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Annex 7 – EFCTC paper on the end-of-life management of F-gases: the case for circularity and recovery

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Executive summary

A key benefit of F-gases is that they can be recovered and reclaimed to be reused for maintenance and servicing of existing equipment or even in new equipment. The recovery, recycling and reclamation of F-gases is **not only economically beneficial**, but it **offers clear benefits for the environment** compared to destruction operations.

The recovery, recycling and reclamation (RRR) of F-gases in the HVACR sector has been taking place for many years and its recent and rapid growth is driven by a mix of policy ambition, particularly by the 2nd EU F-gas Regulation (Reg. (EU) N°517/2014) and its introduction of a phase-down for hydrofluorocarbons (HFCs), which led to **reduced availability and increased value** of HFC refrigerants.

As a consequence, **the interest in recovery of used HFCs by stakeholders grew significantly**, several EU companies have invested in RRR activities and technologies after the entry into force of the Regulation. In addition, amended laws on circular economy and waste (collection targets, recovery obligations) further strengthened these dynamics.

The evaluation study of the EU F-gas Regulation demonstrates that recovery, recycling and reclamation **measures are being enforced** and that both several Member States as well as industry have established Extended Producer Responsibility Schemes which are **effective to support the reduction of F-gas emissions.**

A restriction **could disrupt innovative industries investing in recovery and reclamation activities**. **Reclaimers would no longer have an incentive to invest** in additional technologies and innovation as their recovered and reclaimed gases could eventually no longer be used, but would have to be destroyed instead. In addition to the burden of the destruction of the refrigerant gases in the limited amount of waste incineration facilities, a significant amount of **equipment would have to be scrapped prematurely undermining the EU's Circular Economy goals**.

Therefore, the end-of-life of equipment containing F-gases should not be considered a main source of emissions as the evidence points to the existence of effective control mechanisms. **These, combined with the containment provisions of the EU F-gas Regulation support the argument that this Regulation alone is effective in controlling the emissions of F-gases during their entire lifecycle.**

In conclusion, there should be time unlimited derogation allowing the use of recycled and reclaimed F-gases for the maintenance and refilling of equipment until the end of its lifetime.

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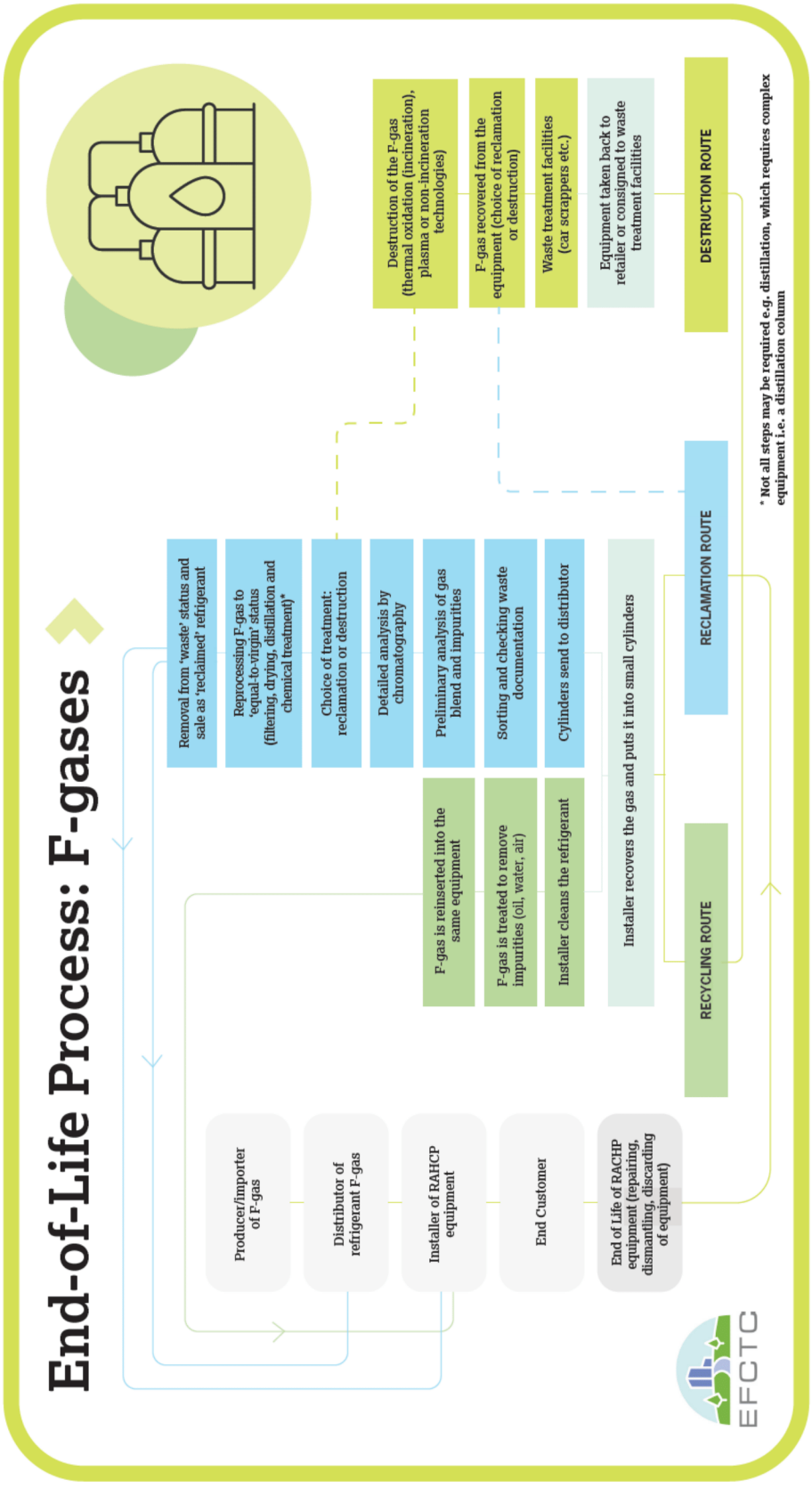

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Introduction

The paper investigates the current drivers and state of play of the end-of-life management of F-gases, using a mix of desk research, literature search, and interviews with a structured written survey. Case studies on the HVACR sector in three EU Member States (France, Germany and Italy) were also analysed[1] to better grasp the best practices in the EU. The report describes the main actors and their role in the circular economy for F-gases, the relevant legislations and the business case that has emerged in the last decade.

The recovery of F-gases in the HVACR sector has been taking place for many years and its recent and rapid growth is driven by a mix of policy ambition, particularly by the 2nd F-gas Regulation (Reg. (EU) N°517/2014) and its introduction of a phase-down for hydrofluorocarbons (HFCs), which led to reduced availability and increased value of HFC refrigerants. As a consequence, the interest in recovery of used HFCs by all market players grew significantly. In addition, amended laws on circular economy and waste (collection targets, recovery obligations) further strengthened these dynamics. The policy interventions have provided a foundation to encourage more collection of equipment and the recovery of F-gases. Procedures for transport, destruction, and handling of waste are ensured through the Waste Shipment Regulation and Industrial Emissions Directive and they provide traceability and best availability techniques for the destruction and handling of waste.

The experience observed in France, Germany and Italy shows a rather fragmented approach to the end-of-life management of F-gases, which is nonetheless effective. The increased economic value of fluorinated gases has gradually led distributors of F-gases and producers to explore the recovered refrigerants market. According to the European Environment Agency (EEA), the current level of reclaimed gases is estimated at 1100 tonnes per year (European Environment Agency, 2022, p. 28; p.44). However, the EEA data might be incomplete, and it might underestimate actual reclamation activities as they are based on information retrieved from the EU F-gas Portal, where there is currently no registration possibility for reclaimers and thus, no possibility to report their reclaimed quantities.

The overall assessment concludes that the circular economy of F-gases is first and foremost driven by the economic viability of the businesses involved while the collection and recovery are regulated by policy intervention in the field of waste prevention. The upcoming revision of the F-gas Regulation could reinforce measures to handle the end-of-life of F-gases by advancing the introduction of mandatory EPR schemes.

The increased market value of fluorinated gases gradually strengthened the recovery, recycling and reclamation activities by F-gas distributors in the market of used refrigerants, according to interviews with different European distributors. As per information shared by the interviewees, while there are data gaps on the quantities of refrigerants that are being recycled, the market realistically assumes that recycling of refrigerants is increasing.

[1] To ensure full compliance with competition law, the sector group relied on the support of a third party, FleishmanHillard.

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1. Review of existing and upcoming legislative requirements on the management of F-gases during maintenance and at the end-of-life

The legislative framework around the end-of-life management of F-gases has developed gradually over the past 15 years. Due to the fact that F-gases are a very diverse group of substances with many end-uses, multiple pieces of legislation co-exist and complement each other to support the circularity and the end-of-life management. This report focuses on the end-of-life management of F-gases in the HVACR sector, but briefly details legislative requirements for other applications in order to provide an overview. More in-depth evaluations of the other legislative files relating to the management for F-gases, often application-specific, can be found in Annex II.

The current legislative framework, centred around the F-gas Regulation, is foundational as it provides targets and key requirements for the collection, and recovery of F-gases. This applies to all types of equipment relying on refrigerants. In addition, other legislation pre-date the introduction of the F-gas Regulation which contributed to the establishment of collection streams (especially the WEEE Directive, as well as legislation concerning passenger and light commercial vehicles). There are currently no mandatory EPR requirements for F-gases across the EU, nor dedicated legislation regulating the reclamation process. However, several Member States have national legislations in place for the recycling of F-gases, going beyond EU requirements. Moreover, the European Parliament suggested to include mandatory schemes in the 2022 revision of the F-gas Regulation with the final wording of the text to be confirmed in the ongoing interinstitutional negotiations.

From a practical standpoint, the regulatory framework acts on three levels.

The first level targets the containment of emissions during the use-phase of the equipment, including when maintenance and repair operations are performed. This is ensured via the F-gas Regulation and for specific applications, the Mobile Air Conditioning Systems (MAC) Directive, which sets rules on controlling leakages and on the retrofitting and re-filling of air-conditioning systems.

The second level targets the recovery and collection of the F-gases. F-gases are identified as hazardous waste based on the Waste Framework Directive (European Union, 2018) and the European Commission notice on technical guidance on the classification of waste (European Commission, Commission notice 2018/C 124/01, 2018). As such, their handling at the end-of-life as well as their potential transboundary shipment is regulated within a multi-level regulatory regime. Other legislations such as the End of Life Vehicle Directive also cover the management of waste F-gases for specific applications. The F-gas Regulation sets the ground rules for the recovery of F-gases, albeit with some nuanced differences between stationary equipment and the trucks and trailers' refrigeration units and the other equipment.

The third level of regulatory requirements is even more prescriptive and focuses on the incineration and waste treatment under the Industrial Emissions Directive (IED). These rules are complemented by specific international requirements under the Montreal Protocol.

Destruction facilities in the EU are required to report their annual volumes of destruction and the technology used in the EU F-gas Portal, established as part of the F-gas Regulation.

These rules on recovery and safe handling of F-gases are complemented by additional waste regulations, the Waste Framework Directive and the Waste Shipment Regulation, that are targeting the collection, storage, transport and treatment of used refrigerants classified as hazardous waste.

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Permits for the collection, storage, transport and treatment of waste are needed and are granted for a limited period of time (Articles 23-26,Waste Framework Directive). The permits should mention the specific waste code, applicable to the waste that is being handled. For CFCs, HCFCs and HFCs the relevant waste code – 140601* – is provided in the Commission Decision 2000/532/EC of 3 May 2000 establishing a list of wastes.

These rules target all undertakings, who are involved in the handling of used refrigerants. Unless recycled and used in the same equipment, installers and service engineers usually return recovered refrigerant to their suppliers (usually F-gas distributors), who provide specific recovery bottles for this procedure. The F-gas distributors may be able to reclaim some of the used refrigerant at their local sites, but they might have limitations regarding reclamation technologies. If a more specialized reclamation or destruction facility is located in another EU Member State and transboundary shipment is needed, then the distributors must conclude a contract with the respective waste treater and set up a so-called Transfrontier Notification of waste (TFS notification) for transboundary shipment of waste (Article 4-7,Waste Shipment Regulation).

As shown above, the regulatory framework is extremely complex as it involves different pieces of legislation. This paper intends to focus mainly on the role that the F-gas Regulation is playing in encouraging the uptake of the recovery, recycling and reclamation of fluorinated gases. Accordingly, the following section will provide an overview of the specific requirements under the F-gas Regulation. More detailed information on the rules applying under the WEEE Directive, the ELV Directive and the IED have been included in Annex II.

1.1 The F-gas Regulation (No 517/2014) and its ongoing revision

The EU F-gas Regulation contains several measures for emissions prevention, containment and end-of-life management of F-gases and its ongoing revision will further strengthen these measures (Annex III).

As the Commission's impact assessment attests, the leakage rates of F-gases decreased following the introduction of improved containment measures with the current F-gas Regulation in force since 2015 (European Commission, 2022, p. 68). Moreover, the progressive substitution of old equipment with newer less leaky equipment, is already leading to declining equipment lifetime emission rates (European Commission, 2022, p. 122).

Lower emissions during the use phase of equipment are expected to translate into higher recovery rates at the end-of-life. Regarding measures addressing potential emissions occurring at the end-of-life of F-gases, the 2014 Regulation sets out requirements for operators of equipment containing F-gases for their recovery, recycling, reclamation and destruction.

A key benefit of F-gases is that they can be recovered and reclaimed to be reused for maintenance and servicing of existing equipment or even for the production of new equipment. The evaluation of the 2014 F-gas Regulation highlights that the Regulation has increased the recovery and reclamation rates of refrigerants (David Birchby, 2022, p. 97). To further enable the refrigerant reclamation and contribute to the circular economy, the 2022 proposal for the revision of the F-gas Regulation empowers the Commission to adopt delegated acts to establish a list of products and equipment

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where the recovery or destruction should be considered feasible and which technology should be applied.

The evaluation study further demonstrates that recovery, recycling and reclamation measures are being enforced and that both several Member States as well as industry have established Extended Producer Responsibility Schemes which are effective to support the reduction of F-gas emissions (David Birchby, 2022, pp. 97,111-114). However, as there are no mandatory requirements for such schemes, there is no comprehensive system and there is a scarcity of available data. Further monitoring of such schemes was recognized as a key avenue to boost the recovery and reclamation (David Birchby, 2022, p. 97). In its position on the ongoing review of the F-gas Regulation, the European Parliament seeks to establish mandatory EPR Schemes for the recovery of F-gases and requests the Commission to set minimum requirements for such schemes by 2025 (European Parliament, 2023). The introduction of a mandatory EPR scheme could be a good step forward, yet the specificities of each Member States should be taken into account.

The ongoing revision of the F-gas Regulation is expected to extend containment and end-of-life measures to unsaturated F-gases listed in the Annex II of the F-gas Regulation, in particular H(C)FOs. This is a fundamental change that will ensure that all fluorinated refrigerants are well contained and can be recovered at their end of life. H(C)FOs have become a preferable alternative to HFCs as they present similar characteristics to HFCs in terms of their performance, safety and energy efficiency and have low global warming potential (GWP). In the current F-gas Regulation, for H(C)FOs, there is a reporting obligation on the production, import, export feedstock use and destruction (Article 19). The 2022 Commission revision proposal however would oblige operators of equipment using H(C)FOs (not only HFCs) to check their applications for leaks and keep detailed records on relevant information such as the results of those checks, the quantity of gas added or recycled and the measures taken to recover or dispose of the gas. These amendments will play an important role to ensure that more gases can be recovered at the end-of-life, further strengthening the business case for recovery, recycling and reclamation of F-gases.

2 The waste management cycle of used refrigerants on the ground

Refrigerants become “waste” when they are recovered from equipment during service, maintenance or decommission, unless the refrigerant is recycled and re-used locally by the service engineer. This means that when a refrigerant reaches its end-of-life it will require specialised treatment and handling as well as the issuing of special permits. Certified personnel, contractors undertake the recovery of the refrigerants during service, maintenance or decommission. Thus, the waste-management cycle of HFC refrigerants effectively begins during recovery by contractors.

The following sections will review in detail the typical waste-management cycle, from the initial recovery of the fluorinated refrigerant to the ultimate reclamation or destruction.

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2.1 Recovery

Recovery is the first step in the end-of-life management of F-gases as it represents a prerequisite for recycling, reclamation or destruction of the gas. The recovery of F-gases is defined and stipulated in the F-gas Regulation[2], which requires to collect and recover them at the end of equipment's useful life so that they can be sent for reclamation or disposal as special and hazardous waste.

Recovery is an activity that involves removing refrigerants from a device and storing it in an external container. It requires dedicated recovery equipment as the refrigerants are typically compressed liquified gases. Recovery of used refrigerants may be conducted during maintenance of equipment or when the equipment reaches its end-of-life and is dismantled. The refrigerant recovery process consists mainly of removing the refrigerant from the refrigeration system without changing its condition. The recovered refrigerant should be managed in accordance with applicable Regulations, i.e. the F-gas Regulation, the Waste Regulation and the EN378 Part 4 standard (relating to refrigeration systems and heat pumps).

The recovery must be done with the appropriate equipment and by certified technicians, and the F-gases must be recovered in labelled containers. Information on the actions taken to remove and recover F-gases during disposal must be recorded in a logbook, along with information identifying the technician who performed these activities (Article 6, F-gas Regulation). According to distributors, the recovery equipment on the market is able to recover 100% of the refrigerant gas, avoiding any leakage.

Whenever a technical intervention is carried out on a specific piece of equipment, the technician fills out the respective record in the intervention record booklet containing all the data relating to the intervention carried out, as well as the technical options taken within the scope of the intervention if they are relevant to the history of the equipment or refrigerants used. The register of interventions is provided by national accredited entities to carry out the certification of technicians, respective monitoring, and renewal of certification. (Martinho, et al., 2023).

In terms of route of used refrigerants, recovery from household appliances—i.e. waste electrical or electronic equipment—could be performed either onsite or after transportation and disposal to a waste facility or waste recycling company.

Recovery from commercial and industrial equipment is generally performed onsite using mobile recovery equipment. These used F-gases are then returned by the service technicians (installers) to their suppliers of virgin refrigerant, either a wholesaler or distributor.

The recovery of F-gases has been subject to research, e.g. the European Commission commissioned an "Analysis on the Recovery of Fluorinated Greenhouse Gases in EU-27 in the Period 2004-2007" (ICF International, Analysis on the Recovery of F-gases in EU-27 in the Period 2004-2007 and Determination of Options for Further Progress, 2008) which identified several (infrastructure, technical, economic, regulatory, information) barriers. Today, the "recovery efficiency of refrigerants from installations at

[2] Article 2 §14 of the EU F-gas Regulation, defines "'recovery' as the collection and storage of fluorinated greenhouse gases from products, including containers, and equipment during maintenance or servicing or prior to the disposal of the products or equipment".
According to Article 8, operators of stationary equipment and refrigerated trucks and trailers containing F-gases, as well as of other equipment, including mobile equipment, are obliged to ensure that the recovery of these refrigerants is carried out by certified technicians for recycling, reclamation or destruction.

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EoL" is reported to be high (more than 75%) in most cases, irrespective of the installation type or the activity (Figure 11) (Dauwe Tom, Altdorfer, & Gschrey, 2018, p. 21). Other studies note that "LCA results show that developing new recovery technologies for F-gases in a circular economy context has a high potential for reducing its environmental impact" (Jovell, Pou, Llovell, & Gonzalez-Olmos, 2022).

2.2 Recycling

The F-gas Regulation defines recycling as "the reuse of a recovered fluorinated greenhouse gas following a basic cleaning process" (Article 2 § 15), however it does not specify what basic cleaning process means. It is therefore necessary to refer to the norms that indicate the methods of proceeding in this area. ISO 11650 describes in detail the requirements for recovery and recycling equipment. According to this standard, recycling means reducing the level of contamination of the refrigerant used by separating the oil, removing non-condensing gases and using equipment such as filters to reduce humidity, acidity and solids. Recovery and recycling equipment is designed to achieve these basic cleaning processes.

According to the EN378 Part 4 standard defining safety and environmental requirements for refrigeration installations, the decision to reuse the refrigerant in the same system should be based on careful assessment by the installers. AREA's (Air conditioning and Refrigeration European Association representing European Refrigeration, Air Conditioning and Heat Pump Contractors) Technical Bulletin on F-gas recycling (2018), mentions several steps that contractors need to follow when recovering or recycling a refrigerant.

Recycling operations do not require any laboratory analysis using a gas chromatograph. The recycling and local re-use is more cost effective when compared to reclamation or destruction, which both have additional transport and processing costs.

2.3 Reclamation

The EU F-gas Regulation defines 'reclamation' as: "the reprocessing of a recovered fluorinated greenhouse gas in order to match the equivalent performance of a virgin substance, taking into account its intended use" This process, as explained by reclaiming companies, is done in a closed system, leading to insignificant levels of emissions.

During the process, the recovered F-gas is first cleaned from impurities such as non-condensable gases, moisture, oil, and acids, which can occur in the refrigerant after a long operation period of the device.

Reclamation differs depending on whether a single refrigerant type (including blends) or a mix of different refrigerants needs to be regenerated. When dealing with a mix of different refrigerants (i.e., refrigerants not belonging to the same type that have been mixed by operators in the same recovery bottle), separation of the components is needed. Compared to the first cleaning from impurities, which can easily be performed, the separation of different refrigerant types requires a complicated technology and significant investment.

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Several EU companies[3] publicly announced their investment in separation technologies after the entry into force of the current EU F-gas Regulation.

The last step in the reclamation may consist of adjusting the reclaimed refrigerant with refrigerant components to achieve the required specification tolerances for the refrigerant blend.

Eventually, specialised laboratory tests are completed to certify the reclaimed product. The final analysis guarantees that the reclaimed refrigerant meets the same standard as the virgin substance. Since there is no specific legal requirement concerning the purity of F-gases in the EU, the EU F-gas industry follows the AHRI700 Standard.

The certification ensures certainty about the composition of the refrigerant which in turn guarantees the avoidance of problems that result from the use of inadequate quality refrigerants, i.e., increased energy consumption, reduction of cooling efficiency, reduction of compressor life, serious equipment failures, emissions.

The certification also represents the end-of-waste status. It is very important that the regeneration process results in the cessation of waste status of the recovered refrigerant, so that it can be reused in a different installation than the one which it originates from in accordance with (national) waste regulations.

As such, reclamation is a multi-stage process that requires a specialised installation and analytical laboratory.

2.4 Destruction

For those cases where substances are prohibited in the European Union, or when they cannot be recycled or reclaimed, the refrigerants need to be destroyed. Based on the interviews, it is clear that destruction is considered only as a last resort option, to the point that even destruction facilities, when receiving waste gases, assess whether there is anything that could be saved from destruction and that they could still sell to professional reclaimers for reclamation. Moreover, to avoid destruction and ensure recovered F-gases remain in the market, distributors offer several incentives to installers for zeotropic waste F-gases, such as sharing the part of the value of the later reclaimed F-gas and renting cylinders to allow installers flexibilities in the recovery.

In context of the 30th Meeting of the Parties to the Montreal Protocol (November 5–9, 2018), a list of approved destruction technologies for controlled substances has been adopted. Under the EU F-gas Regulation, destruction companies are required to annually report in the F-gas Portal the volumes that have been destroyed and the technology used for destruction.

[3] https://www.agas.com/news-insights/a-gas-buys-dutch-reclamation-business/
https://www.coolingpost.com/world-news/a-gas-buys-dutch-recycler-btc/
https://www.daikinchemicals.com/company/sustainability/refrigerant-reclamation.html
https://life-prozon.eu/en/about-the-project/objectives
https://www.lemondedusurgele.fr/equipements-et-services/10689/climalife-va-regenerer-les-fluides-voues-a-la-destruction

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The technical performance of approved technologies for the destruction of HFCs are reported in a series of UNEP documents[4].

The revised F-gas Regulation, is expected to specify the approved destruction technologies in accordance with the list approved by the Parties to the Montreal Protocol for F-gases listed in Annex I, section 1 of the Regulation. For those gases identified as "Other fluorinated gases" for which destruction technologies have not been approved, the most environmentally acceptable technologies should be used in compliance with EU and national waste legislation (see Annex II for more details).

Currently 17 facilities are registered in 2021 for destruction of F-gas Annex I & II substances in the EU, as required by the F-gas Regulation (European Environment Agency, 2022, p. 64 & 66).

Destruction technologies are expensive, with high initial investments and high operation and energy costs. A report by ICF (2010), commissioned by the European Commission, estimated the cost of destroying HFCs and ozone-depleting substances in the EU to be between EUR 1 and 10 per kg for 2010. Since most destruction facilities are also located far from the places where the refrigerants are recovered and collected additional costs in the range of EUR 0.10 per tonne per kilometre in the EU must be added to account for recovery and transport. Estimations in the ICF report are based on data assessed for ODS by the UNEP Technology and Economic Assessment Panel Task Force decision XX/7 – Phase 2 Report "Environmentally sound management of banks of ozone-depleting substances" of October 2009 (p. 57). More recent data on the cost for destruction might be available.

3 The business case for enhancing the circular economy of used fluorinated gases

The increased market value of fluorinated gases (as a result of the introduction of a phase-down schedule and quota system in the EU F-gas Regulation) gradually strengthened the recovery, recycling and reclamation activities by F-gas distributors in the market of used refrigerants, according to interviews with different European distributors. As per information shared by the interviewees, while there are data gaps on the quantities of refrigerants that are being recycled, the market realistically assumes that recycling of refrigerants is increasing. Reclaimed gases need to abide by exactly the same standards (AHRI700 Standards) as virgin gases and can be used in new equipment, rather than only for maintenance or refilling of the existing older equipment.

A restriction **could disrupt innovative industries investing in recovery and reclamation activities**. **Reclaimers would no longer have an incentive to invest** in additional technologies and innovation as their recovered and reclaimed gases could eventually no longer be used, but would have to be destroyed instead. In addition to the burden of the destruction of the refrigerant gases in the limited

[4] Report of the UNEP Technology and Economic Assessment Panel, April 2018, Volume 2, Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances;
Report of the UNEP Technology and Economic Assessment Panel May 2018, Supplement to the April 2018 Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances;
Report of the UNEP Technology and Economic Assessment Panel September 2018, Volume 1, Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances (Addendum to the May 2018 Supplemental Report-Revision).

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amount of waste incineration facilities, a significant amount of **equipment would have to be scrapped prematurely undermining the EU's Circular Economy goals**.

From an environmental perspective, making the life of refrigerants longer is generally more energy and resource efficient than destroying them. The proposed REACH restriction would lead to a premature termination of current HVACR equipment with many years of service life left, which could be serviced with reclaimed F-gases.

In the following paragraphs the paper will explain more in detail the growing market for recovery, recycling and reclamation as well as their environmental benefits compared to destruction. The paper will also review how the operations of recovery, recycling, reclamation or eventually destruction are integrated today.

3.1 Why the recovery and reclamation of F-gases makes economic sense

Since the introduction of the EU F-gas Regulation and the creation of a regulated market for fluorinated gases based on the quota system, the market value of F-gases increased due to the regulated supply while facing pressure from illegal trade (Öko-Recherche, Ricardo, & Öko-Institut e.V., 2022, p. 92).

According to information shared by Verband Deutscher Kälte-Klima-Fachbetriebe e.V. (VDKF) (based on a study conducted by Öko-Recherche for the European Commission on HFC prices), compared to 2014, prices of HFC-134a were almost five times higher in Q1 2023. Prices of HFC-404A went up by 13.5 times and HFC-410A increased almost by seven times. Prices increased year on year as well.

VDKF Information newsletter for May-June 2023 also highlights that the end user prices for the high-GWP refrigerants (e.g. recycled or reclaimed refrigerants) have risen more strongly than in the previous year. They attributed this increase to inflation on the one hand but also to the quota system under the current EU F-gas Regulation (Verband Deutscher Kälte-Klima-Fachbetriebe e.V., 2023, p. 12). In interviews, distributors of reclaimed F-gases underline the drastic increase in price by 200% since the introduction of the Regulation. They, as well as the VDKF, further assume that prices for high-GWP refrigerants will continue to rise due to the potential further reduction of available quotas for HFCs as a result of the 2022 review of the F-gas Regulation.

This demonstrates the incentive for all economic operators to handle F-gases as efficiently as possible to minimize any product loss.

For F-gas distributors who are selling the gases to installers, it is a logical step to expand reclamation activities, as this allows them to grow their margin significantly. As distributors explained during the interviews, once the initial investment of the required equipment is made, the cost of reclaiming waste refrigerant gases compared to the purchasing cost of virgin gases is limited.

During the interviews, F-gas distributors indicated that volumes received for reclamation from their customers (service companies) increased over the years due to a combination of the F-gas Regulation and of the implementation of waste legislation that identifies recovered refrigerants as hazardous waste.

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This seems to be confirmed also by data for Norway reported in the Nordic cooperation on F-gas emissions inventories project report prepared by the Nordic Council of Ministers (Urbancic Ásgeirsson, et al., 2022). While Norway is not an EU Member State, it is aligned with the EU F-gas Regulation and reinforced by the uniform application of Single Market legislation. The report by the Nordic Council of Ministers shares the conclusions of another Norwegian study (COWI, 2018) establishing that in Norway, based on surveys conducted with Norwegian service companies, around 50% of the interviewed companies are recycling refrigerants. At the same time, only 16% of the installed amounts of F-gases in A/C installations are received for controlled destruction. This broadly suggests that the quantities that are recovered and recycled are comparatively larger.

Likewise, Martinho et al. (2023, p. 345) in their behavioural study on the technicians dealing with refrigerant gases, conducted within the framework of the EU funded project KET4F-gas (KET4F-Gas, 2018), pointed out that out of the 586 technicians interviewed in Portugal, France and Spain, 52% stated that the refrigerant gases are sent for recovery/recycling by type of refrigerant gas and 10% reported that the gases are mixed and shipped for recovery/recycling. 10 % of technicians stated that the gases are sent to incineration by type of refrigerant and 9% claimed that refrigerants are mixed and sent for incineration. Finally, beyond the recovery and recycling, 11% of respondents reported that they would reuse or reintroduce the refrigerant in the same or other equipment.

Even though it is not possible to draw exact conclusions on the samples used respectively in the study conducted in Norway (COWI, 2018) and in the survey conducted throughout Spain, Portugal and France (Martinho, et al., 2023), it is interesting to note that the reported percentages for recovery/recycling and for destruction are very close. This suggest that, notwithstanding potential differences in the enforcement of existing legislation, the technicians' efforts to recover the gases are fairly similar across countries and the amounts that are recovered are higher than those that are destroyed. Moreover, the efficiency of recovery processes is increasingly high (Federal Environment Agency, 2021, p. 374). Maximising efficient recovery and minimising emissions is further incentivised by the distributors that have been interviewed for this report, who shared that they implemented value-sharing cooperation systems for installers sending non-mixed F-gases for reclamation.

The latest European Environmental Agency (EEA) Report on "Data reported by companies on the production, import, export and destruction of fluorinated greenhouse gases in the European Union" (Ludig, Jörß, & Liste, 2022) also supports the view of increasing reclamation activities as it shows that quantities for reclamation increased between 2014 and 2020 (Ludig, Wissner, & Jörß, 2021). In 2021, a drop of about 30% was registered, but this is due to the missing data of a single UK-based company, whose reclamation data was no longer included after the Brexit. When correcting the scope of reporting for this change, it is claimed that EU-27 HFC reclamation in 2021 was at roughly the same level as 2020. Moreover, these data are expected to provide only an underestimated picture of the actual volumes that are reclaimed on the ground. However, the EEA data might be incomplete, and it might underestimate actual reclamation activities as they are based on information retrieved from the EU F-gas Portal, where there is currently no registration possibility for reclaimers and thus, no possibility to report their reclaimed quantities.

A further indication of the economic viability of recovery and reclamation operations can be inferred from increasing ongoing investment into technologies that allow the separation of recovered gases when they are mixed together. The level of investment might vary depending on the scale of the installation and the batch-size to process. Industry trends such as the expansion of specialist recovery units for recovery from systems with bigger volumes at higher speed (rapid recovery systems) indicate that the recovery business is profitable, and making further investments in new technologies makes

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economic sense. These systems make it much easier to recover the gas onsite while reducing the downtime for large applications in supermarkets or industrial refrigeration, where longer times for maintenance and servicing translate into higher costs. Nevertheless, as shared by some of the interviewed distributors, the simple fact that investment is occurring is an indication of the value that can be extracted out of these operations. It is thus not surprising that even the EU has been funding via the Interreg Sudoe Programme, a project to design, test and validate different Key Enabling Technologies (KET) to implement the most efficient option for the separation and recovery of fluorinated gases used in refrigeration and air conditioning equipment (KET4F-Gas, 2018)[5]. The F-gas trading platform RETRADEABLES was created from the project Life3R, funded by the LIFE Programme of the European Union.

Finally, the increased set up of cooperation systems along the supply chain for waste F-gases is a clear indication of the economic benefits of their circular economy. According to the interviewed distributors, practices such as value-sharing offer incentives to both, installers and waste facilities, to send waste F-gases of high quality to the reclamation facilities. This ensures F-gases are recovered, reclaimed and re-used, while minimising emissions from potential mistreatment and limiting the waste of valuable resources.

3.2 Recovery, recycling and reclamation more beneficial than destruction

The recovery, recycling and reclamation of F-gases is not only economically beneficial, but it offers clear benefits for the environment compared to destruction operations. There are limited studies focused on the environmental assessment of the recovery and treatment of refrigerants (Jovell, Pou, Llovell, & Gonzalez-Olmos, 2022) (Wang, Wang, Mi, Zang, & Wang , 2022). Yasaka et al. (Yasaka, Karkour, Shobatake, Itsubo, & Yakushiji, 2023) have investigated the actual performance data of reclamation, destruction, and manufacturing facilities for HFC-410A, HFC-32, HFC-134a, and HFC-22. When assessing the data, the system boundary for the study started from the equipment disposal to the supply of other equipment. The authors analysed what would be the best ways of treating recovered refrigerants from a life-cycle point of view. They took into account both the global warming mitigation potential as well as the circular economy potential in terms of resource efficiency. The authors found that the GHG emissions from reclaimed treatment per kg of used refrigerant were approximately 5.7 to 15.9 kg CO_2eq less than those from destruction, confirming that the promotion of reclaimed treatment together with refrigerant recovery can contribute to global warming mitigation.

3.3 Case studies: Germany, France and Italy

[5] KET4F-Gas is a European project co-funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF), with a funding of 1.7 million euros. The objective of this project is to contribute to the reduction of F-gases emissions by developing and implementing Key Enabling Technologies, which follow benign and efficient green chemistry principles and use alternative climate-friendly solvents to recover F-gases. The project resulted in the development of two prototypes for F-gases separation (among other results).

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To allow for a more in-depth picture of the actual application of legislative requirements on the end-of-life management of F-gases, this paper utilizes three case studies based on literature research and interview data. The 2022 Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases finds that recovery and reclamation are treated or supported differently across Member States (Öko-Recherche, Ricardo, & Öko-Institut e.V., 2022). Therefore, this report chose to analyse France, Germany and Italy as they have the most advanced systems for recovery, recycling and reclamation of F-gases.

3.3.1 Germany

Since 2002, Germany has had legislation in place to decrease the end-of-life emissions of fluorinated gases. In the "Technical Instruction on Air Quality Control" (TA Luft), operators of refrigerated equipment are obliged to recover the fluorinated gases without emissions. They must demonstrate, for a sample group of 100 appliances, that they are able to recover at least 90 per cent of the amount of refrigerant. This is tested annually by independent experts (Erste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz (Technische Anleitung zur Reinhaltu–g der Luft - TA Luft), 2002, para. 5.4.8.10.3/5.4.8.11.3). For further treatment (which is especially relevant for the disposal of the insulating foams), the fluorinated gases need to be separated from other gases to be collected separately, and then disposed of as hazardous waste. The emissions produced during this process have to be continuously monitored (Umweltbundesamt, 2009, S. 5).

National requirements for F-gases in the TA Luft have been supplemented since 2008 with a mandatory recovery and take-back scheme of used F-gases, included in the Chemicals-Climate-Protection Regulation (Chemikalien-Klimaschutzverordnung, 2008). F-gas producers and distributors are therefore obliged to take back the gases after use or ensure their collection by designated third parties. Despite this obligation, there is no nationwide collection of data concerning the recovery of refrigerants HCFCs, HFCs and HFOs.

The initial step, the recovery of fluorinated gases, is mostly done by regional HVACR contractors, that are responsible for maintaining or servicing the equipment. This is monitored by the Federal States (Bund/Länder-Arbeitsgemeinschaft Abfall, 2023). According to a survey conducted with 19 RACHP equipment recyclers (examining the implementation of the WEEE directive in Germany), between 2019 and 2021, 160,000- 180,000 tonnes of refrigerant equipment was treated. Over this collection period, approx. 152,400 kg refrigerant was collected in 2019, approx. 155,800 kg refrigerant in 2020 and approx. 147,400 kg refrigerant in 2021 (ibid., p.7- 10). It is relevant to note, that documentation regarding the kind of refrigerant is only done by a limited number of operators, hence there is no concrete data on the type of fluorinated refrigerants recovered.

According to Germany's 2021 National Inventory Report, the recovery of F-gases is increasingly efficient with losses decreasing compared to the initial refrigerant charge for commercial, household and industrial emissions (p.374). The 2023 report by the Federal/State Working Group on Waste confirms this, finding the recovery rates for equipment containing fluorinated gases to be between 99.8 % and 90,9 % (Bund/Länder-Arbeitsgemeinschaft Abfall, 2023, S. 12- 13).

Following the final recovery, the regional contractor has the choice to either send the waste refrigerant to a destruction facility or take it back to a distributor. To avoid the destruction of increasingly valuable gases and facilitate the circularity for F-gases, several distributors in Germany

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sell and rent refillable gas cylinders (0,5kg-3kg/ 12l-88l) to local contractors. According to distributors interviewed for this paper, this practice further encourages a circular approach to the end-of-life management for F-gases.

Upon reception, the distributor analyses the waste refrigerant to assess the potential for reclamation of the gas to virgin standard using gas chromatography. Depending on the level of contamination and the value for the remaining gas, the refrigerant is either sent to destruction or is cleaned. Additionally, fractional distillation might be needed if different types of refrigerants that are returned to reclaimers are mixed together. Fractional distillation is only done by specialised reclaimers (in total 4 in the EU). The process of reclamation ends with a final gas chromatography analysis, that ensures that the reclaimed product meets the AHRI700 Standard.

3.3.2 France

France has been among the pioneers in recovery, recycling and reclamation operations promoting the inclusion of mandatory requirements into national legislation many years ahead of its counterparts at the EU level.

Already back in 1989, when the Montreal Protocol had been just ratified, a French company introduced recovery cylinders on the French market. The initiative then led to a wider industry agreement on F-gases (so-called "Convention fluides"), endorsed by the French Minister for the Environment. Under the agreement, distributors committed to take back used fluids from refrigeration specialists. (Devin, et al., 2015).

After a few years, Decree No. 92-1271 of December 7, 1992 made the recovery of CFCs, HCFCs and HFCs mandatory by law in France (Decree No. 92-1271 of December 7, 1992 relating to certain refrigerants used in refrigeration and air conditioning equipment, 1992). Only one year later, in 1993, the industry agreement on F-gases was revised to introduce an eco-contribution system that would support the recovery of F-gases.

Each distributor would charge an amount comprised between EUR 0,85-1,05 per kg of virgin refrigerant sold to installers, to support the recovery activities on the distributor side[6]. In 2017, it was estimated that on average, distributors provided around 200 000 recovery bottles per year for installers in different collection points in France and received around 100 000 bottles back with refrigerants to be recovered (Le Batiment Performant, 2017). A study carried out by Armines, a branch of the Ecole des Mines de Paris, calculated that the amount of greenhouse gases emissions avoided between 1993 and 2015 thanks to this measure amounted to 45 million tonnes of CO_2 equivalent (Association of distributors, fillers, recoverers & reclaimers of refrigerants, n.d.)

Since the early 90s, the French system benefits from a well-established network of distributors and diffused points of collection to promote waste management. Effectively a national "distributor responsibility" scheme is in place.

France is the only country that expanded on the 2006 EU F-gas Regulation by including specific obligations for producers. Article R543-94 of the French Environmental Code establishes that

[6] There are several sources mentioning that the agreement had to be revised in 2012 and 2017, but no concrete reference can be found.

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producers of refrigerants and producers of pre-charged equipment, are required each year to take back (free of charge) the refrigerants from distributors in proportion to the overall quantities that they declared to have placed on the market the previous year. Article R543-95 mandates producers of refrigerants and pre-charged equipment to treat the recovered refrigerant or have them treated in order to bring them into conformity with their original specifications enabling their reuse. If such compliance is impossible or if reuse of the fluid is prohibited, the recovered fluids must be destroyed. For the fulfilling of these obligations, producers are allowed to set up producers' responsibility organisations (Article R532-97).

Recovery obligations are complemented by record-keeping requirements. Distributors must keep a register showing, for each transfer of fluid, the name of the purchaser, the purchaser's certificate number if applicable, the nature of the fluid and the quantities transferred. Likewise, operators are required to declare the fluids they have handled to the approved body that issued their certificate of competence, before 31 January every year.

It is important to notice that France is also among the pioneers when it comes to implementing the Kigali amendment in national legislation. In fact, differently from other countries France already extended the reporting obligations to HFOs with decree no. 2019-526 of 27 May 2019.

Besides, the ADEME Fluorinated Gases Observatory already provided registrants with the opportunity, via the SYDEREP portal[7], to declare the volumes of HFOs placed on the market, sold, processed and stored where applicable since 2014. It is difficult to state that the information on HFOs is representative of reality, as it is unclear what proportion of players chose not to declare this type of gas. However, it is already a good advancement compared to data reported at the European level and could potentially allow for further extrapolations.

Overall, 6660 tonnes of HFCs have been placed on the French market in 2020 (ADEME, 2021). Recovery volumes that have been declared both by actors in the WEEE supply chain as well as by actors in the fluorinated gases chain show that 1988 tonnes of gases have been recovered in total by operators, 557 tonnes of which after treatment of waste electrical and electronic equipment and 1431 tonnes during maintenance. Of these amounts 1572 tonnes were given back by operators to producers and distributors of F-gases who declared taking back 1549 tonnes. Of these, 913 tonnes have been reclaimed and 174 tonnes have been destroyed (ADEME, 2021).

As mentioned above, in addition to HFCs, France is also reporting data for HFOs (although mandatorily only since 2019). As far as HFOs are concerned 313 tonnes have been placed on the market in 2020, showing a decreasing trend compared to 2019, however, in 2021 an increase can be observed (see figure 4 below).

[7] The French register to keep records related to sectors where extended producer responsibility applies.

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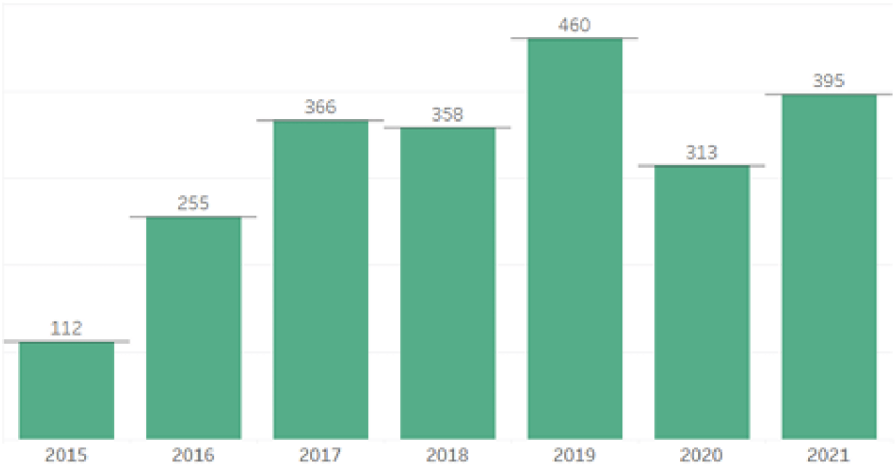

Figure 4 Evolution of declared tonnages of HFOs between 2015 and 2021 (ADEME, 2021)

222 tonnes of the 313 tonnes of HFOs reported for 2020 are attributed to HFO-1234yf which is progressively substituting HFC-134a in France, based on data reported to ADEME by equipment manufacturers in the automotive industry (ADEME, 2021).

In terms of recovered and reclaimed amounts of HFOs in the French market, aggregated data were not reported by ADEME, however there is detailed reporting per type of gases[8].

From a practical standpoint, the process of recovery, recycling, reclamation and destruction follow the prescriptions in national laws. During maintenance operations or when equipment is no longer in use, operators recover the used fluids contained in refrigerant circuits.

Operators must obtain a certificate of capacity issued by an approved organization in order to be able to handle refrigerants and have the obligation to return recovered fluids which cannot be reintroduced into equipment (or whose reuse is prohibited), to distributors They also have the option of having used fluids and packaging treated under their responsibility. There are 55,593 certified operators registered in the SYDEREP database (Agence de la transition ecologique, 2023).

The distributors then pass the recovered fluids on to the refrigerant producers, who can then treat the gases themselves or have them treated under their responsibility by approved treatment operators. They usually deploy collection and recovery solutions for this equipment in context of the four collective systems (ECO-SYSTEMES, ECOLOGIC, RECYCLUM and PVCYCLE) set up by French producers to satisfy the EPR obligation for WEEE.

In practice, operators and distributors assume the responsibility of the refrigerant producer and treat the refrigerants they have recovered or have them treated directly under their responsibility. This is

[8] According to information reported by F-gas accredited operators, 781 kg of R1234yf were recovered from waste equipment and 11923 kg from maintenance operations in 2020. Producers and distributors did not recover any HFOs based on data reported but they did play a role in their reclamation and destruction. Based on data reported by ADEME (2021, producers and distributors sent 3898 kg of R1234ze to reclamation and 22 kg to destruction. Some additional 113 kg of R1234ze were sent to destruction by producers of pre-charged equipment and operators collectively. As for R1234yf, producers and distributors sent 217 kg to reclamation (with no destruction at all). On the contrary 672 Kg of R1233zd were destroyed. No data were reported by operators and producers/distributors of pre-charged equipment on these two gases.

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particularly common when the fluid recovered by the operators can be recycled or regenerated for reuse (ADEME, 2021).

3.3.3 Italy

Italy has a well-established system for the recovery, recycling, reclamation or destruction of F-gases. According to the distributors that have been interviewed, the Italian system is effective in driving the recovery of F-gases.

Italy implemented the EU Directive on Waste from Electric and Electronic Equipment (WEEE) by the Legislative Decree n. 151/05. According to this Decree when equipment is disposed, it is by law required to recover the remaining F-gas and either reuse or destruct it which has led to low emission levels.

In addition, Italy has established an electronic register, the National Telematic Registry of fluorinated greenhouse gases and equipment containing fluorinated gases, which provides traceability on all pieces of equipment. Based on obligations laid out in the F-gas Regulation itself, Presidential Decree n. 43 of 2012 introduced the earliest version of the F-gas register, requiring operators of stationary appliances for air conditioning, heat pump, refrigeration and for stationary fire extinguishing systems with a charge of greenhouse F-gas exceeding 3 kg to report data on emissions. Presidential Decree No. 146/2018 (Gazzetta Ufficiale della Repubblica Italiana, 2019), implementing relevant provisions in the revised EU F-gas Regulation No. 517/2014, further revised the F-gas register to create the electronic database mentioned above where the sales of fluorinated greenhouse gases and equipment containing such gases, as well as the servicing, maintenance, repair and decommissioning of such equipment, are reported.

The National Registry (Ministero della Transzione Ecologica, 2023) is managed by Ecocerved (Ecocerved, 2023), a consortium of which the Italian Chambers of Commerce are part of, which fulfil the numerous tasks required by national and EU environmental legislation and, to this end, design, develop, and manage the related information systems.

This system and the considerable amount of data therein are being exploited to demonstrate relevant actors and considerable economic activity in Italy. For 2022, the database reports several key figures such as the number of certified personnel and operators of equipment[9].

The price surge of F-gases has led to an increasingly efficient handling of F-gases and distributors have invested in instruments to carry out recovery and reclamation and an increasing trend of recovery and improved containment practices can be observed in the Italian market which is supported by legal considerations (waste F-gases are considered hazardous waste and prohibited to dispose of into the environment) (ISPRA, 2023, pp. 191, 199)

[9] F-gas certified enterprises 35,000
F-gas certified personnel 73,000
Operator (company/body) of equipment using its own certified personnel (942)
Number of appearances (4,3 million times) for installation, maintenance, repair, leakage control and dismantling
Total interventions (6,3 million times)

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Today's availability of technical instruments, that, when used correctly, ensure near zero emissions during the recovery of F-gases supports efficiency and the reduction of emissions during the end-of-life handling of F-gases. Furthermore, Italian distributors are coordinating with the supply chain to facilitate a high rate of recovery and reclamation. As such, they provide separate cylinders to incentivise the separate collection of the different gases to increase waste stream separation to facilitate the recycling and reclamation of F-gases, as F-gas blends are more difficult to recycle and reclaim.

Based on data reported by Italy as part of their national greenhouse gas reporting obligations, there is a huge potential to exploit for the reclamation of F-gases. In fact, the report details the amounts of appliances sold and specific volumes of gases remaining in the equipment at the end of life. According to Italy's national experts, recovery reaches almost 100% of gases in larger size machines, with lower recovery rates for smaller equipment (ISPRA, 2023, pp. 190-210). For air conditioning equipment, 70-90% of the gas can be recovered at the end of their lifetime. This percentage is even higher for domestic, commercial and industrial refrigeration, where 85-90% of the F-gas can be recovered.

Overall, there are indications based on the interviews and desk research, that many forces are working towards making the recovery of F-gases run smoothly and benefit from the good collaboration of the whole value chain with the regulators.

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Conclusion

The recovery of F-gases in the HVACR sector has been taking place for many years and its recent and rapid growth is driven by a mix of policy ambition, particularly by the 2nd F-gas Regulation (Reg. (EU) N°517/2014) and its introduction of a phase-down for hydrofluorocarbons (HFCs), which led to reduced availability and increased value of HFC refrigerants. As a consequence, the interest in recovery of used HFCs by all market players grew significantly. In addition, amended laws on circular economy and waste (collection targets, recovery obligations) further strengthened these dynamics. The policy interventions have provided a foundation to encourage more collection of equipment and the recovery of F-gases. Procedures for transport, destruction, and handling of waste are ensured through the Waste Shipment Regulation and Industrial Emissions Directive and they provide traceability and best availability techniques for the destruction and handling of waste.

While the data remains scattered and potentially incomplete on the reclamation quantities across the EU, the French case study demonstrates that a successful circular economy for refrigerants can become a reality when the right policy mix and infrastructure is in place. As such, there is room to improve the traceability and management of the end of life of F-gases, together with measures that would improve the quantities to be recovered and preventing emissions into the environment. As per information shared by the interviewees, while there are data gaps on the quantities of refrigerants that are being recycled, the market realistically assumes that recycling of refrigerants is increasing.

The overall assessment concludes that the recovery, recycling and reclamation of F-gases is not only economically beneficial, but it offers clear benefits for the environment compared to destruction operations. The combined efforts of the European policymakers, diverse pieces of legislation governing the emissions of fluorinated gases, and the cooperation of the value chain has enabled the emergence of a circular economy for refrigerants which has expanded over the past years and is steadily increasing. The upcoming revision of the F-gas Regulation could reinforce measures to handle the end-of-life of F-gases by advancing the introduction of mandatory EPR schemes.

Therefore, the end-of-life of equipment containing F-gases should not be considered a main source of emissions as the evidence points to the existence of effective control mechanisms. These, combined with the containment provisions of the EU F-gas Regulation support the argument that this Regulation alone is effective in controlling the emissions of F-gases during their entire lifecycle.

In conclusion, there should be time unlimited derogation allowing the use of recycled and reclaimed F-gases for the maintenance and refilling of equipment until the end of its lifetime.

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Appendix I

Questionnaire

Assessment of the business case for RRR

1. When did you start recovering/reclaiming refrigerants?
2. Has this activity increased after the entry into force of the EU FGR? How far?
3. Do you notice any recycling activities on the installer/customer side? Any presumptions?
4. What are you doing with a refrigerant that you cannot reclaim? i.e. mixed refrigerants
5. Do you have a collaboration with a reclaimer that has a separation/distillation column?
6. Are you aware of investments to allow for the separation of mixtures of F-gases? How costly would you say that such investments could be?
7. What percentage of returned refrigerants do you have to send to destruction?
8. What are the barriers to increasing recovery rates? What needs to improve?
9. Do you see an increase in reclamations, if yes, what is the percentage of increase?
10. Are more recovery cylinders being supplied to your customers for recovery?
11. Does the rotating of recovery cylinders take more time (indicating that recycling is happening)?
12. Do you have any information on recycling activities?
13. Do you have a TFS notification in place (cross-border shipment of waste)?
14. Do you want to highlight any information that shows that recovery and reclamation has been increasing in the EU in the past years?
15. Are you aware of increasing investments in lab chromatographs for the analysis of F-gases?
16. Which are the top 3 returned refrigerants?
17. Are you aware of any data on volumes, percentages on MS level?

<u>Refrigerants' recovery, recycling, reclamation</u>

1. Could you provide an overview of the steps involved in recovery, recycling, reclamation (i.e. who does what)? Can you explain the role of the partners (if any) you're working with?
2. Do you recover refrigerants from all different applications, including end of life vehicles?
3. If yes is who are your main customers (no need to name, it is fine to identify the actors in the value chain)?
4. To whom would you normally sell the refrigerants that you purchase? And those that you regenerate? (which actors in the supply chain)
5. Do you have estimates of the fugitive emissions during the recovery, recycling, reclamation and transport of the gases?
6. Which impurities need to be treated to be able to recycle or to reclaim F-gases?
7. Given that F-gases can be found in closed systems within equipment how do these impurities occur?
8. Could you explain when destruction is considered to be the best option and who is responsible for such decision?

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Appendix II

Waste of Electric and Electronic Equipment's (WEEE)

Since 2012, EEE waste is primarily regulated through national return schemes (Romagnoli, de Bruijne, Drapeau, Ollion, & Anaëlle, 2022). This includes sealed domestic refrigeration such as fridges, freezers or small air-conditioning equipment. The directive establishes an obligation for member states to put systems allowing the end-users to return their WEEE free of charge (Article 5).

Concretely, once the consumer has returned their equipment to the retailers, the device is shipped to a certified waste facility by the retailers, the gas is extracted on a specific line equipped with an extractor. Alternatively, consumers can return their equipment to the relevant municipal waste treatment facilities. In addition to the F-gases used as a refrigerant, the insulating foams are also processed to extract the gases contained in the material (Ardente, Pastor, Mathieux, & Talens Peiró, 2015). The gas is extracted directly into a cylinder using a direct feeding system to avoid fugitive emissions. Once this process is completed, the used gases are either sent to a reclaimer or to a destruction facility.

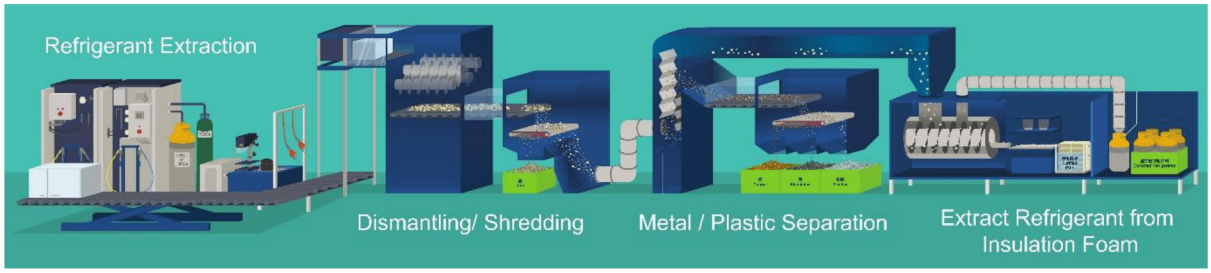

Figure 1 Overview of EOL process for refrigerators (Source: Hong Kong Environmental Protection Department, WEEE - PARK (WEEE Treatment and Recycling Facility), available at the following link https://weee.gov.hk/en/background/weee-park-weee-treatment-and-recycli ng-facility/)

While the WEEE directive establishes an obligation for Member States, the fundamental question remains to see how system delivers on the ground. For example, in Italy, a non-profit consortium of companies, Erion, has been established, which supports companies in the logistics and waste treatment activities of waste electrical and electronic equipment (Erion, 2023). Together with the Erion Compliance Organization, a common platform, the companies harmonise their operations to fulfil the obligations deriving from the Extended Producer Responsibility set out in the WEEE Directive.

The collection target included in the Directive is set at 65% of the average weight of EEE placed on the market in the three preceding years in the Member State concerned, or alternatively 85% of WEEE generated on the territory of that Member State.

While discrepancies exist between eastern and western Europe in the achievement of the targets set by the EU, most Member States have experienced challenges in implementing effective return schemes.

According to Eurostat data (Eurostat, 2023a), in 2020, 15 EU Member States surpassed the 45% WEEE collection target. Three EU Member States achieved the more ambitious target of a 65% collection rate in 2020, with another five countries coming close, with rates from 60.4% to 62.4%. Seven countries still reported rates in the range 40.9% to 44.3%.

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Collection rates very much depend on the type of appliances. There are six categories of EEE established under the WEEE Directive. These includes:

- Category 1: Temperature exchange equipment[10],
- Category 2: Screens and monitors,
- Category 3: Lamps,
- Category 4: Large equipment,
- Category 5: Small equipment,
- Category 6: Small IT and telecommunication equipment with an external dimension of no more than 50 cm.

Overall collection rates per category started to be gathered as of 2018. Unfortunately, Eurostat data do not identify overall percentage rates for the EU or by country (data in tonnes by country are available though) (Eurostat, 2023b). Nevertheless, some projections of collection rates for 2019 per product category were included in the 2015 European Commission Study on collection rates of waste electrical and electronic equipment (Magalini, et al., September 2015). The study showed that unlike very small WEEE for which the collection rate is estimated to be below 15%, large domestic appliances are expected to be well-collected, with an estimated collection of 90% for 2019, with a trend that is expected to grow slightly in through 2024.

Scenario 1: GENERIC collection rate of 85% of WG in 2019								
Category	Quantities of WEEE generated (kT)		Collection rate		Quantities Collected (kT)		Corresponding coll. rate POM	
	2010	**2019**	**2010**	**2019**	**2010**	**2019**	**2010**	**2019**
Cat 1	1.349	1.740	38%	95%	509	1.653	24%	76%
Cat 2	1.350	1.314	47%	95%	630	1.248	69%	100%
Cat 3	131	213	12%	16%	15	34	9%	13%
Cat 4 exc. PV	2.782	3.126	38%	95%	1.056	2.970	30%	90%
Cat 5	2.382	2.737	26%	70%	620	1.916	22%	64%
Cat 6	737	719	49%	70%	362	503	49%	75%
PV Panels	3	45	3%	85%	0,08	38	0%	2%
Total EU	**8.734**	**9.894**	**37%**	**85%**	**3.192**	**8.362**	**30%**	**66%**

Table 14 – Quantities at stake in 2019, if an overall collection rate of 85% of WEEE generated was to be reached in 2019.

Table 1 Quantities at stake in 2019, if an overall collection rate of 85% of WEEE generated was to be reached in 2019. Adapted from Magalini, et al., September 2015.

Actual data collected as part of the United Nations Institute for Training and Research (UNITAR) SCYCLE Programme for the WEEE Forum show that indeed only 3 EU Member States managed to hit the target for 2021.

[10] Refrigerators, Freezers, Equipment which automatically deliver cold products, Air-conditioning equipment, Dehumidifying equipment, Heat pumps, Radiators containing oil and other temperature exchange equipment using fluids other than water for the temperature exchange.

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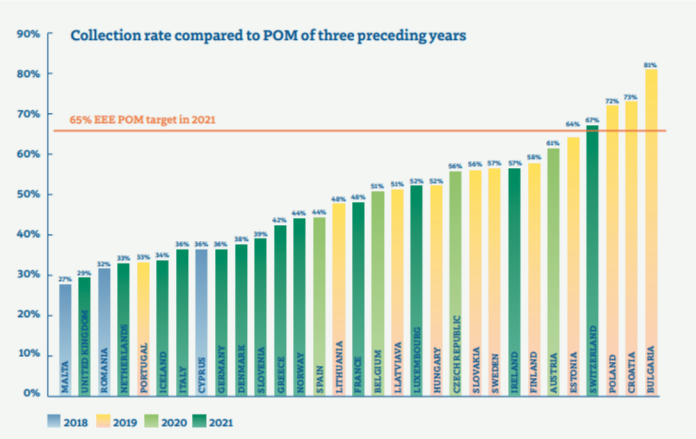

Figure 2 Overview of collection rate compared to EEE POM of three preceding years for Member States of the EU-27, United Kingdom, Switzerland, Iceland, and Norway (Baldé, Wagner, Iattoni, & Kuehr, 2020, p. 10)

In conclusion, while we are still far from the set targets, collection systems have been rolled out across the EU 27 and the infrastructure is in place. Large household appliances such as fridges and freezers have a high collection rate in comparison to other type of appliances. The collection has increased across all member states over the years and the trend is expected to continue. This could lead us to expect that for 15-20 years old fridges that still used R-134a, the end-of-life management of the refrigerant is properly handled.

Mobile Air Conditioning Directive (MAC) & the End of Life of Vehicles Directive

Mobile Air Conditioning is one of the single largest uses of F-gases. According to ACEA for the year 2021, around 9,7 million new passengers' cars and commercial vehicles were registered in the EU (ACEA, 2022). In parallel, around 11 million cars are dismantled every year in the EU based on the European /Commission estimates (European Commission, 2021). The servicing of existing mobile air conditioning systems is a large market for reclaimed F-gases, whereby emissions in this application can occur.

According to a study performed by the European Automobile Manufacturers Association (ACEA) in 2006, and cited by Sousa (2008, p.10), the average charge of light vehicles is around 0,6 kg and the annual leak flow rate of mobile air conditioning in cars is on average 10 g/yr. Compared to leakage rates of different vehicle models tested by the Minnesota Pollution Control Agency in 2021, the value of 10g per year appears to be stable. Depending on the charge size of the refrigerant (ranking from 420g to 1.9kg), the vehicles tested in 2021 lost between 0.7%- 4.2% of their refrigerant per year.

With relatively low leakage rates, recovery even in the MAC sector becomes more attractive, although charges are comparatively lower with respect to other applications.

The regulatory framework specific to the automotive sector is particularly relevant in the context of this analysis as it enabled the collection and used gases and their treatment as hazardous waste, through the end of life of vehicles Directive. ELVs are considered hazardous waste. The ELV directive sets out restrictions on the use of hazardous substances in new cars, obligations relating to the collection and treatment of ELV and sets recycling targets. Importantly, heavy duty vehicles such

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trucks and buses are currently outside of the scope of the ELV Directive. Around 6.2 million trucks (ACEA, 2022) are not in scope of the ELV directive.

In addition to the specific waste legislation, a product Regulation also plays an important role. The MAC Directive bans the use of refrigerants with a GWP higher than 150 in new vehicles while allowing certain quantities to be used for the maintenance of the old vehicles, hence regulating the outlet for recovered gases.

The Directive on the End of Life of Vehicles (ELV)

The ELV Directive's primary objective is the prevention of waste.

Article 4 stipulates that Member States shall encourage vehicle manufacturers and their supply chain *"to limit the use of hazardous substances in vehicles and to reduce them as far as possible from the conception of the vehicle onwards, so as in particular to prevent their release into the environment, make recycling easier, and avoid the need to dispose of hazardous waste".*

The Directive also requires that "systems for the collection of all end-of life vehicles" are set up in all Member States, which should have "adequate availability" within their territory. As such the ELV introduced the concept of "authorised treatment facility" (ATF).

The legislation also foresees provisions to ensure the collection and the treatment of ELV waste. Minimum requirements for installations for storage and treatment of ELVs in such authorized treatment facility (ATFs). This includes:

- the appropriate storage tanks for the segregated storage air-conditioning system fluids and any other fluid contained in the end-of-life vehicle,
- removal and separate collection and storage of air-conditioning system fluids and any other fluid contained in the end-of-life vehicle, unless they are necessary for the re-use of the parts concerned,
- storage operations are to be carried out avoiding damage to components containing fluids or to recoverable components and spare parts.

Overall, the ELV has been effective in the delivery of many of its initial objectives, especially by creating new infrastructure and setting rules for hazardous waste and in terms of attainment of recycling targets. Based on the European Commission estimates, 6.5 million ELVs are reported to be treated according to the ELV Directive, while approximately 4 million vehicles annually seem to escape the proper handling of the ELV Directive. This could be due to non-reported export of used vehicles to non-EU-countries or the treatment of a non-authorized treatment facilities which would be considered as an illegal activity. Another possibility is the non-reported treatment in ATF facilities, in which case it should be of no concern, if the ATF operates according to its permits.

Member States claimed to have attained their overall recycling targets for the re-use and recycling of ELVs (85% by an average weight per vehicle and year) as well as re-use and recovery of ELVs (95% by an average weight per vehicle and year). Based on our assessment, the targets do not provide a sufficient incentive to increase the recovery of F-gases. This is because that calculation is based on the overall weight of vehicles, which does not encourage the materials recovery beyond metal waste. F-gases accounts for less than 0,1% of the average composition of an ELV.

The ELV Directives does not allow a conclusion about a reliable collection rate for F-gases for mobile air conditioning. There is no data collected under the ELV to quantify that F-gases are extracted by car

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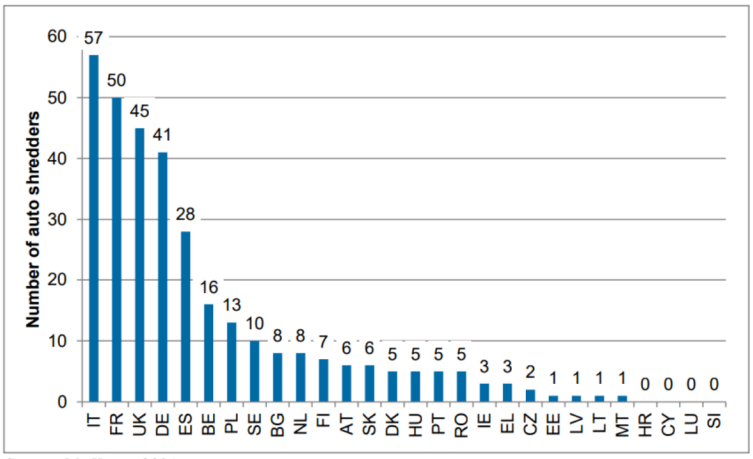
scrappers, who usually extract the used refrigerants and send them to further treatment, either destruction or reclamation. However, clear obligations are established to extract the refrigerants gases from the vehicles.

The ELV directive is as an effective enabler of the circularity of F-gases:

- First, the ELV has led to considerable investments and the creation of many new facilities for the handling and storage of F-gases. Currently there are approximately 14 000 ATFs and 350 automotive shredding facilities in Europe (European Commission, 2021),
- Second, the legislation also facilitates identification of components and materials in vehicles which are suitable for reuse and recovery also to the establishment of the International Dismantling Information System (IDIS). 26 manufacturers representing 77 brands and 3 161 models and variants /use IDIS to provide dismantling information to 6 476 registered users,

Figure 5-1: Number of auto shredders per country



Source: Mc Kenna 2014

Figure 3 Number of auto shredders per country (Williams, Keeling, & Petsinaris, 2020)

- Third, when the vehicles are appropriately directed to the ATF, the systems work well. No problems were reported on the implementation of these standards during the evaluation process. Specific best available techniques are established since 2018 under the Industrial Emissions Directives to provide benchmarks to the local permitting authorities,
- Finally, the availability of the infrastructure mandated by the ELV Directive plays in concert with other factors that can increase recovery of F-gases, such as the higher market value/prices for F-gases (see section 3).

The Mobile Air Conditioning (MAC) Directive

The MAC Directive was passed in 2006 to gradually ban greenhouses gas with a global warming potential of 150 or higher in passenger cars (up to 8 passengers)[11] and commercial vehicles with a permissible total weight of up to 3.5 metric tonns[12].

This led to the phase out of the standard solution at that time (R-134a). Since 2017, almost 100% of new passenger cars sold in the EU use HFO-1234yf with GWP lower than 1 to maintain the energy

[11] Class M1
[12] Class N1

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consumption that were provided the previous R-134a system. This also applies to electric passenger cars, although a limited number of electric vehicles use CO_2 as refrigerant.

R134a is still required to supply some specific markets. This includes the cars that were already in the market before the final ban on the use of high GWP refrigerants in new vehicles (2017) introduced by the MAC Directive. In those instances, R134a is only allowed as an exception for refilling vehicles fitted with air conditioning systems containing refrigerants with a GWP higher than 150 before January 2017 (article 6, para 2). In addition, other type of mobile air conditioning, such as heavy-duty trucks and buses are not regulated by the MAC directive and may still use R134a.

The Industrial Emissions Directive: BREF For Waste Incineration and Waste Treatment

There are three possible scenarios when dealing with the end-of-life of F-gases, when recycling for reuse by the installers is not possible:

- Scenario 1: the F-gases are extracted by the installers, using specialist recovery equipment, and sent back to distributors for reclamation, typically in dedicated recovery cylinders. This is more likely to occur for large equipment.
- Scenario 2: The F-gases are extracted from equipment within Waste Treatment Facilities that need to treat them with special care, due to their hazardous nature. Recovered F-gases may then be sent to facilities for reclamation or destruction.
- Scenario 3: the F-gases must be destroyed. This would entail several situations, for instance because of the non-conformity of the gas or because there are fractions that can no longer be reclaimed.

Companies undertaking the reclamation of F-gases must first analyse the gas composition to determine the quality of it. When destruction is the only available route, the Best Available Techniques (BAT) Reference Document for Waste Incineration adopted in 2019 shall apply when defining the permits on each treatment facility (Joint Research Centre, 2019). The permitting process is local, meaning that the treatment facilities operate based on permits that are issued by the authorities of the Member State where they are located. Today, the Industrial Emissions Directive leaves a certain degree of flexibility to the local permitting authorities for setting emissions limits within a defined range (the so-called BAT-AELs). The main parameters measured will be Hydrogen Fluoride (HF) and Hydrogen Chloride (HCl). The abatement process includes the following techniques listed in the 2019 BAT Reference Document:

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BAT 27. In order to reduce channelled emissions of HCl, HF and SO_2 to air from the incineration of waste, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
a.	Wet scrubber	See Section 5.2.2	There may be applicability restrictions due to low water availability, e.g. in arid areas.
b.	Semi-wet absorber	See Section 5.2.2	Generally applicable.
c.	Dry sorbent injection	See Section 5.2.2	Generally applicable.
d.	Direct desulphurisation	See Section 5.2.2. Used for partial abatement of acid gas emissions upstream of other techniques.	Only applicable to fluidised bed furnaces.
e.	Boiler sorbent injection	See Section 5.2.2. Used for partial abatement of acid gas emissions upstream of other techniques.	Generally applicable.

Table 5.5: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of HCl, HF and SO_2 from the incineration of waste

Parameter	BAT-AEL (mg/Nm^3)		Averaging period
	New plant	Existing plant	
HCl	< 2–6 (1)	< 2–8 (1)	Daily average
HF	< 1	< 1	Daily average or average over the sampling period
SO_2	5–30	5–40	Daily average
(1) The lower end of the BAT-AEL range can be achieved when using a wet scrubber; the higher end of the range may be associated with the use of dry sorbent injection.			

In the second scenario, where F-gases are extracted from the equipment they're discarded with in waste treatment facilities, the Best Available Techniques (BAT) Reference Document for Waste Treatment adopted in 2018 will apply (Joint Research Centre, 2018). This requirement covers a very large scope of facilities disposing or recovering of hazardous waste with a capacity exceeding 10 tons per day. This is particularly relevant for the uses described above include the WEEE, ELV and HVACR equipment.

For WEEE, the BAT will cover the Removal of refrigerants and oils, the condensation of waste gas and the adsorption. There are BAT-AELs for HFCs or HFOs (only CFCs).

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BAT 29. In order to prevent or, where that is not practicable, to reduce emissions of organic compounds to air, BAT is to apply BAT 14d, BAT 14h and to use technique a. and one or both of the techniques b. and c. given below.

	Technique	Description
a.	Optimised removal and capture of refrigerants and oils	All refrigerants and oils are removed from the WEEE containing VFCs and/or VHCs and captured by a vacuum suction system (e.g. achieving refrigerant removal of at least 90 %). Refrigerants are separated from oils and the oils are degassed. The amount of oil remaining in the compressor is reduced to a minimum (so that the compressor does not drip).
b.	Cryogenic condensation	Waste gas containing organic compounds such as VFCs/VHCs is sent to a cryogenic condensation unit where they are liquefied (see description in Section 6.6.1). The liquefied gas is stored in pressurised vessels for further treatment.
c.	Adsorption	Waste gas containing organic compounds such as VFCs/VHCs is led into adsorption systems (see description in Section 6.6.1). The spent activated carbon is regenerated by means of heated air pumped into the filter to desorb the organic compounds. Subsequently, the regeneration waste gas is compressed and cooled in order to liquefy the organic compounds (in some cases by cryogenic condensation). The liquefied gas is then stored in pressurised vessels. The remaining waste gas from the compression stage is usually led back into the adsorption system in order to minimise VFC/VHC emissions.

Table 6.4: BAT-associated emission levels (BAT-AELs) for channelled TVOC and CFC emissions to air from the treatment of WEEE containing VFCs and/or VHCs

Parameter	Unit	BAT-AEL (Average over the sampling period)
TVOC	mg/Nm^3	3–15
CFCs	mg/Nm^3	0.5–10

The analysis above demonstrates that the legislative framework is well developed to mainstream the recovery, recycling and reclamation of F-gases across sectors.

The industry ensures that a large part of the recovered F-gases never reaches the destruction stage and is either directly used in another system (recycled) or reclaimed and adjusted by a distributor to meet the same specifications as virgin refrigerant (based on AHRI700 Standards).

Especially, for the WEEE and ELV sectors the responsibility within the supply chain are clearly defined. Both WEEE and ELV scrappers have to extract the F-gases and either send them to a reclaimer or a destruction facility. Likewise, waste treatment operations are heavily regulated at the EU level. Proper enforcement as well as further clarification of responsibilities especially for those appliances not covered by the WEEE or ELV schemes could make a difference to ensure the circular economy of F-gases.

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Appendix III

List of measures on the containment and end-of-life management of F-gases being negotiated in context of the current revision of the F-gas Regulation

Article 4 – Prevention of Emissions

1. **Prevention of emissions:** The 2022 F-gas Regulation revision proposal expands the obligation to prevent F-gas emissions from annex I-gases in the current F-Gas Regulation to annex II-substances, which include HFO/ HCFOs and to manufacturers of equipment containing F-gases (Art. 4.2). Moreover, the revision further increases the scope by setting out that all necessary precautions need to be taken to prevent the emissions of F-gases during the production, storage, transport or transfer of F-gases, at end of life, as well as to the processes where F-gases are by-products (Art. 4.3). While the intentional release of F-gases is prohibited, the Council here offers leeway by including an exception for cases where the release is technically necessary. The Parliament adapts the information requirements for placing on the market trifluoroethane, which is a by-product of the intermediate HCFC-22.

Article 5 – Leak Checks

1. **Leak Checks:** The 2022 Commission revision proposal adds stricter controls for specific F-gases. Leak checks would be mandatory, in respect of F-gases in Annexes I and II of Section 1, which include HFO/ HCFOs (Art.5.1). Exception from mandatory leak checks would only be possible for hermetically sealed equipment, containing less than 10 tonnes of F-gases listed in Annex I or less than 2kg of F-gases listed in Annex II Section I and the connected parts have a leakages rate tested to be less than 3 grams per year (Art. 5.1.)The Parliament expands the leak checks to refrigeration units of vans and ships (Art. 5.1.e), while Council extends it to a variety of operators with mobile equipment (e.g. air-conditioning equipment and heat pumps in trucks, vans, busses, non road mobile machinery). While expanding the equipment scope (Art. 5.2a), Council offers a transition period for operators of mobile equipment of 3 years following entry into force and removes leak check obligations in case of a regular inspection regime.

Article 6 – Leakage Detection System

1. **Leak Detection System:** The 2022 revision proposal does not include any changes to the current Regulation from 2014. Meanwhile, Council includes equipment containing more than 100 kg of F-gases under Annex II to the scope of mandatory leak detection systems (Art.6.1) The Council text further proposes that for equipment including F-gases listed in Annex I in quantities of 500 tonnes of Co2 or more, the leakage detection system shall alert the operator of any leakage (Art.6.5.)

Article 7 – Record Keeping

1. **Record Keeping:** The 2022 revision proposal does not include any changes to the current Regulation from 2014. Both, Parliament and Council reinforce the information requirement, adding the quantity of F-gas addition during an installation and the exact timing of such

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addition (Art. 7.1.) The Council further obliges undertakings producing or placing F-gases intended for exempted uses in the record keeping requirements (Art. 7.3b).

Article 8 – Recovery and Destruction

1. **Destruction (Art. 8.1):** In comparison to the existing F-Gas Regulation, the Commission proposal aims to facilitate destruction procedures across the EU, to ensure emissions of F-gases do not occur due to insufficient destruction technologies. The new proposals singles out F-gases used in buildings in the recovery or destruction obligations, as insulation material in many EU Member States contains foam blown with HFC blowing agents (HFC-134a, HFC236fa and HFC-365mfc). As there is 1) no proper disposal process, 2) a high amount of buildings to be renovated or demolished and 3) foams characteristically have a high emission risk, the new proposal obliges building owners and contractors to avoid emissions by recovering or destroying the foams and included gases (Art. 8.4-5) (David Birchby, 2022, p. 104). If that is not feasible, proper justification needs to be made available. Parliament made no changes to these provisions, Council added clarifications.

   As only a few Member States have destruction facilities (with different incineration procedures) for F-gases on their national territory, cross-border waste shipment remains of importance.

2. **Recovery (Art. 8.2):** The 2022 revision of the F-gas Regulation empowers the Commission to adopt delegated acts to establish a list of products and equipment where the recovery or destruction should be considered feasible and which technology should be applied (Art. 8.8). This aims to prevent the use of arguments related to economic cost and technical feasibility as excuse for not recovering F-gases and accept the possibility of emissions. Member States are asked to support this by promoting the recovery, recycling, reclamation and destruction of F-gases (Art. 8.9). With regards to the Commission list of products and equipment where recovery or destruction is feasible, the Parliament expands the potential products covered to Section 2 and 3 in Annex II.

   The basis for the decision whether F-gases can be recovered or not remains unclear. As a minimum, this should require the European Commission to analyse the complete recovery cycle and be mindful of EU national differences.

3. **Destruction (Art. 8.7 – 8):** The European Commission specifies which technologies should be used for the destruction of fluorinated gases. Paragraphs 7 and 8 mention that fluorinated greenhouse gases listed in Annex I, Section 1, and products containing such gases shall only be destroyed by technologies approved by the Parties to the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer ('the Protocol') or by technologies not yet approved, but are environmentally equivalent and comply with Union and national legislation on waste and with additional requirements under such legislation.

   Other fluorinated greenhouse gases for which destruction technologies have not been approved, shall only be destroyed by the most environmentally acceptable destruction technology not entailing excessive costs, and that comply with Union and national legislation on waste and that additional requirements under such legislation are met.

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The Commission is empowered to adopt delegated acts to establish a list of products and equipment for which the recovery of fluorinated greenhouse gases listed in Annex I and Annex II, Section 1, or destruction of products and equipment containing such gases without prior recovery of these gases shall be considered technically and economically feasible, specifying, if appropriate, the technologies to be applied.

Article 9 – Producer Responsibility Schemes

1. **Producer responsibility schemes (Art. 9):** The 2022 revision proposal fails to make producer responsibility schemes mandatory. Member States are asked to encourage their establishment (Art. 9). Currently, no Union legislation extends the responsibility for F-gases to the producer. This gap has been picked up by the European Parliament, which has included Extended Producer Responsibility schemes in their position from March 2023. The Parliament thus requests the Commission to set minimum requirements for such EPRs by 2025, including on collection, reclamation, recycling, disposal facilities, equipment provision to certified technicians, reporting. Within two years, Member States are then required to establish such schemes while taking into account the schemes already applicable. The Council meanwhile reduces the scope of producer responsibility schemes to Annex I and in Annex II, Section 1.

   PRS can vary in their objective and design and therefore require an adequate analysis before a decision on the implementation is taken.

Article 10 – Certification and training

1. **Certification and training:** The 2022 Commission revision proposal expands the training and certification requirements for natural persons installing, servicing, repairing and decommissioning equipment containing F-gases to Annex II, Section 1 i.e. H(C)FOs and other alternatives. In their General Approach, the Council requests the certification system to cover natural refrigerants, particularly with regards to the safe handling of equipment with flammable and toxic gases. Member States further set clear deadlines for the Commission to proposes the minimum requirements for the training and certifications of natural persons handling carrying out installation, servicing, maintenance, repair or decommissioning of the equipment containing fluorinated greenhouse gases listed in Annex I and in Annex II, Section I1, and other relevant alternatives to fluorinated greenhouse gases including natural refrigerants.

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