.02	0.09	0.28	0.02	0.06	0.01	0.19	0.23	0.10	1
Methyl formate	0.16	0.10	0.27	0.06	0.19	0.09	0.02	0.02	0.09	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-8Distribution proportion of various foaming agents in different sub-industries in 2014

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.26	0.22	0.05	0.20	0.10	0.01	0.04	0.03	0.09	1
HC	0.45	0.06	0.04	0.00	0.19	0.10	0.00	0.10	0.05	1
HFC	0.20	0.27	0.00	0.00	0.18	0.13	0.00	0.14	0.07	1
HFO	0.87	0.00	0.00	0.00	0.01	0.09	0.01	0.00	0.03	1
Water	0.02	0.10	0.33	0.03	0.02	0.01	0.16	0.27	0.06	1
Methyl formate	0.08	0.10	0.27	0.06	0.01	0.01	0.10	0.30	0.08	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-9Distribution proportion of various foaming agents in different sub-industries in 2015

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.24	0.22	0.10	0.20	0.10	0.01	0.07	0.04	0.02	1
HC	0.59	0.01	0.06	0.00	0.08	0.10	0.00	0.08	0.07	1
HFC	0.45	0.25	0.00	0.00	0.02	0.10	0.00	0.06	0.12	1
HFO	0.36	0.14	0.00	0.00	0.01	0.01	0.00	0.15	0.33	1
Water	0.03	0.11	0.30	0.02	0.04	0.04	0.14	0.22	0.10	1
Methyl formate	0.15	0.10	0.25	0.28	0.01	0.01	0.07	0.12	0.02	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-10Distribution proportion of various foaming agents in different

sub-industries in 2016

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.24	0.09	0.01	0.25	0.05	0.06	0.08	0.17	0.04	1
HC	0.55	0.01	0.06	0.00	0.13	0.09	0.00	0.08	0.08	1
HFC	0.69	0.03	0.00	0.00	0.03	0.10	0.00	0.09	0.06	1
HFO	0.89	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.10	1
Water	0.03	0.08	0.26	0.04	0.01	0.03	0.15	0.30	0.10	1
Methyl formate	0.11	0.10	0.01	0.13	0.03	0.06	0.10	0.30	0.17	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-11Distribution proportion of various foaming agents in different sub-industries in 2017

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.17	0.12	0.08	0.26	0.12	0.07	0.04	0.10	0.04	1
HC	0.62	0.02	0.00	0.00	0.14	0.07	0.00	0.10	0.07	1
HFC	0.68	0.01	0.00	0.00	0.01	0.10	0.00	0.10	0.10	1
HFO	0.68	0.12	0.00	0.00	0.01	0.01	0.00	0.10	0.08	1
Water	0.03	0.08	0.33	0.03	0.00	0.02	0.10	0.31	0.09	1
Methyl formate	0.01	0.10	0.01	0.13	0.03	0.09	0.10	0.30	0.23	1
Others	0.01	0.19	0.29	0.36	0.10	0.01	0.01	0.01	0.01	1

Table Annex1-12Distribution proportion of various foaming agents in different sub-industries in 2018

Foaming agent	Refrigerator and freezer	Water heater	管 Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others	Total
HCFC-141b	0.07	0.05	0.26	0.26	0.19	0.03	0.01	0.09	0.04	1
HC	0.69	0.05	0.06	0.00	0.07	0.04	0.01	0.03	0.05	1
HFC	0.57	0.12	0.00	0.00	0.06	0.14	0.01	0.06	0.05	1
HFO	0.70	0.01	0.00	0.00	0.02	0.02	0.00	0.10	0.16	1
Water	0.04	0.08	0.30	0.01	0.02	0.01	0.21	0.28	0.05	1
Methyl formate	0.28	0.14	0.01	0.16	0.11	0.16	0.01	0.11	0.03	1

Others	0.05	0.05	0.10	0.60	0.10	0.05	0.05	0.00	0.00	1

Table Annex1-13 Lower estimated value of distribution proportion of various foaming agents in different sub-industries during 2008-2018

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others
HCFC-141b	0.01	0.10	0.10	0.20	0.10	0.01	0.01	0.01	0.01
HC	0.20	0.01	0.01	0.00	0.02	0.10	0.00	0.01	0.01
HFC	0.20	0.01	0.00	0.00	0.01	0.10	0.00	0.01	0.01
HFO	0.20	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01
Water	0.01	0.05	0.10	0.00	0.00	0.01	0.10	0.20	0.01
Methyl formate	0.01	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Others	0.01	0.01	0.01	0.1	0.1	0.01	0.01	0	0

Table Annex1-14 Higher estimated value of distribution proportion of various foaming agents in different sub-industries during 2008-2018

Foaming agent	Refrigerator and freezer	Water heater	Pipe thermal insulation	Spray coating	Plates	Cold closet	Filler	Automobile	Others
HCFC-141b	0.50	0.30	0.40	0.70	0.50	0.50	0.30	0.20	0.10
HC	0.90	0.30	0.10	0.01	0.30	0.30	0.01	0.15	0.10
HFC	0.90	0.30	0.01	0.01	0.20	0.20	0.01	0.15	0.10
HFO	0.99	0.30	0.01	0.00	0.01	0.01	0.00	0.15	0.10
Water	0.05	0.30	0.70	0.05	0.15	0.15	0.40	0.50	0.08
Methyl formate	0.20	0.10	0.30	0.30	0.20	0.30	0.10	0.30	0.10
Others	0.01	0.2	0.3	0.8	0.3	0.2	0.3	0.1	0.1

(4) The ratio of the difference between statistic consumption and calculated consumption with statistic consumption through foaming agent market survey

1) Normal conditions

Table Annex1-15The ratio of the difference between statistic consumption and calculated consumption with statistic consumption through foaming agent market survey (1)

Foaming agent	2008		2009		2010		2011	
	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)

HCFC-141b	119	0.31	2810	6.11	-2578	4.95	1514	2.38
HC	-1666	8.13	-1619	6.66	-942	3.35	480	1.46
HFC	-261	28.95	-149	13.52	-444	29.63	-61	2.92
HFO	0		0		0		0	
Water	661	24.50	347	11.96	-7	0.22	415	12.22
Methyl formate	58	16.64	33	9.23	39	10.54	52	14.16
Others	0		0		0		0	

Notes: Ratio = Difference value/ Statistic consumption from market survey

Table Annex1-16The ratio of the difference between statistic consumption and calculated consumption with statistic consumption through foaming agent market survey (2)

Foaming agent	2012		2013		2014		2015	
	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)
HCFC-141b	4828	8.17	1668	3.60	1555	3.32	1971	5.76
HC	4198	10.52	1056	2.20	647	1.33	3974	7.61
HFC	159	3.38	45	0.64	1961	23.91	1624	15.46
HFO	0		0		-130	32.39	151	11.63
Water	510	14.56	683	11.57	1166	19.43	1441	22.17
Methyl formate	40	12.06	18	5.58	43	15.73	8	2.84
Others	0		0		0		0	

Notes: Ratio = Difference value/ Statistic consumption from market survey

Table Annex1-17The ratio of the difference between statistic consumption and calculated consumption with statistic consumption through foaming agent market survey (3)

Foaming agent	2016		2017		2018	
	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)
HCFC-141b	6249	17.95	5328	14.62	3027	8.86
HC	11779	21.03	11132	18.87	9347	14.42
HFC	2489	17.53	2684	16.26	1711	11.11
HFO	209	13.04	227	13.33	101	5.31
Water	1932	26.84	1188	15.84	1299	15.28
Methyl formate	73	23.07	48	14.51	12	3.26
Others	0		0		0	

Notes: Ratio = Difference value/ Statistic consumption from market survey

2) Extreme conditions

Table Annex1-18The ratio of the difference between statistic consumption and calculated consumption with statistic consumption through foaming agent market survey (1)

Foaming agent	2008		2009		2010		2011	
	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)
HCFC-141b	-1508	3.96	1145	2.49	-4874	9.36	-852	1.34
HC	-1736	8.47	-1870	7.70	-1055	3.76	367	1.12
HFC	-276	30.64	-155	14.06	-465	30.98	-95	4.53
HFO	0		0		0		0	
Water	584	21.64	268	9.24	-140	4.39	333	9.79
Methyl formate	43	12.34	19	5.36	22	5.83	37	10.15
Others	0		0		0		0	

Notes: Ratio = Difference value/ Statistic consumption from market survey

Table Annex1-19The ratio of the difference between statistic consumption and calculated consumption with statistic consumption through foaming agent market survey (2)

Foaming agent	2012		2013		2014		2015	
	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)
HCFC-141b	2950	4.99	-741	1.60	-768	1.64	222	0.65
HC	3892	9.76	961	2.00	376	0.77	3617	6.93
HFC	125	2.65	-40	0.56	1889	23.03	1493	14.22
HFO	0		0		-134	33.41	26	2.01
Water	410	11.70	498	8.44	1043	17.39	1266	19.48
Methyl formate	28	8.36	7	2.06	34	12.53	-13	4.41
Others	0		0		0		0	0

Notes: Ratio = Difference value/ Statistic consumption from market survey

Table Annex1-20The ratio of the difference between statistic consumption and calculated consumption with statistic consumption through foaming agent market survey (3)

Foaming agent	2016		2017		2018	
	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)	Difference value (ton)	Ratio (%)
HCFC-141b	4653	13.36	3622	9.94	1181	3.45
HC	11405	20.37	10781	18.27	8903	13.74
HFC	2416	17.01	2537	15.38	1605	10.42
HFO	168	10.52	192	11.28	-20	1.06

Water	1742	24.20	1008	13.44	1152	13.55
Methyl formate	56	17.67	26	7.75	-3	0.75
Others	0		0		0	

Notes: Ratio = Difference value/ Statistic consumption from market survey

(5) Uncertainty analysis of rigid PU foam production and consumption balance model

The relationship between variables and parameters of the model is determined completely according to production process of rigid PU foam and the composition of the rigid PU foam industry. The model is a type of distinct and simple physical model, and has no uncertain logic relation. With accurate variables and parameters, the model could reflect the specific balancing relationship between various materials.

The uncertainty of the model is from accurate variables and reasonable parameters, which will be discussed below respectively.

Variables

Variables in the model are A, B, D, T and M. T and M are variables of accesible statistical data from market survey, while A, B and D are variables derived based on T and M. Therefore, T and M are active variables of accessible statistical data in the model. In terms of variables, the certainty of model depends on accuracy of T and M data.

T is the statistical data of total annual consumption of various foaming agents. The market statistic value is mainly acquired from collection of market historical data, sort-out of enterprise database and survey on manufacturers; the water consumption is estimated through collection of historical data and output of PU products produced with water as foaming agent. Except water, data of other foaming agents is acquired from the production side, and then to estimate the consumption based on historical experience. There are many foaming agent manufacturers, and more selling and using enterprises. Their relationship is complicated. In addition, the data is mainly from market survey and statistics, i.e. integrated from multiple sources. Thus, the total annual consumption of foaming agent may have certain error. The data of HCFC-141b is from government reports, which should be accurate; HC data is mainly from the manufacturer, seller and professional judgment, and may have error; for HFC and HFO, due to less manufacturers and low output, the data could be believed accurate preliminarily; since methyl formate is a kind of chemical raw material with extensive application, the dose in foaming agent is difficult to estimate accurately, and the data may have error; water as the foaming agent could not be estimated from the production side of water, and mainly be estimated by PU production output with water as foaming agent and professional judgment; water is mainly applied to sub-industries such as pipe thermal insulation, automobile and filler, and also to other sub-industries. Particularly white materials all contain water, so the water data has error.

M refers to the annual consumption statistical data of black material, i.e., Polymeric MDI, in various sub-industries. The output of polymeric MDI is from the market data of five MDI manufacturers and import/export data of the Customs, and the data is accurate. The distribution data of polymeric MDI in each industry is acquired from industrial data of the State Statistics Bureau and industrial associations, and survey on polymeric MDI manufacturers and sellers, and industrial experts. Therefore, the statistical data of polymeric MDI market survey is not the very accurate statistical data. However, compared to some data of the foaming agent, the accuracy is relatively high. According to data source estimate, the data accuracy shall be accurate at least on the ten thousand ton level.

Aforesaid analysis shows the accuracy of market survey statistical data of various foaming agents is different; the market survey statistical data of polymeric MDI is accurate at least on the ten thousand ton level.

Parameters

Parameters in the model are H, R, E, P, $H_t$and R_t, in which, $H_t$and R_t are calculated directly from H and R, and are not independent parameters; P is the derived data through calculation of H, R, E, T and M, and is not an independent parameter, either. Thus, the parameters of the model are H, R and E. In terms of parameters, the uncertainty of model depends on reasonability of H, R and E data.

H refers to the mass ratio of black material and white material. In rigid PU foam industry, the proportional relation for different foaming agents is largely stable. Although the ratio varies within certain range, the range is narrow. For different foaming agents, the ratio will be stabilized at common value in normal rigid PU foam industry. Therefore, the common value used in calculation is reasonable, and in favor of guarantying reasonability of calculation results.

R refers to the proportion of foaming agent in white material, i.e., polyether polyol system. In rigid PU foam industry, the proportional relation for different foaming agents is also stable. Although the ratio varies within certain range, the range is narrow. To treat the manufacturers and sub-industries as a whole, it is impossible for all sub-industries and all manufacturers to adopt the larger value or lower value simultaneously. For each different foaming agent, the ratio will be stabilized at common value in normal rigid PU foam industry. Therefore, the common value used in calculation is reasonable, and in favor of guarantying reasonability of calculation results.

E refers to the application distribution proportion of various foaming agents in various sub-industries. Such proportion may vary in different years according to change of production situations but follow some patterns and common view of experts in the industry. For instance, the application distribution proportion of HC in the refrigerator and freezer industry is high, some in plates and cold closet industry, but not in the spray coasting and filler industry. In the market, the parameter has no historical statistical data from survey. In order to reasonably determine the parameter, the initial assigned value comes from the professional estimation of 14 experts of the industry. However, the professional estimated value is within a variation range. In order to reasonably determine the distribution proportion, the initial apportioning value is adjusted and application distribution proportion is obtained through mathematical optimization under the condition of reflecting presumption of innocence.

According to aforesaid analysis, the parameters selected in model calculation are largely reasonable.

The analysis on accuracy of variable data and reasonability of parameters shows the uncertainty of the model is reduced maximally under current accessible data conditions. In accordance with the preliminary subjective assessment, the calculation error of the model for various foaming agents may be below 20% of foaming agent quantity.

Annex 2 Statistical explanation of results of the survey questionnaire on supervision, law enforcement, policy and market conditions for phase-out of ODS

Relevant personnel of methane chloride production enterprises

Questionnaires have been distributed to relevant personnel in 16 methane chloride companies, hoping that 2 people from each company would participate in the survey. A total of 26 responses from 14 companies were recovered. The survey participants were mainly production supervisors and technicians, and the statistical results of the questionnaire survey are explained as follows.

1. Do you understand the current ODS-related regulations and policies in China? (Single choice)

Among the 26 participants of the questionnaire, 18 people responded with understanding, accounting for 69.23%; 5 people responded with basic understanding, accounting for 19.23%; and 3 people responded with partial understanding, accounting for 11.54%.

2. Do you understand the requirements for the phase-out process of CTC? (Single choice)

Among the 26 participants of the questionnaire, 14 responded with understanding, accounting for 53.85%; 7 responded with basic understanding, accounting for 26.92%; 4 responded with partial understanding, accounting for 15.38%; 1 responded with no understand, accounting for 3.85%.

3. According to your understanding, how is China's performance in the industry that you are familiar with? (Single choice)

Among the 26 participants of the questionnaire, 14 people believed that the expected goal was fully achieved, accounting for 53.85%; 12 people believed that the expected goal was basically achieved, accounting for 46.15%.

4. Regarding the management of methane chloride production enterprises, how do you think your company is performing? (Multiple choices)

Among the 26 participants of the questionnaire, 26 responded that their companies have transformed and disposed of CTC in strict accordance with government requirements, accounting for 100%; Among the 14 companies, only 2 companies have the qualification to sell CTC. 4 people from the 2 companies participated in the questionnaire, responding that their companies strictly sold CTC only to qualified units, accounting for 100%; 23 people responded that their companies had established CTC-related accounting systems, accounting for 88.46%; and 23 people responded that their companies have a special person in charge of the management of CTC ledger, accounting for 88.46%.

5. How has the average CTC by-product rate changed in your company's methane chloride production over the years? (ABC single choice/DE single choice)

Among the 26 participants of the questionnaire, 11 responded with a decline, accounting for 42.31%; 1 responded with slight increase, accounting for 3.85%; 6 responded with little fluctuation, accounting for 23.08%; 6 responded with possible fall in the future, accounting for 23.08%; 2 responded with little probability of falling in the future, accounting for 7.69%.

6. How about the control of the CTC by-product rate in the production of methane chloride in your company? (Single choice)

Among the 26 participants of the questionnaire, 25 responded with continuous records and monitoring, accounting for 96.15%; 1 responded with basic records and monitoring, accounting for 3.85%.

7. What do you think of the conversion and disposal of the methane chloride by-product CTC of your company? (Single choice)

Among the 26 participants of the questionnaire, 17 responded with great progress in conversion rate, product quality, conversion cost, etc. over the years, accounting for 65.38%; and 9 responded with relatively little progress in conversion rate, product quality, conversion cost, etc., accounting for 34.62%.

8. How does your company's deal with CTC? (Multiple choices)

Among the 26 participants of the questionnaire, 7 responded that their companies built their own incinerators for incineration, accounting for 26.92%; only 2 of the 14 companies are qualified to sell CTC, and 4 people from these 2 companies participated in the survey, responding that the raw material is used for export, accounting for 100%; 21 people responded that their companies have one or more products that are converted into CH_3Cl ,$CHCl_3$, and C_2Cl_4,accounting for 80.77%; and 4 people responded that their companies have other products that are converted into CH_3Cl ,$CHCl_3$, and C_2Cl_4, accounting for 15.38%.

9. How is the company's handling of the residual liquid produced by CTC refining? (Single choice)

Among the 26 participants of the questionnaire, 10 people responded with other comprehensive utilization methods, accounting for 38.46%; 13 responded with company's own incinerator for incineration, accounting for 50.00%; 3 responded with entrusted qualified enterprises for incineration, accounting for 11.54%.

10. What management practices do you think are better for CTC in the production of methane chloride? (Multiple choices)

Among the 26 participants of the questionnaire, 13 responded that their companies are trying to minimize the by-product ratio, accounting for 50.00%; 26 responded that their companies convert CTC into non-ODS chemicals, accounting for 100%; 16 responded that their companies are developing CTC feedstock usages, accounting for 61.54%; and 6 responded that their companies incinerate and dispose of CTC, accounting for 23.08%.

11. What do you think is the main reason for the price changes in the CTC market over the past years? (Multiple choice)

Among the 26 participants of the questionnaire, 15 responded with the price change of methane chloride raw materials (methanol and chlorine), accounting for 57.69%; 21 responded with the production capacity change of methane chloride manufacturers, accounting for 80.77 %; 15 responded with the government's supervision change of methane chloride production and CTC, accounting for 57.69%.

12. Do you think there is illegal outflow of CTC in the methane chloride industry? (Single

choice)

Among the 26 participants of the questionnaire, 24 responded with no illegal outflow, accounting for 92.31%; and 2 responded with only sporadic cases, accounting for 7.69%.

13. What do you think might be the main reason for the illegal outflow of CTC? (Multiple choice)

Among the 26 participants of the questionnaire, 12 responded with high cost of CTC conversion and negative conversion income, accounting for 46.15%; 11 responded with insufficient demand for CTC feedstock, accounting for 42.31%;12 responded with CTC incineration, accounting for 46.15%;8 responded with regulatory loopholes that can be exploited, accounting for 30.77%; and 10 responded with low cost of illegality, accounting for 38.46%.

14. What do you think should be strengthened to avoid illegal CTC actions in the future? (Multiple choices)

Among the 26 participants of the questionnaire, 28 responded that the supervision of government departments should be strengthened, accounting for 69.23%; 19 responded that the punishment for illegal actors should be increased, accounting for 73.08%; 19 responded that the multi-channel direct reporting system should be strengthened, accounting for 73.08%; and 20 responded that more raw materials should be developed and the amount of CTC feedstock should be increased, accounting for 76.92%.

15. What do you think about the installation of online monitoring facilities (such as traffic and storage capacity) and on-site video monitors in CTC devices? (Single choice)

Among the 26 participants of the questionnaire, 24 responded that they are completely acceptable, accounting for 92.31%; and 2 responded that online monitoring and live video were of little use in preventing illegal activities, accounting for 7.69%.

16. Does your company have government personnel to supervise the methane chloride production equipment? (Single choice)

Among the 26 participants of the questionnaire, 20 responded with permanent resident supervisors, accounting for 76.92%; and 6 responded with irregular resident supervisors, accounting for 23.08%.

17. HCFCs are reduced and phased-out year by year, so what effect do you think does that have on the production of methane chloride in China in the future? (Single choice)

Among the 26 participants of the questionnaire, 3 responded that the existing production capacity is too large for future market demand, and the production capacity of methane chloride will shrink rapidly in the future, accounting for 11.54%; 7 responded that the current capacity scale is too large for future market demand, and the capacity scale of methane chloride will gradually shrink in the future, accounting for 26.92%;13 responded that the existing capacity scale is basically adapted to the future market demand, and there will be other methane chloride market demand in the future, accounting for 50.00%; 1 responded that the future market demand will increase on the basis of the existing production capacity, because there will be other market demands in the future, accounting for 3.85%; and 2 responded that the change in methane chloride production capacity was not related to the annual reduction and phase-out of HCFCs, accounting for 7.69%.

18. Has there been any illegal production of CFC-11 in China in the past 10 years? (Single choice)

Among the 26 participants of the questionnaire, 17 responded with no illegal production, accounting for 65.38%; and 9 responded with individual cases of illegal production, accounting for 34.62%.

18. How much do you know about the following regulations?

"Controlled ODS" are "other harmful substances" stipulated in the environmental pollution crime in Article 338 of the Criminal Law. Anyone who, in violation of national regulations, discharges, dumps, or disposes of controlled ozone-depleting substances that seriously pollutes the environment shall be sentenced to fixed-term imprisonment of not more than three years or criminal detention, together with a fine; Criminals with particularly serious consequences shall be sentenced to fixed-term imprisonment of not less than three years but not more than seven years, together with a fine.

Among the 26 participants of the questionnaire, 10 responded that I already knew it, accounting for 38.46%; 9 responded that I already knew it, and it was estimated that all personnel related to ODS knew it, accounting for 34.62%; 3 responded that I already knew it, but it was estimated that there were not too many people who knew it, accounting for 11.54%; 4 responded that I did not know it before taking this questionnaire, accounting for 15.38%.

Relevant personnel of government departments

Questionnaires were sent to the competent environmental protection departments of 30 provinces and municipalities, and a total of 31 responses were received from 29 provinces and municipalities. Participants in the survey were mainly management staff of environmental protection of the provincial governments. The statistical results of the questionnaire survey are explained as follows.

1. Regarding the perception of the hazards of ODS, which of the following statements do you think is most consistent with the actual situation? (Single choice)

Among the 31 people who participated in the questionnaire survey, 6 people believed that government staff and the general public could correctly recognize it, accounting for 19.35%; 11 people thought that the government staff and the general public in the fields related to ODS production, sales and use could correctly recognize it, accounting for 35.48%; 9 people thought that some government staff and some people in the fields related to ODS production, sales and use could correctly recognize it, accounting for 29.03%; 5 people thought that the government staff and the general public did not know much about the production, sales and use of ODS, accounting for 16.13%.

2. Has China successfully completed the gradual phase-out of ODS in accordance with the MP and China's National Program for Phasing out ODS? (Single choice)

Among the 31 people who participated in the questionnaire survey, 26 people believed that China had successfully completed the gradual phase-out of ODS, and that the phase-out of CFCs was completed ahead of schedule, accounting for 83.87%; 5 people believed that it was basically completed, accounting for 16.13%.

3. Do China's current ODS-related regulations, policies, and supervision and law enforcement systems effectively ensure that ODS is phased out as planned? (Single choice)

Among the 31 people who participated in the questionnaire survey, 17 people thought they were effective, accounting for 54.84%; 13 people thought they were basically effective, accounting for 41.94%; 1 person thought they were partially effective, accounting for 3.23%.

4. China's ODS phase-out program has moved from project-based phase-out to a new stage of integration of project phase-out, supervision and management, and continuous compliance. Can the current ODS-related regulations, policies, and supervision and law enforcement systems effectively ensure future sustainable compliance without modification and improvement? If it needs to be revised and improved, which regulations or systems should be focused on? (Multiple choices except A)

Of the 31 people who participated in the questionnaire survey, 2 people thought that there was no need to modify, accounting for 6.45%; 27 people thought that in terms of laws and regulations, we should focus on the revision and improvement of the ODS management regulations, accounting for 87.10%; 11 people thought that in terms of management systems, we should focus on the modification and improvement of import and export management systems, accounting for 35.48%; 21 people thought that in terms of management systems, we should focus on the modification and improvement of substitutes management systems, accounting for 67.74%; 27 people thought that in terms of management systems, we should focus on supervision and management and law enforcement systems, especially the modification and improvement of local supervision and management and law enforcement systems, accounted for 87.10%; 22 people believed that in terms of management systems, we should focus on the formulation and modification of relevant technical specifications, accounting for 70.97%.

5. Do China's current ODS-related regulations, policies, and supervision and law enforcement systems need to be strengthened in terms of the supervision of illegal production and use of ODS, and if so, which aspects should be strengthened? (Multiple choices except A)

Of the 31 people who participated in the questionnaire survey, 28 people believed that it was mainly the supervision and enforcement system that should shift from a central government-centered one to a new one where the central and local governments have a common but differentiated responsibilities, accounting for 90.32%; 18 people believed that it was imperative to strengthen the supervision and law enforcement system at the local level, accounting for 58.06%; 21 people thought that the relevant legal liability clauses needed to be revised, accounting for 67.74%; 25 people thought that the detection and reporting system for illegal production and use needed to be strengthened, accounting for 80.65%; 28 people thought that it was necessary to apply market mechanisms to further encourage and support the development, application and promotion of alternative technologies, accounting for 90.32%.

6. Based on your personal judgment, what types of illegal production and use of ODS might exist in China from 2008 to 2018? (Multiple choices except A)

Among the 31 people who participated in the questionnaire survey, 14 people thought that there was basically no illegal production, accounting for 45.16%; 17 people thought that there was CFC-11-related illegal production, accounting for 54.84%.

7. Based on your personal judgment, what industries might illegally use ODS in China from 2008 to 2018? (Multiple choices)

Among the 31 people who participated in the questionnaire survey, 31 people thought it was in the PU foam industry, accounting for 100%.

8. Based on your personal judgment, if there might be illegal production of ODS in China from 2008 to 2018, how big was its scale? (Single choice)

Among the 31 people who participated in the questionnaire survey, 8 people thought that there was no illegal production, accounting for 25.81%; 23 people thought that the production was only sporadic, accounting for 74.19%.

9. Based on your personal judgment, if there was illegal production of ODS in China, what were the main reasons? (Multiple choices)

Among the 31 people who participated in the questionnaire survey, 3 people thought that there were no corresponding clear regulations and policies, accounting for 9.68%; 9 people thought that there was a problem with national-level supervision and reporting channels, accounting for 29.03%; 11 people thought that there was a problem with local-level supervision and reporting channels, accounting for 35.48%; 2 people thought that there was a problem of petty protectionism, accounting for 6.45%; 20 people thought that the monitoring technology was insufficient, accounting for 64.52%; 8 people thought that the competent environmental protection administrations and other relevant government departments were unable to coordinate well, accounting for 25.81%; 2 people thought that technical specifications and standards were problematic, accounting for 6.45%; 15 people thought that the market price of substitutes was too high, accounting for 48.39%; 15 people thought that the technical parameters of substitutes were not good enough, accounting for 48.39%; 22 people believed that the cost of violations was lower compared with the benefits of illegal risks, accounting for 70.97%; 21 people believed that illegal personnel had low awareness regarding the severity of violations and did not care much about environmental protection, accounting for 67.74%.

10. Regarding the knowledge about the following laws and regulations: "Controlled ODS" are "other harmful substances" stipulated in the crime of environmental pollution in Article 338 of the Criminal Law, anyone who, in violation of national regulations, discharges, dumps, or disposes of controlled ODS that seriously pollutes the environment shall be sentenced to fixed-term imprisonment of not more than three years or criminal detention, concurrently or solely with a fine; if the consequences are particularly serious, they shall be sentenced to fixed-term imprisonment of not less than three years but not more than seven years, and be fined.

Among the 31 people who participated in the questionnaire survey, 8 people believed that the relevant government officials and personnel related to ODS production, sales, and use were aware, accounting for 25.81%; 9 people believed that all the relevant government officials knew it, and some people involved in the production, sales, and use of ODS knew it, accounting for 29.03%; 8 people thought that some relevant government officials and personnel related to ODS production, sales, and use knew, accounting for 25.81%; 6 people thought that the number of relevant government officials and those involved in the production, sales and use of ODS who knew it was low, accounting for 19.35%.

11. Do you think the current laws and regulations impose appropriate penalties on units and individuals that illegally produce and use ODS? (Single choice)

Among the 31 people who participated in the questionnaire survey, 2 people thought that the penalties stipulated by the current laws and regulations were appropriate, accounting for 6.45%; 9 people thought that the penalties should be slightly heavier, accounting for 29.03%; 20 people believed that the punishment should be increased reasonably and legally in accordance with the spirit of the current Environmental Protection Law on economic penalties on a routine basis and responsibility for destroying the environment, accounting for 64.52%.

12. In the past administration process of phasing out ODS, has the management of the whole life cycle been implemented, and was the management in place? (Single choice)

Of the 31 people who participated in the questionnaire survey, 16 people believed that the management of the entire ODS life cycle was implemented and the management was basically in place, accounting for 51.61%. 14 people thought that the management of the entire ODS life cycle was implemented, but some links were missing, accounting for 45.16%; 1 person thought that the management of the entire ODS life cycle was not implemented effectively, accounting for 3.23%.

13. In view of future sustainable compliance, what are the key management and control links that should be strengthened in the entire ODS life cycle management? (Multiple choice)

Among the 31 people who participated in the questionnaire survey, 26 people thought it was production, accounting for 83.87%; 22 people thought it was sales, accounting for 70.97%; 20 people thought it was use, accounting for 64.52%; 16 people thought it was import and export, accounting for 51.61%; 24 people thought it was recycling and reuse, accounting for 77.42%; 19 people thought it was destruction, accounting for 61.29%.

14. In your opinion, how can the consumer market further ensure consumers' willingness to use ODS substitutes in the future? (Multiple choices)

Among the 31 people who participated in the questionnaire survey, 24 people believed that the government should increase investment in the development of substitutes, accounting for 77.42%; 26 people believed that the government should give better preferential policies for substitutes, accounting for 83.87%; 23 people thought that the product standards related to substitutes should be improved, accounting for 74.19%; 20 people believed that the penalties for ODS violations should be increased, accounting for 64.52%; 19 people believed that special and severe crackdowns on illegal production, sales and use of ODS should continue every year, accounting for 61.29%.

15. Regarding the administrative management of ODS phase-out and sustainable compliance, which areas need further improvement? (Multiple choice except A)

Among the 31 people who participated in the questionnaire survey, 22 people thought it was the step-by-step reporting procedures and methods from country-level all the way to the central government, accounting for 70.97%; 18 people thought it was the level-by-level supervision and inspection mechanism and methods from the central government to the county-level governments, accounting for 58.06%; 20 people believed that it was the connection and coordination mechanism between various departments of the central and especially local governments, accounting for 64.52%; 16 people thought it was the implementation of the regulations and fulfillment of responsibilities at all levels, accounting for 51.61%; 14 people thought it was the effect evaluation and improvement mechanism, accounting for 45.16%.

16. The results of the ODS phase-out and sustainable compliance supervision and management system in the production and sales of ODS are: (Single choice)

Among the 31 people who participated in the questionnaire survey, 5 people thought that the expected goal was fully achieved, accounting for 16.13%; 21 people believed that the expected goal was achieved, and only individual cases of violations occurred, accounting for 67.74%; 3 people thought that the expected goal was basically achieved, with only a tiny gap, accounting for 9.68%; 2 people thought there was some gap from the expected goal, accounting for 6.45%.

17. The results of the ODS phase-out and sustainable compliance supervision and management system in the PU foam industry are: (Single choice)

Among the 31 people who participated in the questionnaire survey, 3 people thought that the expected goal was fully achieved, accounting for 9.68%; 22 people thought that the expected goal was achieved, and only individual cases of violations occurred, accounting for 70.97%; 5 people thought that the expected goal was basically achieved, with only a tiny gap, accounting for 16.13%; 1 person thought there was some gap from the expected goal, accounting for 3.23%.

18. The results achieved by the ODS phase-out and sustainable compliance supervision and management system in the industrial and commercial refrigeration industry are: (Single choice)

Among the 31 people who participated in the questionnaire survey, 16 people thought that the expected goal was fully achieved, accounting for 51.61%, 8 people thought that the expected goal was achieved, and only cases of violations occurred, accounting for 25.81%; 6 people thought that the expected goal was basically achieved, with only a tiny gap, accounting for 19.35%; 1 person thought there was some gap from the expected goal, accounting for 3.23%.

19. The results of the ODS phase-out and sustainable compliance supervision and management system in the household refrigeration industry are: (Single choice)

Among the 31 people who participated in the questionnaire survey, 14 people thought that the expected goal was fully achieved, accounting for 45.16%; 10 people thought that the expected goal was achieved, and only individual cases of violations occurred, accounting for 32.26%; 6 people thought that the expected goal was basically achieved, with only a tiny gap, accounting for 19.35%; 1 person thought there was some gap from the expected goal, accounting for 3.23%.

20. The results of the ODS phase-out and sustainable compliance supervision and management system in automotive air conditioning, refrigeration maintenance, pharmaceutical aerosols and other industries are: (Single choice)

Among the 31 people who participated in the questionnaire survey, 12 people thought that the expected goal was fully achieved, accounting for 38.71%; 12 people thought that the expected goal was achieved, and only individual cases of violations occurred, accounting for 38.71%; 5 people thought that the expected goal was basically achieved, with only a tiny gap, accounting for 16.13%; 2 people thought there was some gap from the expected goal, accounting for 6.45%.

21. What are the more appropriate detection mechanisms for illegal production and use of ODS? (Multiple choice except I)

Of the 31 people who participated in the questionnaire survey, 16 people believed that it was the inspection and supervision of the central government departments, accounting for 51.61%; 18 people believed that the it was the inspection and supervision of local government departments, accounting for 58.06%; 12 people believed that it was to keep those key positions attended, accounting for 38.71 %; 16 people thought that it was to report a suspicious case level by level when they found it, accounting for 51.61%; 24 people thought it was to directly report the suspicious case to the relevant state departments through the Internet or telephone when it was found, accounting for 77.42%; 2 people thought that it was necessary to report by real name, accounting for 6.45 %; 15 people thought that it was possible to report anonymously, accounting for 48.39%; 13 people thought it was to encourage reporters to visit unannounced, accounting for 41.94%; 26 people thought it was to establish perennial atmospheric ODS concentration monitoring points in key areas, accounting for 83.87%.

22. Regarding the ODS sustainable compliance and the supervision and management of illegal activities in the past, which of the following statements are more in line with your opinion? (Multiple choice)

Among the 31 people who participated in the questionnaire survey, 12 people believed that there was a disconnect between central and local management, and many local authorities did not include the supervision and enforcement of ODS in their routine management scope, accounting for 38.71%; 14 people believed that relevant local government departments had weak supervision and management of ODS-related enterprises, and national policies had not been effectively implemented, accounting for 45.16%; 22 people thought that local grassroots supervision and law enforcement capabilities were insufficient, and there were no professional compliance management and law enforcement personnel, accounting for 70.97%; 13 people thought that the high cost of government supervision and law enforcement, the high cost of law-abiding by producers and users, and the low cost of illegal activities by producers and users were important reasons for illegal activities, accounting for 41.94%; 24 people believed that higher alternative prices, lower illegal ODS prices, and affordable opportunity costs for illegal activities were the most important reasons for illegal activities, accounting for 77.42%; 24 people believed that combined with special actions, we should appropriately strengthen the routine supervision and law enforcement system of government departments, greatly increase the opportunity cost of illegal activities, establish a smooth and direct reporting mechanism for illegal activities for the general public, as well as a rapid response mechanism for the investigation and punishment of illegal activities, which would be an important guarantee for sustainable compliance, accounting for 77.42%; 21 people believed that government departments should support for the development and technological improvement of substitutes in terms of economic policies and technical standards, and promote the reduction of production costs of substitutes, which would be the most important measure to form a sustainable market mechanism, accounting for 67.74%.

23. Can the current local government capacity building ensure sustainable compliance in the future? (Single choice)

Among the 31 people who participated in the questionnaire survey, 6 people thought it was completely okay, accounting for 19.35%; 14 people thought it was basically okay, accounting for 45.16%; 10 people thought there was still some gap and needed to be further strengthened, accounting for 32.26%; 1 person thought there was still a big gap, accounting for 3.23%.

24. In order to ensure sustainable compliance in the future, what aspects need to be strengthened by relevant local government departments? (Multiple choice)

Among the 31 people who participated in the questionnaire survey, 27 people thought that the country's policies and measures on ODS management need to be refined, accounting for 87.10%; 28 people thought it was necessary to train professionals so that relevant managers could reach professional-level, accounting for 90.32%;18 people thought that a special supervision and management team should be established, accounting for 58.06%; 24 people thought that a monitoring and supervision system should be established to institutionalize ODS sampling and monitoring, accounting for 77.42%; 25 people thought that it was necessary to establish a dedicated platform for information-based data, reporting and communication and coordination with relevant central government departments, accounting for 80.65%; 25 people thought that regular professional training was needed, accounting for 80.65%.

25. For the management of enterprises specializing in the production and sales of ODS, which aspects need to be further strengthened? (Multiple choice)

Among the 31 people who participated in the questionnaire survey, 19 people thought it was new renovation and expansion project management, accounting for 61.29%; 19 people thought it was production and sales quota management, accounting for 61.29%; 11 people thought it was import and export management, accounting for 35.48%; 16 people thought it was alternative management, accounting for 51.61%; 18 people thought it was the data reporting system for production and sales, accounting for 58.06%; 14 people thought it was production technical specifications and standards, accounting for 45.16%; 17 people thought it was online monitoring of flow and reserves, accounting for 54.84%; 10 people thought it was online video monitoring on the production line, accounting for 32.26%; 20 people thought it was to increase the analysis and testing capabilities of the government-related chemical substance analysis and testing center for ODS-related substances, accounting for 64.52%; 21 people believed that it was the establishment of ODS credit file system for production and sales enterprises, accounting for 67.74%.

26. Regarding the ODS sustainable compliance supervision, management and enforcement, is it necessary to further strengthen the joint working mechanism between the competent environmental protection administrations and the following government departments? (Multiple choice)

Among the 31 people who participated in the questionnaire survey, 15 people considered the housing, buildings and construction department, accounting for 48.39%; 26 people considered the industry and information technology department, accounting for 83.87%; 25 people considered the public security department, accounting for 80.65%; 20 people considered the transportation department, Accounting for 64.52%; 27 people considered the customs security and anti-smuggling department, accounting for 87.10%; 20 people considered the scientific research department, accounting for 64.52%; 20 people considered the development and reform commission(committee), accounting for 64.52%.

27. Can the current division of ODS management responsibilities at the national and local levels be adapted to the future sustainable compliance supervision and management and law enforcement? (Single choice)

Among the 31 people who participated in the questionnaire survey, 5 people thought they were fully adaptable, accounting for 16.13%; 10 people thought they were basically able to adapt and did not need adjustment, accounting for 32.26%; 16 people thought they needed to be adjusted appropriately, accounting for 51.61%.

28. China’s ODS phase-out-related supervision, law enforcement, and policies have effectively guaranteed the successful compliance for more than 30 years, and lived up to the expected results of formulating these laws, regulations and the supervision and management system in the first

place. (Single choice)

Among the 31 people who participated in the questionnaire survey, they all completely agreed with the above statement, accounting for 100%.

Staff Concerned of HCFCs Producers

Questionnaires were issued to staff concerned of 30HCFCs producers in the hope that two people from each enterprise would participate in the survey. A total of 37 people from 20 enterprises responded eventually, and most of them are production supervisors or technicians. The statistical results of the questionnaire survey are as follows.

1. Do you know the current ODS-related laws and policies in China? (Single choice)

Among the 37 people who participated in the questionnaire survey, 28 answered "Yes, I do", accounting for 75.68%; 9 answered "I have a basic knowledge", accounting for 24.32%.

2. Do you know the requirements for ODS phase-out? (Single choice)

Among the 37 participants, 31 answered "I know", accounting for 83.78%; 6 answered "I have a basic knowledge", accounting for 16.22%.

3. As far as you are concerned, how has China achieved its compliance targets in the industry you know: (Single choice)

Among the 37 participants, 24 answered "completely", accounting for 64.86%; 13 answered "basically", accounting for 35.14%.

4. What do you think of the quota approval management system for ODS production: (Multiple choices except E)

Among the 37 participants, 24 think that the system has effectively managed and promoted ODS phase-out, accounting for 64.86%; 13 think that the system has basically managed and promoted the phase-out in an effective way, accounting for 35.14%; 5 think that the system is too strict and rigid, and should be more flexible, accounting for 13.51%; 11 think that the system should be more stringent, accounting for 29.73%; 4 are from companies that are not involved in

ODS quota management, accounting for 10.81%.

5. What do you think of the filing management system of ODS used as feedstock: (Multiple choices except E)

Among the 37 participants, 25 think that the current filing management system of ODS used as feedstock is reasonable and can effectively manage the phase-out and compliance of ODS, accounting for 67.57%; 16 think that the current system is basically reasonable, and can effectively manage the ODS phase-out and compliance on the whole, accounting for 43.24%; 3 think that the system is too strict and inflexible, and should be more flexible, accounting for 8.11%; 17 people think that the system should be strengthened, especially in supervision and enforcement, accounting for 45.95%; 2 are from companies that are not involved in ODS filing management, accounting for 5.41%.

6. Regarding the management of ODS production enterprises, what do you think of your enterprise: (Multiple choices)

Among the 37 participants, 37 think that their enterprises have been strictly complied with the quota or filing management requirements, accounting for 100%, 20 think their enterprises only produced legal ODS, accounting for 54.05%, and 19 think that their enterprises have established the ledger system related to ODS, accounting for 51.35%. 22 people think that there is a clear responsible person in the management of ODS ledger in their enterprise, accounting for 59.46%.

7. According to the changes of HCFC-22 market price over the years, what do you think are the important reasons for that: (Multiple choices except G)

Among the 37 participants, 18 answered the change in production capacity of enterprises, accounting for 48.65%; 23 answered the change in market demand, accounting for 62.16%; 23 answered the change in the prices of raw materials from upper stream, accounting for 62.16%; 25 answered the mandatory amount of phase-out and the decrease of quota year by year, accounting for 67.57%; 9 are from companies that do not produce HCFC-22 products, accounting for 24.32%.

8. Given the changes in the market price of HCFC-141b over the years, what do you think are the important reasons for that: (Multiple choices except G)

Among the 37 participants, 11 answered the change in production capacity of enterprises, accounting for 29.73%; 12 answered the change in market demand, accounting for 32.43%; 13 answered the change in the prices of raw materials, accounting for 35.14%; 11 answered the mandatory amount of phase-out and the year-by-year decrease of quota, accounting for 29.73%; 5 answered illegal production and transaction, accounting for 13.51%, 7 answered campaigns of combating illegal ODS, accounting for 18.92%; 20 are from companies that do not involve HCFC-141b products, accounting for 54.05%.

9. According to the market price changes of HCFC-142b over the years, what do you think are the important reasons for that: (Multiple choices except G)

Among the 37 participants, 21 answered the change in production capacity of enterprises, accounting for 56.76%; 21 answered the change in market demand, accounting for 56.76%; 19 answered the change in the prices of raw materials from upper stream, accounting for 51.35%; 19 answered the mandatory amount of phase-out and the decrease of quota year by year, accounting for 51.35%; 1 answered illegal production and transaction, accounting for 2.70%, 7 answered campaigns of combating illegal ODS, accounting for 18.92%; 12 are from companies that do not involve HCFC-141b products, accounting for 32.43%.

10. What do you think of the profitability of your enterprise's HCFCs products in these years: (Single choice)

Among the 37 participants, 7 think that their companies have been profitable for many years, accounting for 18.92%; 9 people believe that their companies have basically reported no losses for many years, accounting for 24.32%; 22 people think that their enterprises have reported both profit and loss years for many years, accounting for 56.76%.

11. For the next stage of HCFCs phase-out plan, how do you think your company is prepared: (Multiple choices)

Among the 37 participants, 2 think that their enterprises have already had a response plan and are ready to produce other chemicals, accounting for 5.41%; 16 think that their companies have already had a response plan and are ready to produce HCFCs used as feedstock, accounting for 43.24%; 6 think that their companies have no response plan, and plan to produce HCFCs until the phase-out deadline and then close the production line, accounting for 16.22%; 13 think that their enterprises have other plans, accounting for 35.14%.

12. From the technical perspective, how do you think of HCFCs manufacturers producing other chemicals in the future: (Single choice)

Among the 37 participants, 3 think it is impossible, accounting for 8.11%; 17 people answered that the technology is difficult and it is inappropriate, accounting for 45.95%; 15 think it is basically feasible, accounting for 40.54%; 2 people think it is quite easy, accounting for 5.41%.

13. From the economic perspective, how do you think of HCFCs manufacturers producing other chemicals in the future: (Single choice)

Among the 37 participants, 20 think it is costly and inappropriate, accounting for 54.05%; 14 think the cost is quite high, accounting for 37.84%; 3 think that the cost is moderate and basically acceptable, accounting for 8.11%.

14. What’s your prediction about the production of HCFCs used as feedstock: (Single choice)

Among the 37 participants, 18 think it will continue to grow, accounting for 48.65%; 16 think that it will maintain at a certain level, accounting for 43.24%; 3 think that it will gradually shrink, accounting for 8.11%.

15. Do you think there has been illegal production of CFC-11 in China in recent 10 years: (Single choice)

Among the 37 participants, 15 answered "No", accounting for 40.54%; 22 answered "Yes, but there are rare cases", accounting for 59.46%.

16. What do you think of the possibility that HCFCs production facilities are used for the illegal production of CFC-11: (Multiple choices except E)

Among the 37 participants, 19 think that it is impossible because the comprehensive cost of equipment change is high, the illegal production is unstable, and the input-output ratio is extremely inappropriate, accounting for 51.35%; 6 think it is impossible because the current product income is higher and more stable; 4 think it is impossible, and there is no time to change production in order to ensure the production load of HCFCs facilities, accounting for 10.81%; 22 think it is impossible, because the government regulation is rigid, accounting for 59.46%.

17. Do you think there is illegal outflow of HCFCs used as feedstock: (Single choice)

Among the 37 participants, 21 answered "No", accounting for 56.76%; 16 answered "Yes, but only individual cases", accounting for 43.24%.

18. If you believe there is illegal outflow of HCFCs, what are the main reasons: (Multiple choices)

Among the 37 participants, 23 answered the weak links in supervision, accounting for 62.16%; 26 answered pursuit for higher illegal income, accounting for 70.27%; 19 answered low violation cost, accounting for 51.35%; 4 answered other reasons, accounting for 10.81%.

19. What improvements do you think should be made in order to avoid illegal act regarding ODS? (Multiple choices)

Among the 37 participants, 32 believed that the government supervision should be strengthened, accounting for 86.49%; 31 think that the punishment for illegal act should be enhanced, accounting for 83.78%; 29 believe that the multi-channel direct reporting system should be strengthened, accounting for 78.38%; 29 think that better preferential policies should be provided for the development and production of substitutes, accounting for 78.38%; 24 think that the development of substitute consumption market should be promoted as soon as possible, accounting for 64.86%.

20. Do you know about the following laws and regulations: "Controlled ODS' are 'other harmful substances' stipulated in Article 338 of the Criminal Law on the crime of environmental pollution. Whoever, in violation of state regulations, discharges, dumps or disposes controlled ODS and seriously pollutes the environment shall be sentenced to fixed-term imprisonment of not more than three years or criminal detention, and shall also or shall only be fined; If the consequences are particularly serious, they shall be sentenced to fixed-term imprisonment of not less than three years but not more than seven years and fined."?

Among the 37 participants, 14 answered "Yes", accounting for 37.84%; 18 answered "Yes, and I assume that people who are concerned with the consumption of ODS also do", accounting for 48.65%; 3 answer "Yes, but I assume not many people do", accounting for 8.11%; 2 answered "I don't know until I answer this questionnaire", accounting for 5.41%.

Statistical Results of the Questionnaire on Personnel Concerned from ODS-using Enterprises

In the survey the questionnaire was distributed to 177 ODS-using enterprises, and expected that 2 personnel concerned from each enterprise would respond the questionnaire. As a result, a total of 52 respondents from 36 enterprises responded to the questionnaire, mainly production managers or technicians. The statistical results of the questionnaire are as follows.

1. The main reasons why China has formulated laws and policies to gradually phase out ODS are: (Multiple choices)

Of the 52 respondents, 26 respondents thought one of the reasons was that ODS would greatly reduce the oxygen concentration in the air, which was harmful to humans and the earth's ecology, accounting for 50.00%. 9 respondents agreed with some researches which had found some toxicity of ODS might cause acute poisoning after human exposure, accounting for 17.31%. 7 respondents reasoned that ODS were harmful to airplanes and other aircraft and artificial satellites, accounting for 13.46%. 49 respondents held the view that ODS would destroy the ozone layer, leading to direct ultraviolet rays to the earth, and thus jeopardizing human health and the ecological environment of the earth, accounting for94.23%. 47 respondents believed that the emission of ODS into the air would cause the greenhouse effect and global climate change, accounting for90.38%. 23 respondents believed that chlorine, fluorine and some other elements that ODS contained were harmful to the human body, accounting for44.23%. 45 respondents considered one reason was that China was a signatory of the MP, accounting for86.54%.

2. What will be the ill effects if ODS cause enough damage to the atmosphere? (Multiple choices)

Of the 52 respondents, 42 respondents believed the human immune mechanism would decline, therefore the incidence and severity of human diseases would greatly increase, accounting for 80.77%. 49 respondents believed that the incidence of skin cancer would increase, accounting for94.23%. 28 respondents believed the incidence of cataracts would increase, accounting for53.85%. 30 respondents speculated that the crop yield and quality would decline, accounting for57.69%. 38 respondents inferred that terrestrial and aquatic organisms would suffer from harm, accounting for73.08%. 21 respondents thought the degree of harmful substances in smog would increase, accounting for40.38%. 20 respondents believed that there might be a destructive effect on various protective materials of buildings, accounting for38.46%. 8 respondents believed that metal materials would suffer from damage, accounting for15.38%.

3. According to the situations you have encountered in your work, the current phase-out status of ODS is: (Multiple choices except D)

Of the 52 respondents, 47 respondents believed that ODS were all phased out within the time limit set by the government, accounting for 90.38%) while 36 respondents held the view that some ODS had not been phased out, though all the personnel concerned knew when they should have been phased out, accounting for69.23%.

4. Regarding the regulations and policies on ODS related to your work, based on your own experience, you believe: (Single choice)

Of the 52 respondents, 40 respondents believed that all the related enterprises could produce and operate strictly in accordance with the relevant regulations and policies, accounting for 76.92%. 8 respondents believed that most of the related enterprises could follow the relevant regulations and policies, accounting for15.38%. 4 respondents held the view that the production and operation of a few enterprises could not meet the requirements of relevant regulations and policies, accounting for7.69%.

5. Regarding the degree of awareness of the following regulation: "Controlled ODS" are classified as "other harmful substances" specified in Article 338 Offence of Environmental Pollution of the Criminal Law. Whoever, in violation of the state provisions, discharges, dumps or disposes of any controlled ODS, which has caused serious environmental pollution, shall be sentenced to imprisonment of not more than 3 years or criminal detention and/or a fine; or if there

are especially serious consequences, be sentenced to imprisonment of not less than 3 years but not more than 7 years and a fine.

Of the 52 respondents, 21 respondents responded that they had already known the regulation, accounting for 40.38%. 17 responded that they had already known the regulation, and believed all personnel related to ODS had known it, accounting for 32.69%. 12 responded that they had already known the regulation, but inferred that not many related personnel had known it, accounting for23.08%. 2 hadn't heard of the regulation before the questionnaire, accounting for3.85%.

6. Regarding the examination and approval system for ODS consumption quota, you think: (Multiple choices except E)

Of the 52 respondents, 38 respondents believed the system had effectively managed and promoted the phase-out process of ODS, accounting for 73.08%. 24 respondents believed the system had basically managed and promoted the phase-out process of ODS, accounting for46.15%. 1 respondent thought the system too harsh and inflexible, and hoped for more flexibility, accounting for1.92%. 23 respondents held the view that the system should further strengthen the administration and supervision, accounting for44.23%. The enterprises that 4 respondents were from did not involve in the administration of ODS quota management, accounting for7.69%.

7. Regarding the register system for ODS usage as feedstock, you think: (Multiple choices except E)

Of the 52 respondents, 36 respondents considered that the current register system for ODS usage as feedstock was reasonable, which could effectively administrate the phase-out of ODS and performance of the requirements, accounting for69.23%. 25 respondents considered the system basically reasonable, and believed it could effectively administrate the phase-out of ODS and performance of the requirements in general, accounting for 48.08%. 1 respondent thought the system too harsh and inflexible, and hoped for more flexibility, accounting for 1.92%. 22 respondents advised that the system should be further firmed up especially in terms of supervision and law enforcement which should be refined and strengthened, accounting for42.31%. The enterprises that 3 respondents were from did not involve in the register system for, using ODS as feedstock, accounting for5.77%.

8. Regarding the management in enterprises using ODS, you think your enterprise: (Multiple choices except E)

Of the 52 respondents, 44 respondents believed their enterprises organized production in strict accordance with the quota or the requirements of the register system, accounting for 84.62%. 34 respondents believed that their enterprises purchased only legal ODS strictly, accounting for65.38%. 21 respondents believed that their enterprises had established an account system related to ODS, accounting for40.38%. 20 respondents believed that there was a specified responsible person for the management of ODS accounts in their enterprises, accounting for38.46%.

9. According to your knowledge, the main factors affecting the market prices of ODS that you are familiar with are: (Multiple choices)

Of the 52 respondents, 27 respondents thought that changes in the production capacity of ODS had influenced the balance of supply and demand in the market, accounting for 51.92%, while 35 believed that the reason why the balance was affected was the change of ODS consumption, accounting for67.31%. 31 respondents reasoned one of the main factors was the price change of raw materials upstream of ODS products, accounting for59.62%. 37 respondents attributed to mandatory limits on the ODS cuts and the tightening of quotas year by year, accounting for71.15%.

10. What is the impact of the ODS price change on the product cost of your enterprise? (Single choice)

Of the 52 respondents, 10 respondents considered that the impact was great, accounting for 19.23%. 26 respondents thought there was some impact, accounting for 50.00%, 8thought the impact small, accounting for 15.38%, and 8 thought the impact minimal, accounting for15.38%.

11. How about the use of ODS in your enterprise: (Single choice)

Of the 52 respondents, 2 respondents believed that their enterprises used ODS completely and employed no substitutes, accounting for 3.85%. 6 respondents believed that their enterprises used some ODS as well as some substitutes, accounting for11.54%. 9 respondents believed that their enterprises used a small amount of ODS and more substitutes, accounting for17.31%. 35 respondents believed their enterprises had already employed the substitutes completely, accounting for 67.31%.

12. If your enterprise can choose to use ODS or their substitutes at present, which of the following situations is closer to the reality of your enterprise: (Single choice)

Of the 52 respondents, 2 respondents inferred that their enterprises would give priority to ODS, accounting for 3.85%. 47 respondents inferred that their enterprises would give priority to the substitutes, accounting for90.38%. 3 respondents inferred that their enterprises would choose to use both ODS and the substitutes, accounting for5.77%.

13. Regarding the next stage of the national ODS phase-out plan, what do you think of your enterprise's preparation: (Single choice)

Of the 52 respondents, 49 respondents believed that their enterprises had had a plan and were ready to convert to the substitutes, accounting for 94.23%. 2 respondents believed that their enterprises had had a plan and were ready to exclude the products affected, accounting for3.85%. 1 respondent believed that his/her enterprise had had other plans, accounting for 1.92%.

14. In your opinion, what measures should be adopted for the use of substitutes to ODS: (Multiple choices)

Of the 52 respondents, 51 respondents thought it necessary for the government to make more efforts to encourage and support the research and development of substitutes, accounting for 98.08%. 1 respondent thought that enterprises could use ODS first, and then employ cheaper substitutes after the patent of foreign substitutes expired, accounting for 1.92%. 48 respondents held the view that the government should support the expansion of the production scale of substitutes and should reduce the prices of substitutes, accounting for92.31%.

15. According to your judgment, is there any illegal use of CFC-11 in your industry:

Of the 52 respondents, 49 respondents believed no illegal use existed, accounting for 94.23% while the other 3 respondents believed there were individual cases, accounting for 5.77%.

16. If there is illegal use of CFC-11, you think the main reasons may be: (Multiple choices)

Of the 52 respondents, 27 respondents inferred that the illegal use of CFC-11 could reduce the production cost and ensure the product quality, accounting for 51.92%. 24 respondents believed that the cost of illegal use was relatively low, accounting for46.15%. 7 respondents believed that illegal use could be greatly concealed, accounting for13.46%. 9 respondents thought the enterprises committed illegal use had ways to evade supervision and administration of the government, accounting for 17.31%. 32 respondents reasoned that the prices of legal substitutes were high, accounting for 61.54%, and 12 thought it difficult to employ the legal substitutes, accounting for23.08%)

17. Regarding the ODS usage enterprises, you think: (Single choice)

Of the 52 respondents, 15 respondents believed that there was no risk of illegal activities, accounting for 28.85%, 13 believed that there was no possibility of illegal activities, accounting for 25.00%and 24 didn't know about the situations of ODS usage enterprises, accounting for46.15%)

18. In your opinion, what aspects should be strengthened in order to avoid illegal use of ODS in the future? (Multiple choice)

Of the 52 respondents, 48 respondents considered it necessary to strengthen the supervision and administration and law enforcement of government, accounting for 92.31%. 39 advised increasing penalties for illegal actors, accounting for75.00%. 32 thought a more powerful multi-channel direct reporting system was vital, accounting for 61.54%. 48 believed more favorable policies for the development and production of substitutes were needed, accounting for92.31%. 45 thought the development of a consumer market of substitutes should be promoted as soon as possible, accounting for 86.54%.

19. For the publicity of laws and policies on ODS, what forms do you prefer: (Multiple choices)

Of the 52 respondents, 29 respondents were willing to accept the publicity by television, accounting for 55.77%, 38 respondents by APPs, WeChat mini-programs and official accounts, etc. , accounting for 73.08%, 40 by Internet pages, accounting for 76.92%, and 32 by attending relevant meetings, accounting for61.54%.

Annex 3 Information source

Except the information or data of which the source is stated in the text, the source of the remaining information is as follows:

(1) Laws, regulations and policy documents are sourced from websites and publications of Chinese government departments and interviews with government personnel;

(2) The market data of polymeric MDI for rigid PU foam is from the market survey and research of this study;

(3) The market data of foaming agents for rigid PU foam is from the market survey and research of this study;

(4) The data and information of HCFC-22 is sourced from the information survey data sheets collected from various HCFC-22 production enterprises in China during this study;

(5) The data and information of CTC is sourced from the information survey data sheets collected from various enterprises producing, selling and using methane chloride in China during this study;

(6) The questionnaire results are obtained from the statistical results of the questionnaires conducted for the government administration departments, methane chloride production enterprises, HCFCs production enterprises and consumption enterprises during this study. The study distributed questionnaires to 117 ODS-consumption enterprises, 52 persons responded from 36 enterprises; distributed questionnaires to 30 HCFCs enterprises, 37 persons responded from 20 enterprises; distributed questionnaires to the provincial eco-environmental department of 31 provinces and municipalities, 31 persons responded from 29 provinces and municipalities; distributed questionnaires to 16 methane chloride enterprises, 26 persons responded from 14 enterprises.