Nordic Council of Ministers

End-of-life treatment of Hydrofluoroole-fins (HFOs)

Contents

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1. List of abbreviations

CCl_4	Carbon tetrachloride
CFCs	Chlorofluorocarbons
ECHA	European Chemicals Agency
EoL	End-of-life
GLWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HCFOs	Hydrochlorofluoroolefins
HFOs	Hydrofluoroolefins
HVAC	Heating, Ventilation, and Air Condition
MAC	Mobile air-conditioning system
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substances
RAC	Refrigeration and Air Conditioning
RACHP	Refrigeration, air conditioning and heat pump
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical substances
PFAS	Per- and polyfluoroalkyl substances
PFCAs	Perfluoroalkyl carboxylic acids
TFA	Trifluoroacetic acid
UNFCCC	United Nations Framework Convention on Climate Change
WEEE	Waste Electrical and Electronic equipment

2. Summary

This study examines the current use of hydrofluoroolefins (HFOs), also called unsaturated hydrofluorocarbons (uHFC) in the Nordic countries and maps the existing systems to secure the safe recovery, collection, and treatment of HFOs that are no longer in use. Furthermore, this study explores and proposes measures and options for effective systems for collecting and treating HFOs in the Nordic countries when they are no longer needed. In addition to the Nordic countries of Denmark, the Faroe Islands, Finland, Iceland, Norway and, Sweden, Germany and Switzerland were also included to provide a beyond Nordic perspective.

Use and application in the Nordics

The use of HFOs is increasing and is expected to grow in the foreseeable future. HFOs are, therefore, expected to enter the waste stream continuously in the coming decades because of the longevity of the products where they are used. HFOs are the fourth generation of refrigerants and differ from earlier generations of fluorinated refrigerants in having a very low global warming potential (GWP) and no ozone depletion potential (ODP). HFOs are used in refrigeration, air conditioning and heat pumps (RACHP), cars' air-conditioning (AC) systems, and as foam-blowing agents, and aerosol propellants.

The World Meteorological Organisation states in its latest assessment report that there are no comprehensive global datasets on the production or consumption of HFOs. According to data from the European Commission (EC), the supply of synthetic alternatives H(C)FOs increased from 1,300 tonnes in 2014 to 18,000 tonnes in 2019. There is a general tendency in the Nordics to prefer and promote natural refrigerants whenever possible rather than using fluorinated refrigerants. Currently, HFOs are especially used in car AC systems. With the implementation of the EU mobile air conditioning (MAC) directive 2006/40/EC in 2006 that prohibited the use of refrigerants with a GWP higher than 150 in new cars and small vans, resulting in the need for an alternative to HFC-134a, the previous primary refrigerant of choice in cars AC systems. HFOs entered the Nordics after 2011 when new cars using HFO-1234yf as their AC refrigerant began to enter the market. In the Nordics, HFOs are also used in larger Industrial RACHP installations. HFO-1234ze is used as an aerosol propellant and foam-blowing agent in XPS foam. However, to what extent and in what quantities they are used for some of these applications has not been possible to determine in this study. In addition to pure HFOs, numerous HFC/HFO blends are in use.

Since HFOs are technically HFCs, modifying some existing HFC systems to HFOs or blends is possible. Therefore, HFC/HFO blends can work as drop-ins in existing systems. This is often cheaper than changing to natural refrigerants, which require entirely new systems and are associated with high upfront costs.

HFOs are promoted as environmentally friendly due to their very low GWP and non-existent ODP. There are, however, other environmental and potential health concerns. HFOs degrade to Trifluoroacetic Acids (TFA) in the atmosphere. Some HFOs like HFO-1234yf completely break down to TFA, and others like HFO-1234ze only partly break down to TFA. TFA is an ultra-short PFAS that is highly persistent when it ends up in water bodies. Studies show a continued increase in TFA concentrations in water bodies across Europe.

Legislation

HFOs are listed as Annex II gases in the European F-gas Regulation No 517/2014 and are only partly covered by the regulation. HFOs are currently subject to the reporting requirements described in Article 19. However, this will likely change with the upcoming update of the F-gas Regulation. The proposal, for instance, includes HFOs in Article 4 (prevention of emissions) and 8 (recovery and destruction). ECHA is currently treating a proposal to ban per- and polyfluorinated substances (PFAS), which, if adopted, can greatly impact the future use of HFOs since HFOs fall under the proposed PFAS definition.

The countries mapped in this study have all implemented EU F-gas Regulation or equivalent regulation, except for the Faroe Islands. The Faroe Islands are currently in the process of adopting their first legislation on F-gases, HFOs are not included. Denmark, Iceland and Norway have all implemented refund schemes for HFCs. There is no refund for HFOs in Norway. On the contrary, it is associated with costs to hand in HFOs after recovery. The Danish refund scheme is voluntary. Denmark, Iceland, and Norway have all placed a tax on fluorinated refrigerants. HFOs are exempt in Norway and Iceland. In Denmark, the tax on HFO-1234yf and HFO1234ze is only 0.17 €/kg because the substance's GWP determines the fee. Sweden has implemented a regulation that mandates that those who supply F-gases must take these back and provide containers for this purpose, free of charge. HFOs are not covered by the regulation.

End-of-life

HFOs and appliances containing HFOs are still relatively new on the market, meaning that many of the appliances containing HFOs are still in use and have not yet reached their end-of-life stage. It can take years or decades before they are decommissioned and enter the waste stream. For example, building insulation has a lifetime of decades, and heat pumps have an average lifetime of 15 years. At decommissioning, the initial amount is not always recoverable; some are lost during the use phase. For instance, aerosol propellants are released when used, and in cars

AC systems are allowed an annual leakage rate of 40–60g. However, closed circuit systems should not leak during their lifetime. Accidental leakages during the dismantling process or the following waste processing can happen. It is known to be a problem in the building sector that F-gases are not recovered accordingly during the building demolition or renovation.

There are no treatment technical barriers to fitting HFOs into the existing systems for recovery, collection, recycling, reclamation and destruction. HFOs are already handled through the existing infrastructure to a great extent, and barriers to fitting HFOs into existing systems for other fluorinated refrigerants are rather a lack of inclusion in the legislation than a technical barrier. HFOs generally enter the waste stream through three main channels: refrigerants recovered by a technician from stationary RACHP equipment, waste of electrical and electronic equipment (WEEE), and car scrapping. All the Nordic countries have Extended producer responsibility for WEEE, and all car scrappers must be certified to handle F-gases. The Faroe Islands and Iceland export WEEE to H. J. Hansen in Denmark and Stena Recycling in Denmark and Sweden. Norway also exports WEEE to Stena Recycling in Sweden. Many practitioners working with F-gases reuse and recycle the F-gases themselves, and several professional collectors buy recovered refrigerants, recycle them, and sell them back to operating companies.

The only companies in the Nordics with an environmental permit for reclaiming refrigerants are Darment and Eco Scandic Oy, both located in Finland. Eco Scandic Oy receives refrigerants from Sweden and Finland, so far the amounts of HFO substances are minor. Fortum has destruction facilities in Sweden and Finland with the necessary permits to handle fluorinated refrigerants. Denmark, The Faroe Islands, Iceland and Norway all export refrigerants for destruction elsewhere, primarily France and Germany.

Some HFOs are flammable refrigerants (A2L), so different equipment is needed for leak detection and recovery. The cylinder needs to be approved for flammable refrigerants, and the recovered refrigerant needs to be labelled, showing it contains a flammable substance. This type of equipment is available and required when handling other refrigerants, e.g., HFC-32, commonly used in RACHP applications, especially domestic heat pumps. However, the operators must be qualified to handle flammable refrigerants and their equipment.

The process for destroying HFOs is technically the same as for HFCs. The reclamation process varies slightly since some are A2L-classified refrigerants. Still, there are no technical barriers to reclaiming HFOs, and the Nordic reclamation company Eco Scandic Oy, for instance, reclaims both HFCs and HFOs.

Challenges identified during the study for the safe recovery and end-of-life treatment of HFOs:

- Not sufficiently covered in the legislation.
- Lack of financial incentives when not included in take-back schemes.
- Loss of cylinders when handing them in some countries.
- Proper equipment can be expensive for small operators.
- Long distances to collection points.
- Shortage of qualified practitioners.
- Decreasing interest in taking the education to become a refrigeration technician.
- There is limited acknowledgement or awareness that releasing F gases to the environment poses an environmental risk.

Recommendations

For the Nordic Council of Ministers

- Initiate an informational campaign to create awareness of the detrimental environmental impacts when fluorinated refrigerants are emitted instead of being correctly recovered and disposed of accordingly, as well as any potential health risks from direct exposure.
- Encourage developing and implementing a voluntary labelling scheme to explain and raise awareness about HFOs and HFCs being PFAS.
- Commission a study to examine ultra-short PFAS, such as TFA, to increase our knowledge of environmental and health exposure risks associated with these substances.

EU Perspective

- Await upcoming EU legislation and ensure knowledge sharing concerning implementation practices across Nordic countries. This will also provide an opportunity to align our national frameworks with these regulations and engage in collaborative efforts that bolster our understanding, strategies, and solutions related to these substances. A consistent approach will help prevent regulatory arbitrage and ensure a level playing field for industries.
- Consider unifying the term for HFOs with what the EU legislation applies to ensure better transparency and consistency, so instead of Hydrofluoroolefins/HFOs, they are termed unsaturated hydrocarbons/ uHFCs.

For the Nordic Countries

Operational

- In line with the Nordic countries' stance on climate-friendly refrigerants, look into whether safety codes and existing restrictions on flammable refrigerants are updated accordingly with technological progress.

- Ensure adequate information and guidelines on climate-friendly refrigerants are readily and publicly available.

Mapping the use of HFOs

- Encourage branch organisations to conduct member surveys to uncover what types of refrigerants are being used on the market and in what kind of appliances.
- Consider lowering the threshold value for reporting requirements to cover low GWP substances better.

Include HFOs in current policies

- Realign HFOs with current systems for HFCs to ensure no extra costs are associated with handing in recovered HFOs.
- Apply a combination of voluntary and mandatory measures to ensure that HFOs are recovered and collected for proper waste handling.

While finalising this report, the EU reached a provisional agreement on the revised F-gas Regulation on 5 October 2023. The new rules could become applicable in early 2024, depending on the formal endorsement.

3. Resume

Dette studie undersøger brugen af hydrofluoroolefiner (HFOer) eller umættede hydrofluorkarboner (uHFCer) i de nordiske lande og kortlægger de nuværende systemer for genvinding, opsamling og behandling af HFOer når de når end-of-life. Derudover undersøges hvilke muligheder og potentialer der er for at effektivisere eksisterende praksisser og systemer der sikrer indsamling og slutbehandling af HFOer i de Nordiske lande. Foruden Danmark, Færøerne, Finland, Island, Norge og Sverige, er Tyskland og Schweiz også en del af studies for at bidrage med perspektiver der rækker udover norden.

Anvendelse i Norden

Brugen af HFOer er stigende og det forventes at brugen vil fortsætte med at stige i den nærmeste fremtid. Derfor forventes det også, at HFOer kontinuerligt vil indgå i affaldsstrømmen og kræve slutbehandling i de følgende årtier især også når den relativt lange levetid for produkter og installationer hvor HFOer anvendes tages i betragtning. HFOer betragtes som den fjerde generation af kølemidler og adskiller sig fra tidligere generation af fluorerede kølemidler ved at have et meget lavt globalt opvarmningspotentiale (GWP) og intet ozonnedbrydende potentiale (ODP). HFOer anvendes til køling, aircondition og varmepumper (RACHP), i bilers airconditionsystemer, som skum-blæsemidler og som aerosoldrivmiddel.

World Meteorological Organisation (WMO) konkluderer i deres seneste vurderingsrapport, at der ikke findes et omfattende globalt datasæt for produktionen og forbruget af HFOer. Ifølge data fra EU steg udbuddet af H(C)FOer fra 1300 tons i 2014 til 18.000 tons i 2019. I de Nordiske lande er der generelt en tendens for at foretrække og fremme brugen af naturlige kølemidler i stedet for syntetiske når det er muligt. På nuværende tidspunkt bliver HFOer især brugt i bilers airconditionanlæg som følge af implementeringen af EU's direktiv 2006/40/EC for mobile airconditionanlæg MAC direktivet), der forbød brugen af kølemidler med et GWP højere end 150, hvilket resulterede i behovet for et alternativ til HFC-134a der indtil da var det primært benyttede kølemiddel i personbilers airconditionanlæg. HFOer har været anvendt i Norden siden 2011, da HFO-1234yf begyndte at blive benyttet som kølemiddel i nye personbilers airconditionanlæg. I Norden anvendes rene HFOer også i større industrielle RACHP-installationer. HFO-1234ze bruges som aerosoldrivmiddel og som skumblæsemiddel i XPS-skum. Det har dog ikke være muligt at fastslå i hvilket omfang og i hvilke mængder de er anvendt. Udover rene HFOer bruges der adskillige HFC/HFO-blandinger.

Da HFOer teknisk set er HFCer er det teknisk muligt at modificere eksisterende systemer der benytter HFC til at benytte HFOer eller HFC/HFO-blandinger i stedet for. Der er flere HFC/HFO-blandinger der kan anvendes som 'drop-ins' i eksisterende systemer. Dette er ofte billigere fremfor at skifte til naturlige kølemidler, der vil kræve helt nye systemer som kan være associeret med høje installationsomkostninger.

HFOer markedsføres som miljøvenlige på grund af deres lave GWP og at de ikke er ozonnedbrydende. Det er vigtigt at bemærket at der er andre miljømæssige og potentielle sundhedsskadelige bekymringer forbundet med HFOer. HFOer nedbrydes til trifluoreddikesyre (TFA) i atmosfæren. Nogle HFOer såsom HFO-1234yf nedbrydes fuldstændigt til TFA, andre såsom HFO-1234ze nedbrydes kun delvist til TFA. TFA er en ultrakort PFAS der er persistent i vandmiljøer. Studier viser at der er en stigning af TFA-koncentrationer i vandmiljøet på tværs af Europa.

Lovgivning

HFOer er angivet i annex II i EU's F-gas lovgivning No 517/2014 og er derfor kun delvist dækket af EU-lovgivningen. I øjeblikket er der rapporteringskrav for HFOer i henhold til artikel 19. Dette forventes at ændre sig i den ny F-gas lovgivning der i øjeblikket er under behandling. I lovforslaget til en ny F-gas lovgivning er HFOer bl.a. også inkluderet i Artikel 4 (lækagekontrol) og Artikel 8 (genvinding). ECHA behandler i øjeblikket et lovforslag om at forbyde per- og polyfluoralkyl – substances (PFAS), hvis forslaget vedtages kan det i høj grad påvirke brugen af HFOer da den opgivne definition også indbefatter HFOer.

Alle de undersøgte lande i dette studie på nær Færøerne, har implementeret EU's F-gas lovgivning eller tilsvarende. Færøerne er i øjeblikket i gang med at vedtage deres første F-gas lovgivning, HFO er ikke inkluderet i lovforslaget. Danmark, Island og Norge har alle implementeret tilbagebetalingsordninger for HFCer. Der er ingen tilbagebetaling for HFOer i Norge. Tværtimod kan der være omkostninger ved at indlevere genvundne HFOer. Den danske ordning er frivillig. Danmark, Island og Norge har alle sat en afgift på fluorerede kølemidler. HFOer er ikke pålagt en afgift i Norge og Island. I Danmark er afgiften på HFO-1234yf og HFO-1234ze kun 0,17 €/kg da afgiften afhænger af kølemidlets GWP. Sverige har implementeret en forordning der påbyder, at de, der leverer F-gasser, skal tage disse tilbage og stille beholdere til rådighed for dette formål gratis. HFOer er ikke omfattet af forordningen.

End-of-Life

HFOer samt udstyr der indeholder HFOer er stadig relativt nye på markedet hvilket betyder, en stor del stadig er i brug og ikke har nået end-of-life. Det kan tage år eller årtier før udstyr hvor de er i brug tages ud af drift og derefter skal affaldsbehandles. Bygningsisolering har en levetid på årtier, varmepumper har en gennemsnitlig levetid på 15 år. Ved udgangen af et produkts levetid er det ikke altid at kølemidlet kan genvindes. Aerosoldrivmidler frigives ved brug, og der er et kontinuerligt læk fra bilers airconditionanlæg. Lukkede kredsløbssystemer bør dog ikke lække i løbet af deres levetid. Utilsigtede lækager under demontering eller i løbet af den efterfølgende affaldsbehandling kan ske. Det er en kendt problematik fra byggesektoren at F-gasser ikke altid genvindes som de bør i forbindelse med nedrivning eller renovering af bygninger.

Der er ingen behandlingstekniske barrierer for at indpasse HFOer i de eksisterende systemer for genvinding, indsamling, genanvendelse, regenerering og destruktion. HFOer bliver allerede i vid udstrækning håndteret gennem de eksisterende systemer for andre F-gasser, og nuværende barrierer for at inkluderer HFOer bedre i de eksisterende systemer skyldes i højere grad den manglende inklusion af HFOer i den eksisterende lovgivning. HFOer kommer generelt ind i affaldssystemet på tre måder: Fra RACHP-installationer hvor de er blevet genvundet af en køletekniker, som waste of electrical and electronic equipment (WEEE), eller når biler skrottes. Alle de Nordiske lande har implementeret udvidet producentansvar for WEEE, og autoophuggere skal være certificerede til at håndtere F-gasser. Mange teknikere genbruger genvundne F-gasser selv, der er også flere grossister der indsamler genvundne kølemidler, og sørger for genanvendelse. I Norden er der kun to virksomheder der har de nødvendige tilladelse til at regenerere kølemidler, Ecoscandic Oy og Darment begge er lokaliseret i Finland. Ecoscandic Oy modtager kølemidler fra både Sverige og Finland, indtil videre er mængderne af HFO de modtager små. Fortum har destruktionsfaciliteter i både Sverige og Finland der har de nødvendige tilladelser til at destruerer fluorerede kølemidler. Danmark, Færøerne, Island og Norge eksporterer alle kølemidler til destruktion, primært til Frankrig og Tyskland. Færøerne og Island eksporterer WEEE til H. J. Hansen i Danmark og Stena Recycling i Danmark og Sverige. I Norge eksporterer Stena Recycling WEEE til Sverige, Revac genvinder kølemidler fra WEEE, og sender dem til SRG (Stiftelsen Returgas).

Visse HFOer er mildt brandbare (A2L), så der er andre krav til udstyr for lækagetjek and genvinding end til ikke-brandbare kølemidler, ydermere skal cylindrene der bruges være godkendt til brandbare kølemidler, og mærkede. Den type udstyr er dog allerede tilgængelig og påkrævet til at håndtere andre kølemidler såsom HFC-32 der bruges i adskillige RACHP-applikationer især boligvarmepumper. Ydermere køleteknikerne må være kvalificerede til at håndtere brandbare kølemidler.

Destruktionsprocessen for HFOer adskiller sig ikke fra HFCer. Regenereringsprocessen for A2L klassificerede fluorerede kølemidler adskiller sig fra ikke brandbare kølemidler, der er dog ikke nogen tekniske barrierer for at regenerere HFOer, og som nævnt tidligere udfører EcoScandic Oy regenerering af både HFCer og HFOer.

Barrierer der blev identificeret under studiet:

- Ikke eller kun delvist dækket af lovgivningen i de undersøgte lande.
- Manglende finansielt incitament når HFOer ikke er inkluderet i returneringsordninger.
- I visse lande mister man cylinderen når den indleveres for videre affaldshåndtering.
- Ordentligt udstyr kan være dyrt for mindre aktører.
- Store afstande til indsamlingssteder.
- Mangel på uddannede køleteknikere.
- Faldende interesse i køleteknikeruddannelsen i visse lande.
- I visse tilfælde en manglende anerkendelse af de miljømæssige konsekvenser ved frigivelse til miljøet.

Anbefalinger

Til Nordisk Ministerråd

- Initier en informationskampagne for at skabe opmærksomhed om de skadelige miljøpåvirkninger, når fluorholdige kølemidler udsendes i stedet for at blive korrekt genvundet og bortskaffet på korrekt vis.
- Støtte op om at der udvikles og implementeres en frivillige mærkningsordning for at forklare og sætte fokus på at HFOer og HFCer er PFAS.
- Initier et projekt der undersøger ultrakort PFAS, såsom TFA, for derved at øge viden om de mulige miljø- og sundhedsmæssige risici der er forbundet med disse stoffer.

I EU-perspektiv

- Afvent den kommende EU-regulering og sørg for at sikre vidensdeling om implementeringspraksisser på tværs af de nordiske lande. Det vil også give mulighed for at koordineret af tilpasse de nationale rammeværktøjer og sikre samarbejde der kan styrke fælles forståelse, strategier og løsninger relaterede til håndteringen af disse stoffer. En kontinuerlig tilgang vil forhindre arbitrage og sikre lige vilkår for relevante aktører.

- Overvej at anvende samme betegnelse for HFOer som anvendes i EU-reguleringen for at sikre bedre gennemsigtighed og sammenhæng., så i stedet for at benytte betegnelsen hydrofluoroolefiner/HFOer så benyttes umættede hydrofluorkarboner/uHFCer.

For de Nordiske lande

Operationelt

- I overensstemmelse med de Nordiske landes holdning til klimavenlige kølemidler, kan det undersøges hvorvidt eksisterende restriktioner for brandfarlige kølemidler opdateres i overensstemmelse med teknologiske fremskridt.
- Sørg for, at information og retningslinjer om kølemidler er offentligt og let tilgængeligt.

Kortlægning af brugen af HFOer

- Tilskynd brancheorganisationer til at gennemføre medlemsundersøgelser for at afdække hvilke typer kølemidler der bruges på markedet og i hvilke type apparater.
- Overvej at sænke tærskelværdien for rapporteringskravene for bedre at dække stoffer med lavt GWP.

Inkluder HFOer i den eksisterende regulering

- Sørg for, at HFOer kan inkluderes og indgå de i nuværende systemer for indlevering af HFCer uden dette er forbundet med ekstra omkostninger.
- Gør brug af både frivillige og obligatoriske foranstaltninger for at sikre at HFOer genvindes og indsamles til korrekt affaldshåndtering.

Samtidig med at denne rapport blev færdiggjort nåede EU d. 5. okt. 2023 en foreløbig aftale om den reviderede F-gas forordning. Afhængigt af den formelle godkendelse kan den nye forordning træde i kraft i begyndelsen af 2024.

4. Preface

This report presents results from the project 'End-of-life treatment of Hydrofluoroolefins (HFOs) in the Nordics'. The project has been commissioned by the Nordic Working Group for Chemicals, Environment, and Health (NKE), and the Nordic Ozone Group and F-gas Group (NOFG) with the purpose of increasing knowledge of recovery options and end-of-life treatments for hydrofluoroolefins (HFOs) across the Nordic countries. By doing so, it aims to facilitate the development of more sustainable and environmentally friendly approaches to handle these substances. Furthermore, the project aims to identify best practices and potential areas for improvement in HFO end-of-life management in alignment with the broader sustainability and environmental goals of the Nordic region. The report will support the objectives of the Programme for Nordic Co-operation on the Environment and Climate 2019–2024 under circular economy, climate change and air quality as well as chemicals – environment and health.

The report covers Denmark, the Faroe Islands, Finland, Iceland, Norway, and Sweden, as well as Germany and Switzerland. The inclusion of the two non-Nordic countries allows for an extended examination of HFO treatment practices, taking into account varying regulatory frameworks, waste treatment systems, and industrial contexts.

While finalising this report, the EU reached a provisional agreement on the revised F-gas Regulation on 5 October 2023. The new rules could become applicable in early 2024, depending on the formal endorsement.

The project report is written by Amalie Engelbrecht Hansen, Adam Bergmann Andreasen, Amalie Børglum Ploug Olsen and Rikke Fischer-Bogason, Norion Consult, Morten Nikolaj Mandrupsen and Peter Hørning, the Copenhagen School of Marine Engineering and Technology Management. Other key contributors have played pivotal roles by providing insights through interviews and participating in a joint webinar. The collective expertise of the authors and the consulted stakeholders ensures the quality and relevance of the insights presented in the report.

5. Introduction

Hydrofluorocarbons (HFCs) are a group of manufactured synthetic F-gases with a high Global Warming Potential (GWP). They are used in refrigeration equipment, air conditioning, heat pumps, and as aerosol propellants and foam-blowing agents. The production and use of HFCs are now being phased down globally in accordance with the adoption of the Kigali Amendment, and Europe is at the forefront of this phase-down.

F-gases have been regulated in the EU since 2006. The EU f-gas regulation aims to protect the environment by limiting the total amount of F-gases imported and produced in the EU, restricting the use of high GWP F-gases in certain types of equipment and appliances, and totally banning the use of F-gases in certain appliances. It moreover prevents emissions from existing equipment and appliances by requiring qualified maintenance and installation. The EU mobile air-conditioning systems (MACs) directive from 2006 aims to reduce emissions of fluorinated greenhouse gases in passenger cars. The directive prohibits using F-gases with a GWP higher than 150 in all new passenger cars and light vans and was fully implemented in 2017. The current F-gas Regulation 517/2014 went into force in 2015, replacing the old one. Relevant measures from the preceding F-gas Regulation remain in place. The current F-gas Regulation aims to reduce F-gas emissions by two-thirds by 2030 compared to 2010, and introduced a phase-down timeline that started in 2015. The HFC phase-down is being implemented by annual quotas that are gradually being reduced; the quotas are putting quantitative limits on the placement of HFCs on the EU market by producers and importers.[1]

There are numerous market-available alternatives to HFCs, including Hydrofluoroolefins, natural refrigerants, and HFO/HFC blends. HFOs are unsaturated HFCs and are considered the fourth generation of synthetic refrigerants. They differ from earlier generations of fluorinated refrigerants by having a low GWP and no ozone depletion potential (ODP). After implementing the EU MAC directive in 2006, HFO-1234yf was found to be a suitable alternative for mobile air-conditioning systems.[2] HFOs first entered the Nordic markets in the beginning of the 2010s when new passenger vehicles started using HFO-1234yf in their AC systems. Today, several HFO substances are market available and are used in refrigeration equipment, air conditioning, heat pumps, and as aerosol propellants and foam-blowing agents either in pure form or as part of HFC/HFO blends. There is no production of HFCs or HFOs in the Nordic countries, so everything is imported.

1. EEA (2020)
2. McLinden, M. O. & Huber, M. L. (2020)

As the import and use of HFCs are decreasing, the import of HFOs in Europe is increasing rapidly. Imports of HFCs to EU Member states have decreased by about 30% since 2017, while imports of unsaturated HFCs/HCFCs have increased by 40%. Unsaturated HFCs (which are mainly HFOs) have risen to a share of 23% of the total supply of F-gases in Europe.[3] Due to the longevity of the applications where HFO substances are used, they are expected to enter the waste stream in the coming decades. The environmental impacts of discharging HFOs are now well-known, and it is as such essential to ensure that they are correctly recovered, collected and transported to an appropriate facility for recycling, reclamation or destruction at the end of life by educated personnel.

This project will map existing systems to secure the safe recovery, collection, and treatment of HFOs that are no longer used in equipment. Furthermore, it will explore and propose measures and options for effective systems for collecting and treating the gases in the Nordic countries when they are no longer needed.

The project's objective is to avoid emissions of HFOs into the atmosphere, of which we do not know all future environmental effects, and to contribute to more cost-effective measures for the safe recovery, collection and treatment in the Nordic countries.

3. McLinden, M. O. & Huber, M. L. (2020)

6. Methodology

The present study has mainly been based on desk research of available reports, policy documents and studies, interviews with policy makers, value chain representatives and experts, as well as existing knowledge and expertise among the authors.

Literature study

The literature study has been threefold.

- **Part 1** covered articles and reports from agenda-setting organisations, academic research studies and articles.
- **Part 2** consisted of mapping of relevant policies and regulations at both a global, EU and national level.
- **Part 3** focused on data related to the use of HFOs in different sectors and appliances in Nordic countries, as well as existing recovery systems/practices and end-of-life treatment options.

Interviews

As an essential supplement to the literature study, 26 phone-based or online interviews were conducted with Nordic and European policymakers, value chain representatives, and experts. An average of four interviews were carried out for each of the Nordic countries. In addition to the Nordic countries, Germany and Switzerland were included in the study, and interviews were conducted for both countries. The interviews were qualitative semi-structured interviews with thematic questions covering the following themes:

- Current use and applications of HFOs
- National regulations with relevance for the end-of-life treatment of gases and to what extent HFOs are sufficiently covered by the regulation.
- The existing systems for recovering, collecting, recycling, reclaiming, or destroying HFOs from the following types of equipment or usages:
    - Auto sector
    - RACHP sector
    - Aerosol propellants
    - Foam-blowing agents.
- Current barriers to ensuring proper waste disposal.

Webinar

Selected stakeholders were invited to join a webinar to discuss the overall findings and gain their viewpoints on the following:

- The current situation in the Nordic countries.
- The way ahead for the Nordic countries.
- Insights into which policies, regulations, and solutions they consider useful in light of their respective work or position in the value chain.
- The prerequisites needed for well-functioning end-of-life systems and the current barriers that need to be tackled to ensure this.

Analyses and final report

Part 1 of the report was prepared based on the desk research and interviews. Part 1 presents:

- The global, EU and national regulations (based on part 2 of the literature study and the interviews)
- An overview of the use of HFO, sector- and appliance-wise (based on part 3 of the literature study and the interviews)
- The mapping of existing systems for recovery, collection, and treatment of HFOs in the assessed countries and by sector (based on part 3 of the literature study and the conducted interviews)
- Assessments of barriers, weaknesses and strengths related to the recovery, collection, and treatment systems
- Description of interlinkages between current systems for recovery and end-of-life treatment of ODS, HFC and HFO (based on part 3 of the desk research and the interviews).

Following the webinar, the final analyses, conclusions and recommendations were made, forming part 2 of the report:

- Recommendations for measures for effective systems for the recovery, collection, and end-of-life treatment of HFO, both local and national

7. Background

7.1 History of F-gases – from CFCs to HFOs

Hydrofluoroolefins (HFO) are the fourth generation of synthetic refrigerants, succeeding the generations of natural refrigerants, CFCs, HCFCs and HFCs. This section briefly describes the three earlier generations of fluorinated refrigerants developed and used before HFOs came on the market. This section also briefly explains why CFCs, HCFCs and HFCs have been or are in the process of being phased down or out. The major global agreements that are the driving force behind the phase-outs or phasedowns are described in Chapter 6.

The first generation of refrigerants (1830s–1930s)

Before the introduction of halogenated refrigerants, multiple different substances with good thermodynamic characteristics were used, several of which are still in use today, including ammonia, propane, and carbon dioxide. Many of the first available refrigerants, including ammonia, methyl chloride, and sulphur dioxide, are toxic and/or flammable. When incorrectly handled, severe health and safety risks are associated with their use, and several fatal accidents have occurred.[4]

Chlorofluorocarbons (1930s–1990s) and hydrochlorofluorocarbons (1940s–2010s)

CFCs are fully halogenated chlorofluorocarbons; CFCs were introduced in the late 1920s under the popular name of freon. CFCs have several properties that make them especially suitable for various applications: They are non-flammable, non-toxic and inert in the lower atmosphere with an atmospheric lifetime of 100 years.[5] However, CFCs have a very high ozone-depleting potential (ODP) and a very high global warming potential (GWP). In the 1940s, hydrochlorofluorocarbons (HCFCs) were introduced. HCFCs are partly halogenated substances with a lower ODP than CFCs and an approximate atmospheric lifetime of 12 years.[6] The discovery of the ozone layer depletion caused by chlorinated refrigerants led to the establishment of the Montreal Protocol, a global joint initiative to phase out CFCs and HCFCs to protect the ozone layer. It was signed in 1987 and came into force in 1989.[7] By the 1980s, CFCs and HCFCs were widely used as refrigerants and foam-blowing agents in aerosol sprays and cleaning solvents. The production of CFCs was discontinued in the early 1990s,[8] but there are still several CFC banks in building

4. McLinden, M. O. & Huber, M. L. (2020)
5. Elkins (1999)
6. NOAA (n.d.)
7. Ozone Secretariat (2018a)
8. vanLoon & Duffy (2011)

foams, etc.[9] In the EU, the use of reclaimed or recycled HCFCs was allowed until 2015; globally, a total global phase-out is scheduled for 2040.[10]

Hydrofluorocarbons (1990es–2030)

HFCs were developed to substitute CFCs and HCFCs following the global agreement to phase out these substances due to their impact on the ozone layer. HFCs first entered the market in the 1990s. HFCs are widely used as refrigerants, blowing agents in foams and propellants in aerosol sprays. HFCs do not contain any chlorine and are not ozone-depleting substances (ODS), but HFCs are very potent greenhouse gases with a high GWP. For instance, R-134a, used in mobile air-conditioning systems (MACs), has a GWP of 1,430. The GWP for certain HFCs is as high as 14,800 (HFC-23). Because of their potency as greenhouse gases, it was decided to initiate a global HFC phasedown with the Kigali Amendment to the Montreal Protocol in 2016.[11]

The next primary refrigerant?

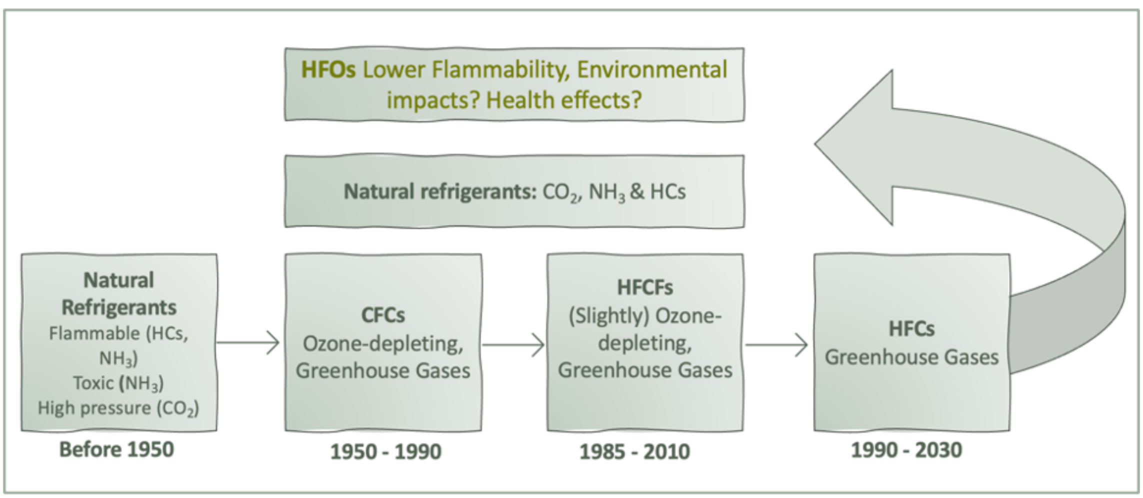

Figure 1 Historical development of refrigerants, adapted from the report 'Legislation and practices for End-of-life Management of refrigerants and other F-gases in Norway and the EU' by Asphjell et al. (2023)

There exist multiple alternatives that can replace most HFCs in different appliances, both the so-called natural refrigerants and a new generation of fluorinated refrigerants. No 'one size fits all' solution exists due to the wide array of applications where HFCs are in use and the alternatives' different operating pressures, safety properties, and thermodynamic properties. Alternatives to HFCs include:

9. Papst (2020)
10. Ozone Secretariat (2018a)
11. Ozone Secretariat (2018a)

- Natural refrigerants
- Hydrofluoroolefins (HFOs)
- HFC-HFO Blends

Many low GWP alternatives present other challenges, environmental, safety and cost implications, many natural refrigerants are flammable (hydrocarbons), and some are toxic (ammonia). Some HFO substances are mildly flammable, and several HFOs break down to TFA in the environment; some partly and others completely (see section 6.6). Many refrigerants will likely be blends of currently used refrigerants.

A3	B3	**Higher Flammability**
A2	B2	**Flammable**
A2L	B2L	**Lower Flammability**
A1	B1	**No Flame Propagation**
Lower toxicity	**Higher Toxicity**	

Figure 2 Refrigerant safety classification ISO 817 (ISO 817:2014)

7.2 Hydrofluoroolefins

Hydrofluoroolefins (HFOs) are, together with hydrochlorofluoroolefins (HCFOs), considered the fourth generation of fluorinated refrigerant gases. Hydrofluoroolefins are unsaturated hydrofluorocarbons composed of hydrogen, fluorine, and carbon. HCFOs contain chlorine as well. The carbon-carbon double bond greatly reduces their atmospheric lifetime. Many HFOs are low-pressure fluids with a high boiling point.[12] HFOs have neither ozone-depleting properties nor a high Global Warming Potential (GWP). Some HFOs are mildly flammable, and their safety classification is A2L (ISO 817:2014).[13]

12. Ozone Secretariat (2018b)
13. Mota-Babiloni et al (2015)

Box 1: Nomenclature for Hydrofluoroolefins:

Exemplified with 1234yf.

HFO- 1234yf

HFC-1234yf

R1234yf

uHFC- 1234yf

HFOs are not a recently developed novelty. The first synthesis of HFO-1234yf was reported in 1946. But when the EU adopted the MAC directive in 2006, which prohibits refrigerants with a GWP higher than 150 in mobile air-conditioning of new vehicles, HFO-1234yf was found to be a suitable alternative for mobile air-conditioning systems.[14] HFOs entered the market in 2008. Several different HFOs are now on the market, and their use and applications have increased in response to earlier generations of F-gases being phased out or down. HFOs are in use as refrigerants, foam-blowing agents, and aerosol propellants.

HFOs are mainly produced in the US, China, Japan, and India. There is no manufacturing of these gases in the EU,[15] but the following HFO substances are commercially available on the EU market.[16] They are all listed in Annex II of the EU Regulation No 517/2014.[17]

Table 1 HFOs listed in annex II of the F-gas Regulation 517/2014/EU, GWP values Based on the Sixth Assessment Report adopted by the Intergovernmental Panel on Climate Change.

Substance name	Main use	GWP 100
HFO-1234yf	Refrigerant (esp. mobile air conditioning)	0.501
HFO-1234ze	Refrigerant, foam blowing agent, aerosol propellant	1.37
HFO-1336mzz	Refrigerant, foam blowing agent	17.9

14. McLinden, M. O. & Huber, M. L. (2020)
15. Behringer et al. (2021)
16. Behringer et al (2021) & A-GAS (n.d.)
17. Regulation (EU) No. 517/2014

The World Meteorological Organisation frequently publishes a scientific assessment of ozone depletion. The most recent assessment (2022) concludes that there are no comprehensive global datasets on the production or consumption of HFOs.[18] According to data from the EC, the total EU import of synthetic alternatives H(C)FOs increased from 1,900 tonnes in 2014 to 21,763 tonnes in 2019.[19] However, the import of HFOs, especially in products (e.g., passenger cars), is currently underreported due to the threshold of 500 t CO_2-eq for reporting obligations when putting products containing F gases on the market.

There are also indications of regional concentration increases of HFOs measured in the environment. European atmospheric observations from the two observatories, Dubendorf and Jungfraujoch, have registered increases in the background concentration of some HFOs. Jungfraujoch documented increases from less than 0.01 ppm in 2016 to annual median levels of 0.10 for HFO-1234yf and 0.14 ppt for HFO-1234ze(E) in 2020.[20]

7.2.1 HFO/HFC Blends

There are several different substance blends of HFOs and HFCs on the market. These blends are manufactured to lower the flammability of the substance or, in other words, enhance their performance while lowering the GWP of the blend.

The gases often used in blends are:

- HFC refrigerants: R32, R125, R152a and R134a
- HFO refrigerants: R1234yf and R1234ze(E)
- And/or natural refrigerants such as R-290, R-600a and R-744

There is a need for further research since there are some uncertainties concerning these blends. There are studies that investigate the stability of blends to see whether they maintain their expected original compositions when in use or try to establish the most reliable route to recovering these gases, including an ongoing Swedish-funded project.[21][22] The following table provides an overview of some of the blends that have been commercially available in the EU for some years. The market is rapidly evolving, and numerous new blends have likely entered the market. One of the commercial benefits of blends is that they technically can serve as a drop-in in existing systems designed for HFCs, meaning no or little modification is required.[23]

18. Regulation (EU) No. 517/2014
19. European Commission (2022a)
20. European Commission (2022a)
21. KTH (n.d.)
22. Mota-Babiloni et al (2015)
23. European Commission (n.d.)

Table 2 Common market-available blends of HFCs and HFOs (European commission n.d.a). GWP based on the Fourth Assessment Report adopted by the Intergovernmental Panel on Climate Change.

Substance	GWP	Composition	Safety Group	Replacement for	Suitable for
R448A	1387	R32/125/1234yf/ 1234ze(E)/134a	A1	R404A	Centralised systems for commercial refrigeration, condensing units, and refrigerated vehicles
R449A	1397	R32/125 /1234yf/134a	A1	R404A	Centralised systems for commercial refrigeration, condensing units, industrial refrigeration, refrigerated vehicles
R452A	2140	R32/125/1234yf	A1	R404A	Refrigerated vehicles, refrigerated containers
R454C	148	R32/1234yf	A2L	R410A	Heat pumps and chillers
R455A	148	R32/1234yf/CO_2	A2L	R404A	Chiller
R513A	631	R1234yf/134a	A1	R134a	Condensing units, industrial refrigeration, heat pumps, chillers, refrigerated containers
R515B	299	R1234ze/R227ea		R134a, R450A, R513A, R227ea, R124	Heat pumps, chillers

7.3 Natural Refrigerants

The use and application of natural refrigerants have come a long way since the early 1900s, and many of the previous challenges, such as flammability, have been addressed by lowering the amounts of refrigerants and optimising system designs, making them safer to use. There are often additional technical training requirements when working with natural refrigerants to ensure safe use and proper handling. Switching from HFCs to natural refrigerants in RACHP applications requires entirely different systems than switching to fluorinated blends that can be used as drop-ins.

The most commonly used natural refrigerants are carbon dioxide (R744), hydrocarbons, ammonia (R717) and dimethyl ether (R-E170).

7.3.1 Carbon dioxide (R744)

CO_2 is a non-flammable and non-toxic refrigerant that operates at a higher pressure than other refrigerants, both fluorinated and natural.[24] CO_2 has been used since the end of the 19th century, and historically the higher pressure has given some technical challenges. Today, these are largely solved.[25] CO_2 is not considered applicable for split systems because of the high-pressure requirement and the lower efficiency in transcritical operation. Furthermore, high-pressure requirements impose extra costs to ensure a safe design.[26] In Europe, CO_2 is widely used as a refrigerant in supermarket cooling systems.[27] The application of CO_2 has previously been limited to regions with lower temperatures, but currently technical progress allowing CO_2 to operate in high ambient temperature climates is being made.[28]

7.3.2 Hydrocarbons

Numerous different hydrocarbons are used as refrigerants and foam-blowing agents. Some of the most common are listed below. Hydrocarbons have similar thermodynamic properties to fluorinated refrigerants, but hydrocarbons are flammable and, therefore, have higher safety requirements.[29]

- Propane (R290) is a classified A3 refrigerant, meaning there are some limitations from product standards and/or building codes.
- Isobutane (R600a) Isobutane is widely used in low-charge hermetically sealed applications such as refrigerators and freezers.[30]

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24. The Natural Voice Magazine (2016)
25. Ozone Secretariat (2018b).
26. European Commission (2020).
27. Ozone Secretariat (2022a).
28. Ozone Secretariat (2018b).
29. Ozone Secretariat (2018b).
30. Copenhagen School of Marine Engineering and Technology Management (2023)

- Propylene (R1270) is also classified as an A3 refrigerant, so there are some limitations from product standards and/or building codes. Propylene is mainly used in chillers today.
- Pentane (R601), cyclopentane, and isopentane are applied as foam-blowing agents.[31]

7.3.3 Ammonia (R717)

Ammonia has been used for over a century. Ammonia has great thermodynamic properties but is toxic and flammable in certain conditions, so additional safety measures are required. Ammonia can be used for both cooling and heating. Due to the toxicity of ammonia, it is often used in conjunction with other refrigerants, such as CO_2, in cascade systems to make it safer. Ammonia is used in appliances at an industrial scale.[32]

7.3.4 Dimethyl ether (R-E170)

Dimethyl ether (DME) was one of the first refrigerants and was first used in the late 1800s. Today, DME is used as an aerosol propellant, a (co-)blowing agent for foam, and in refrigerant blends. The application of dimethyl ether is projected to increase in the future. DME is both highly flammable and explosive. DME is often more expensive than other low-GWP non-fluorinated refrigerants since it is chemically synthesised.[33]

7.4 Environmental Concerns

Market stakeholders often highlight in their marketing that HFOs have little to no adverse impacts on the environment. Therefore, the HFOs are promoted as an environmentally friendly alternative to HFCs. This claim is based on the short atmospheric lifetime of HFOs, low GWP, and zero ODP. However, there are concerns about the environmental impact of HFOs, not least in relation to the current increase in usage and the expected future increase. One of the major environmental concerns is the persistence, aqueous mobility and toxicity of HFO breakdown products, especially trifluoroacetic acid. Moreover, even though HFOs are listed as non-toxic (toxicity level A), some HFO feedstock substances are toxic, have a high GWP or are ODSs.[34][35]

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31. European Commission (n.d.)
32. Ozone Secretariat (2018b).
33. Ozone Secretariat (2018b); (2018c); (2018d)
34. WMO (2022)
35. Molar yield = The amount of a substance obtained in a chemical reaction expressed in moles (SI unit for amount of substance)

7.4.1 Trifluoroacetic Acid (TFA)

HFOs have an approximate lifetime of days in the atmosphere before being degraded.[36] One of the breakdown products of some HFO substances is trifluoroacetic acid (TFA). According to the OECD definition for PFAS, TFA can be considered an ultrashort per- and polyfluoroalkyl substance. Furthermore, there is a new class of very persistent and very mobile substances (vPvM), another major cause for concern. TFA fulfils the criteria for this classification as well.[37]

The OECD's PFAS definition

PFAS are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it) i.e., with a few noted exceptions, any chemical with a least a perfluorinated methyl group (-CF_3) or a perfluorinated methylene group (-CF_2-) is a PFAS (OECD, 2021)

TFA is formed when HFOs are emitted into the atmosphere, where they oxidise. It is uncertain to what extent TFA naturally occur in the environment.[38] There has generally been a widespread consensus that there are natural sources of TFA in the deep sea, but this assumption has recently been challenged.[39] However, the steeply increasing concentrations of TFA in freshwater bodies over the last few decades can only be explained by anthropogenic sources. Significant anthropogenic sources of TFA exist. Other sources aside from some fluorinated refrigerants include pesticides and pharmaceuticals, and substantial amounts of TFA are now found in inland waterbodies.[40] TFA is also detected in crops and food.[41]

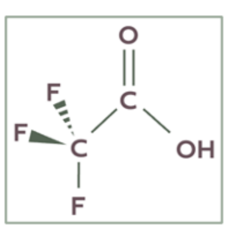

Figure 3 Structure of Trifluoroacetic Acid (TFA)

36. Behringer et al (2021)
37. Miljødirektoratet (2023)
38. WMO (2022)
39. Joudan et al (2021)
40. WMO (2022)
41. German Environment Agency (2021)

TFA has a relatively short lifetime in the atmosphere of approximately four months.[42] However, within the lifetime, TFA is often washed out of the atmosphere by precipitation and thus enters the soil and water bodies. TFA is highly persistent in waterbodies where it accumulates.[43] A Swedish study estimated an overall yearly input of 170 kg TFA into the Swedish lake Vättern, with 98 kg originating from atmospheric deposition.[44] Measurements of TFA concentrations in German rivers show an increase since 1996 from concentrations of 0.04–0.3 to above 1, although varying greatly during time and between locations.[45] For instance, in 2018, a maximum of 12.8 mg/l was measured where the river Elbe exits Hamburg harbour, but at Schmilka on the Upper Elbe 1.8 mg/l was measured.[46]

In 2021, the Danish Environmental Protection Agency reported findings of TFA in 219 out of 247 groundwater wells (89% of all samples). TFA was also found in some drinking water supplies; the concentration was lower than 1mg/L for most findings.[47]

HFO-1234yf completely breaks down to TFA, and with a continued substitution of HFC-134a with HFO-1234yf, the total amount of TFA deposited from the atmospheric degradation of fluorinated substances is projected to increase by more than 300% in 2050 (compared to 2018). This results in a projected annual increase of 49,718 tonnes of TFA by 2050 from EU-28; 96% will come from the atmospheric degradation of HFO-1234yf.[48]

Increasing TFA concentrations also pose a health concern, especially since TFA is persistent and accumulates in water bodies. According to current knowledge, toxicological and ecotoxicological effects are only observed at very high concentrations. However, according to the background report 'Reducing the input of chemicals into waters: trifluoroacetate (TFA) as a persistent and mobile substance with many sources' from the German Environmental Agency in 2021, the long-term impacts of TFA are still very uncertain.[49] In drinking water production, no practicable and economical method exists for its removal.[50] Germany has put a threshold on allowable TFA concentrations in freshwater, and it is currently set to 60µg/l with recommendations of not exceeding 10µg/l in drinking water. The threshold value is based on the no observed effect concentration threshold (NOEC) of 30 ppm for humans, corresponding to 1.8 mg/kg body weight.[51] Denmark has also implemented a threshold value for TFA in drinking water at 9µg/l.[52]

42. Holland et al (2021)
43. Behringer et al (2021)
44. Björnsdotter et al (2022)
45. Brunn et al (2023)
46. German Environment Agency (2021)
47. Danish Environment Agency (2021)
48. Behringer et al (2021)
49. German Environment Agency (2021)
50. Umweltbundesamt (2021)
51. Atmosphere (2022)
52. Drikkevandsbekendtgørelsen (2021)

Molar yield of TFA from different HFOs:

1234yf	100%
1234ze(E)	<10%
1336mzz(Z)	<20%
1225ye(E)	100%
1225ye(Z)	100%

(Behringer et al 2021)

TFA is already widely present in the environment and in freshwater reservoirs. There is a need for further research to better understand the atmospheric and hydrospheric cycle of TFA and to clarify some of the current uncertainties concerning the lifecycle of TFA as well as long-term impacts.

7.4.2 HFC-23

HFC-23 (Trifluoromethane ($CHCl_3$)) is a potent GHG with a GWP_{100} of 12400.[53] HFC-23 is produced as a by-product of HCFC-22 production. HCFC-22 is a widely used feedstock for several refrigerants, including HFO-1234yf, meaning the production of HFO-1234yf and any blends containing HFO-1234yf indirectly leads to a by-production of HFC-23. HCFC-22 production is still allowed for feedstock use under the Montreal Protocol. However, the Kigali Amendment initiated reporting requirements for HFC-23.[54]

Although this study focuses on the end-of-life treatments of HFOs, it is important to note some of the environmental concerns related to the HFO production feedstock since they pose a potential risk for counteracting results obtained due to the Montreal Protocol and the Kigali Amendment, as well as EU strategies.

7.5 Health and Safety

When exposed to high temperatures or high doses of UV light combined with heat, HFOs like HFCs will decompose to toxic substances, including hydrofluoric acids and carbonyl fluoride, raising concerns over potential toxicity hazards in the workplace. In high concentrations, HFOs are asphyxiant, and contact with evaporating liquid can lead to frostbite. Therefore, proper education of practitioners and adequate safety measures in the workplace are crucial. According

53. Myhre et al (2013)
54. WMO (2022)

to a Norwegian study from 2017, there is a lack of publicly available information on HFOs' effect on health.[55][56]

Since the MAC Directive was adopted in 2006, the use of HFO-1234yf as a replacement for HFC-134a in MAC systems has raised some debate that continued up through the 2010s due to safety concerns. Consequently, numerous tests were conducted in the same period.[57] One of the main concerns was if the MAC system was disrupted in a car accident, it could leak toxic gases with a potentially fatal outcome for passengers due to the flammability of HFO-1234yf.[58] However, the risk was small, and HFO-1234yf is considered safe to use in MAC systems.[59]

HFO foam-blowing agents have similar toxicity exposure limits to HFCs, and exposure concerns include frostbite and oxygen deprivation when large amounts are released in an enclosed space. Several studies have been conducted to determine when foam-blowing agents have degassed sufficiently and when it is safe to re-enter the area in question.[60]

55. Ozone Secretariat (2018b)
56. Fleet et al (2017)
57. European Commission (2014b)
58. BAM (2010)
59. European Commission (2014a)
60. Ozone Secretariat (2023)

8. Current and Possible Future Applications of HFOs and natural refrigerants

The use of HFOs is increasing, and new types are continually being developed, both pure HFOs and new blends. The WMO noted in their 2022 report that since its last publication in 2018, one new HFO substance (HFO-1132(E)) and 23 unique refrigerant blends had become designated refrigerants. Low-GWP alternatives exist for all refrigeration, air conditioning and heat pump (RACHP) appliances.

The sectors presented this section are chosen with this project's end-of-life scope in mind, and the sector descriptions are largely built on those applied by the Ozone Secretariat's Technical Options Committees assessment reports.

Numerous aspects impact the choice of refrigerant, including:

- Environmental legal obligations
- Safety requirements
- Energy efficiency
- Materials compatibility
- Component availability
- Refrigerant availability
- Technician competence
- System Architecture

8.1 Vehicle Air-Conditioning and Transport Refrigeration

Mobile AC for vehicles

Before the introduction of new low-GWP alternatives, HFC-134a was predominantly used in air-conditioning systems in vehicles. After implementing the MAC Directive (see section 7), HFO-1234yf has been widely adopted as the low GWP alternative in new passenger vehicles in Europe.[61] Another low-GWP alternative for vehicle AC is R-744; R-744 is increasingly used in fully electric passenger cars and buses.[62]

Transport refrigeration

Transport refrigeration entails refrigeration units for trucks, trailers, light commercial vehicles, and marine and air containers that transport temperature-sensitive products such as foods and pharmaceuticals. Some specific requirements for refrigerants to be suitable for transport refrigeration include shock, vibration, corrosion, and broad operating conditions.[63]

Many newer refrigerated trucks and trailers in Europe employ R-452A; an HFC/HFO blend with a GWP of 2140, significantly lower than R-404A (GWP 3922). Projections predict that R-744 and R290 will be the refrigerants of choice for vehicle refrigeration in the future. Small units utilising these refrigerants are already becoming available on the market.[64] One challenge for these new alternatives is that R-744 is less efficient at moderate or high ambient temperatures.[65]

8.2 Sealed Domestic and Commercial Refrigeration Appliances and Heat Pump Tumble Dryers

All the devices in the categories 'Sealed domestic and commercial refrigeration appliances' and 'Heat Pump Tumble Dryers' are plug-in, stand-alone and have a factory-sealed refrigeration system. Domestic appliances include refrigerators, freezers and heat pump tumble dryers. Commercial appliances include, for example, stand-alone display cases, beverage coolers, vending machines and ice machines found in supermarkets, restaurants, etc. Most domestic refrigerators and freezers utilise HC-600a. For stand-alone commercial appliances, there is an increase in devices using HC-290. In larger retail refrigeration charge systems, R-744 is also used. However, hydrocarbons are expected to be used primarily long-term

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61. European Commission (2014)
62. Ozone Secretariat (2018b).
63. Ozone Secretariat (2018b).
64. Ozone Secretariat (2022a)
65. Ozone Secretariat (2018b)

after the revision of safety standards in 2019 and the additional costs due to greater material use to protect against the higher pressure level.

No current, significant use of HFOs has been identified in these product categories. HFO-1234ze, HFO-1234yf and several blends are suitable refrigerants for these appliances since they have similar properties to HFC-134a, the previous dominant refrigerant in this category. One study has successfully tested R-450A as a drop-in replacement for HFC-134a in domestic heat pump tumble dryers.[66] Still, they are unlikely to be deployed on a larger scale. For pure HFOs, this is mainly due to conversion costs.[67]

In the EU, it has been prohibited since 2015 to put new domestic refrigerators and freezers on the market that contain HFCs with a GWP of 150 or more. Since January 1st, 2020, it has been prohibited to put refrigerators and freezers for commercial use on the market if they contain HFCs with a GWP of 2500 or more. January 1st, 2022, this limit was lowered to 150 GWP.[68]

8.3 Larger Refrigeration and Air Conditioning Equipment

The category 'Larger stationary refrigeration and AC' is characterised by the refrigerant systems being filled, refilled, and recovered on site. Refrigerant charges vary from a few kilos to several tonnes.

Food retail and food service refrigeration

Three types of equipment are used in food retail and food service refrigeration : stand-alone equipment (described above), condensing units, and centralised and distributed systems. Previously, HCFC-22 and, later, HFC-134a and R-404A have been used. There have been technology developments for equipment using low-GWP refrigerants, and low-GWP alternatives are available:

- R744 is increasingly used in retail food systems in cascaded systems with another refrigerant (R-450A, R513A, HFO-1234ze, R-717, HC-290, etc.)
- Some transcritical systems are using only R744.
- Several new HFO/HFC blends based on HFO-1234yf, HFO-1234ze(E) and HFC-32 can be used and are in use in several different equipment types.
- HC-290 is in use in smaller capacity systems.

Considerations related to energy efficiency are essential when choosing refrigerants since these installations typically are in permanent use.[69]

66. Gataric & Lorbek (2021)
67. Ozone Secretariat (2022a)
68. Regulation (EU) No. 517/2014
69. Regulation (EU) No. 517/2014

In the EU, stationary refrigeration equipment that contains or whose functioning relies upon HFCs with a GWP of 2500 or more, has been prohibited from being placed on the market since 1 January 2020. Exemptions are equipment intended to cool products to below -50 °C. Multipack centralised refrigeration systems for commercial use with a capacity of at least 40 kW that contains or rely on fluorinated GHGs with a GWP of 150 or more to function have been prohibited from being placed on the market since the 1st of January 2022, with an exception for fluorinated GHGs used in the primary refrigerant circuit of cascade systems, they may have a GWP of less than 1500.[70]

Industrial refrigeration

Industrial refrigeration is used in several industries, including food processing, cold storage, leisure applications, and process refrigeration. Most industrial refrigerant systems with a capacity from 300 kW to over 100 MW use R-717 as the refrigerant, but there are also newer industrial transcritical systems with R-744 refrigerant, especially in milder climates. HFO blends are also used in smaller industrial systems but to a lesser extent.

There are numerous different refrigerant combinations used for cold storage systems:

- In cold and mild climates, R-744 trans-critical systems are used.
- In warmer climates, R-717 is used.
- Cascade systems using a combination of R-744 and R-717 are also in use.
- HFC/HFO blends
- HFC-23 has been widely used in temperature-sensitive storage installations, such as pharmaceuticals. Cascade systems using a combination of HC-170 and either R-717 or HC-290 have been used as replacements for HFC-23 instalments.[71]

Industrial heat pumps

Industrial high-temperature heat pumps up to 95 °C and heat pumps used for district heating also use R-717. HFOs, namely HFO-1234ze(E), are a suitable refrigerant for industrial heat pumps as an alternative to HFC-134a, and several market-available options exist. For temperatures above 100 °C (steam production), R-718 and HCs are both viable and commercially available.

70. Regulation (EU) No. 517/2014
71. Regulation (EU) No. 517/2014

Building cooling systems

The category 'Building cooling systems' refers to AC systems in commercial buildings for heating and cooling, also called large HVAC. Different air- and water-cooled chiller systems using HFC refrigerants are most frequently used. There are several market-available low-GWP alternatives for new chiller equipment. Which refrigerants are suitable for which equipment depends on whether low, medium, or high-pressure refrigerants are needed. HFO-1233zd is a low-pressure refrigerant, whereas HFO-1233zd(E) and HFO-1234yf are medium-pressure refrigerants. HFO-1233zd(E) is expected to be more widely adopted in products that need medium-pressure refrigerants.

Natural refrigerants are also used in chillers, including R-717- R-718 and R-744, but are less common.
It is possible to change refrigerants in existing equipment by replacing them with drop-in blends with the same safety classification and similar energy efficiency, cooling capacity, discharge rates and volumetric flow rates. The HCFO/HFO blend R-470A has similar properties to R-410A and is therefore considered a potentially suitable drop-in for R-410A. Another option is to retrofit the systems. HFOs are considered especially promising in this category due to their lower flammability; flammability is a severe problem when considering building safety codes.[72]

8.4 Domestic Air-Conditioners & Heat Pumps

ACs and heat pumps of 1 kW–1,100 kW comprise most of the market of domestic air-conditioners and heat pumps. They are typically used in domestic housing, offices, etc. Historically, first HFCF-22 and later R-410A have been the refrigerant of choice for this type of equipment, followed by R-32.

72. Ozone Secretariat (2022a)

Table 3 AC Types and suitable refrigerants

Type		Primary configuration	Capacity range (kW)	Viable low-GWP options
Small self-contained (SSC)	Window	Small self-contained	1–10	HFO-1234yf, HC-290, R-744, HC-1270.
	Movable	Small self-contained	1–10	
	Through-the-wall	Small self-contained	1–10	
	Packaged terminal	Small self-contained	1–10	
Non-ducted single split		Non-ducted split	2–30	HFO-1234yf, HC-1270 (≤20 kW), HC-290 (≤20 kW).
Ducted residential split		Ducted split	4–17.5	HFO-1234yf, HC-1270 (≤20 kW), HC-290 (≤20 kW).
Ducted commercial split		Ducted split	10–1,100	HFO-1234yf, HC-1270 (≤20 kW), HC-290 (≤20 kW).
Multi-split		Non-ducted and ducted split	4–300	HFO-1234yf HC-1270 (≤15 kW), HC-290 (≤20 kW).
Packaged ducted		Ducted self-contained	5–1,100	HFO-1234yf, R-744, HC-1270 (≤20 kW), HC-290 (≤20 kW).

In addition to the low-GWP options listed in the right column, numerous blends are also available and suitable for AC products. There are also AC systems using R-744 in capacities ranging from 3 to 300 kW, mainly available in Northern Europe.[73]

In the EU, movable room AC equipment that contains HFCs with a GWP of 150 or more has been prohibited from being placed on the market since the 1st of January 2022. From 2025, it will be prohibited to place any single split AC systems containing less than 3 kg of fluorinated GHGs on the market if they contain or rely on fluorinated GHGs with a GWP of 750 or more to function.[74]

8.5 Foam in Buildings and Construction

Foam-blowing agents are widely used in buildings and construction. Foams used for building and construction have long lifetimes, often 50 years or longer.[75] Foams are either blown on-site or fabricated into products at the manufacturer. No single drop-in replacement exists for the HFC and HCFC foam-blowing agents, but different alternatives are available for all appliances. In the EU, placing extruded polystyrene (XPS) foams containing HFCs with a GWP of 150 on the market has been prohibited since January 1st, 2020. The same prohibition was implemented for other foams January 1st, 2023.[76] Hydrocarbons, including cyclopentane, pentane, isopentane, HFOs/HCFOs and water, are all used as foam-blowing agents. In building and construction, foam-blowing agents are used in the following products:[77]

73. Ozone Secretariat (2022a)
74. Regulation (EU) No. 517/2014
75. European Commission (2022a)
76. Regulation (EU) No. 517/2014
77. Ozone Secretariat (2023)

Table 4

Product	Commercially available low-GWP no-ODP alternatives	Comment
Extruded polystyrene (XPS) for insulation	HFOs/HFCOs, HCs and water	Due to flammability concerns, the hydrocarbon isobutane is only used as a co-blowing agent. HFO-1233zd(E) is anticipated to be the primary replacement for HFC-134a because they have similar properties.
PU spray foams	HFO-1233zd(E) and HFO-1336mzz(Z), HCs, Water	Hydrocarbons are not widely used because of flammability concerns.
PU panels	HFOs/HFCOs, HCs and water	Hydrocarbons are currently the primary foam-blowing agent used in PU panels. In the future, HFO/HCFO and hydrocarbon blends might be considered to increase thermal performance.
PU board stock	HFOs/HFCOs, HCs and water	Hydrocarbons are currently the primary foam-blowing agent used in PU board stock. In the future, HFO/HCFO and hydrocarbon blends might be considered to increase thermal performance.
PU in-situ and block foams	HFOs/HFCOs, HCs and water	Hydrocarbons are most often used in PU in-situ and block foams. In the future, HFO/HCFO and hydrocarbon blends might be considered to increase thermal performance.

8.6 Foams in Products

Refrigeration foam insulation

Foams are used as refrigeration foam insulation in domestic appliances such as refrigerators and freezers, commercial refrigeration, and refrigerated transport. HFOs, HCFOs, Hydrocarbons and water are all used as foam-blowing agents. HFO-1233zd(E) and HFO-1336mzz(Z) are both in use. Most emerging technologies in the appliance sector are based on HFOs and HCFOs. Many manufacturers use HFOs or HCFOs as co-blowing agents with pentane. [78]

78. Ozone Secretariat (2023)

Polyurethane (PU) integral skin and other non-insulating foams

Polyurethane (PU) integral skin and other non-insulating foams are used in several appliances, including automotive parts and furniture. Water and hydrocarbons are generally utilised as foam-blowing agents. Some new emerging technologies are based on HFOs or HCFOs. HFO-1233zd(E) and HFO-1336mzz(Z) are used, but the prices for HFOs and HCFOs are significantly higher than hydrocarbons and water. It is as such common to blend them with hydrocarbons to lower the costs.[79]

8.7 Aerosol Propellants

Aerosols have many different applications. Aerosols are often divided into the categories of consumer aerosols, technical aerosols, and medical aerosols. Suitable liquefied gas propellants include HCFCs, HFCs, HFOs, Hydrocarbons and dimethyl ethers. Hydrocarbons and dimethyl ethers are predominantly used in the consumer market. HFCs, namely HFC-134a, are still used in medical applications and for applications where non-flammable propellants are needed. HFOs are more expensive than hydrocarbons and HFCs, but are in use.[80] HFO-1234ze(E) is used in consumer aerosols, and research is being conducted on the safety of HFO-1234ze(E) as an alternative for use in Metered Dose Inhalers (MDIs).[81] Since January 1st, 2018, technical aerosols containing HFCs with a GWP higher than 150 were no longer allowed to enter the European market. Aerosols needed to meet national safety standards or for medical applications are exempt from the prohibition.[82]

8.8 Fire Suppression

HFOs are not yet in use for fire suppression. However, studies show that HFO-1336mzz(E) has application potential.[83]

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79. Ozone Secretariat (2023)
80. Ozone Secretariat (2022b)
81. European Commission (2022a)
82. Regulation (EU) No. 517/2014
83. Zhang et al (2020)

9. General Lifecycle of HFOs

This section provides a short overview of the different stages in the life cycle of HFOs. Since none of the Nordic countries manufacture HFOs, the national lifecycles begins with the import of HFO substances. The general lifecycle of HFOs does not differ from the general lifecycle of HFCs.

The specific infrastructure across the Nordic countries will be further elaborated in the later sections.

9.1 Import

Refrigerants are imported in bulk in gas cylinders to fill, refill and maintain equipment, or they are imported concealed in products. Refrigerants can also re-enter the market after reclamation.

9.2 Use

The gases are typically used as a working fluid in products or equipment. In some appliances, refrigerants may leak during the use phase. For instance, a vehicle's AC gradually and continuously leaks refrigerants from the system and must be re-filled every few years. Other equipment, such as domestic AC equipment, only needs to be refilled if there is a breach in the system.

In case there is a breach in installed equipment or a product, the general procedure for the qualified technician is to recover the refrigerant from the system by transferring the refrigerant to a gas container, repairing the leakage, and then refilling the system, either with the recovered refrigerant after a basic cleaning process or with new virgin refrigerant of the same type. However, some blends can be drop-ins for other previously used refrigerants.[84]

The lifetime of gas-containing products varies. Building and construction foams typically have lifetimes spanning decades, meaning that there are still vast amounts of refrigerants from previous generations in circulation.

84. Copenhagen School of Marine Engineering and Technology Management (2023)

9.3 Recovery

At end-of-life, the product or equipment is decommissioned. For smaller products, refrigerants are often recovered at a centralised facility after collection. On-site installations are emptied on-site, often by RAC companies. Recovered gases are then either recycled, reclaimed, or destroyed.

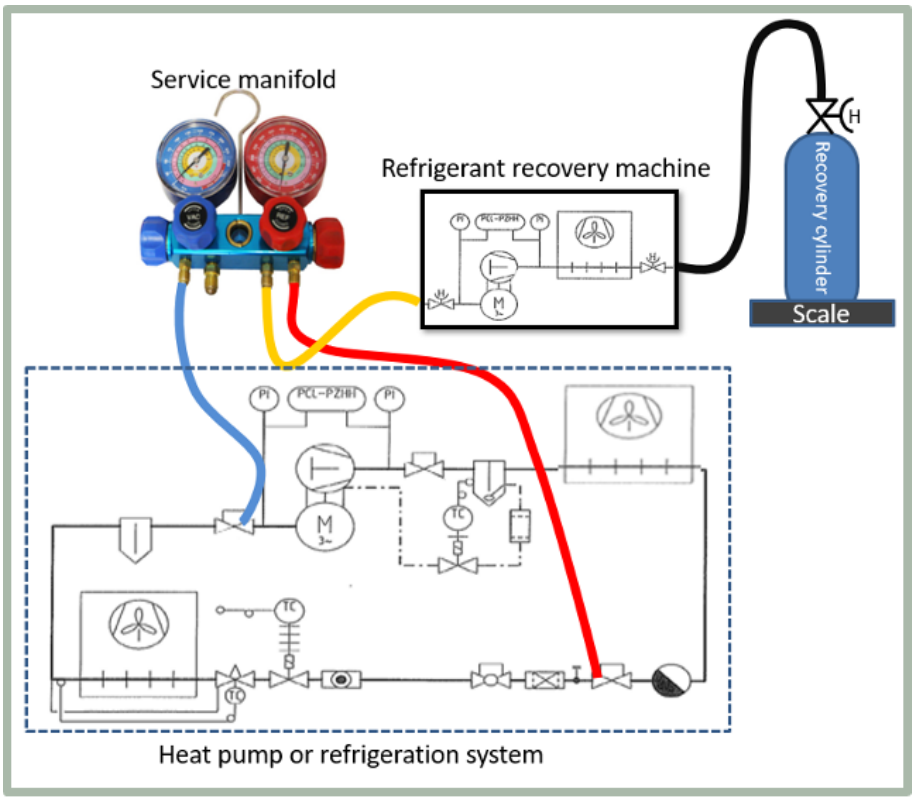

Figure 4 Illustration of refrigerant recovery from a Heat pump or refrigeration system from 'Køleanlæg og Varmepumper - Grundbog om køleteknik' (Refrigeration systems and heat pumps Basic book on refrigeration technology) by Peter Hørning, 2022

9.4 End-of-life Treatment

Export/Import of waste

Some countries do not have the facilities to handle end-of-life treatments of refrigerants, but export refrigerants in bulk or products for destruction, recycling or reclamation in other countries after recovery and collection. Transboundary waste transfer requires permission under the Waste Shipment Regulation[85] and must only be undertaken by registered waste carriers with sufficient permits.

Recycling

Recycling refers to a process where the refrigerant goes through a basic cleaning process before it is reused. Recycling is often done on-site, where the technician performs a basic refrigerant cleaning during maintenance to remove water, oil, and particles from the substance. The recycling process can also be done commercially at a treatment facility. The recycling process requires that the refrigerant is free of cross-contamination.

Reclamation

Reclamation means that the refrigerant is reprocessed by a licensed facility, where it is analysed, purified, certificated, guaranteed, and then returned to the market. The reclaimed refrigerant will have a performance equivalent to a virgin refrigerant and must meet a specified performance standard such as AHRI-700. A chemical analysis is required to ensure that the specifications are met.[86]

Destruction

In the final stage of the lifecycle, the refrigerant is neutralised by destruction. The destruction of refrigerants takes place at a licensed destruction facility. Several different destruction practices are approved for fluorinated refrigerants. They are usually destroyed using thermal oxidation (incineration) or high-temperature plasma arc technology.

85. Regulation (EC) No 1013/2006
86. RTOC (2022b)

10. Current use and legislation of HFOs in the selected countries

This section provides an overview of key global agreements and EU regulations that shape the current HFO relevant political landscape across the Nordic countries. The focus will be on those with relevance for end-of-life treatments, as well as a brief description of upcoming revisions of existing regulation and the proposed ban on PFAS currently being processed at ECHA. Furthermore, it sums up the sectors where HFOs have been identified to be used and where waste will be generated.

10.1 Global Agreements on F-gases or with relevance to F-gases

10.1.1 The Vienna Convention, the Montreal Protocol, and the Kigali Amendment

In response to the depletion of the ozone layer, the Vienna Convention was adopted in 1985 to protect human health and the environment against the adverse effects of UV radiation. The Vienna Convention aims to monitor and observe the ozone layer, providing the parties to the ozone treaties with a sound knowledge foundation for their decisions.[87] In 1987, the Montreal Protocol was established to phase out the production and consumption of ozone-depleting substances, including CFCs, HCFCs and halons. The Montreal Protocol went into force in 1989. Since its establishment, the Montreal Protocol has been amended several times. So far, the global phase-out is proceeding on schedule.

The latest amendment to the Montreal Protocol is the Kigali Amendment from 2016; the protocol was amended to regulate HFCs and initiate a phase-down of both the production and the consumption of HFCs due to their high GWP. The Kigali Amendment went into force in 2019 and the measures started immediately for non-article 5 parties (industrialised countries). According to the timeline in the Kigali Amendment, the consumption and production of HFCs (all HFCs are listed in Annex F of the Kigali Amendment) for non-article five parties shall be cut down by 85% by 2036 compared to the baseline (based on previous consumption of HFC and HCFC). Article 5 parties have more lenient timelines and are scheduled to reduce production and consumption from 2029 and, for others, not before 2032.[88]

87. Ozone Secretariat (2019)
88. Ozone Secretariat (2018a)

Reducing emissions of HFCs remains within the remit of the UNFCCC and the Paris Agreement.[89]

10.1.2 United Nations Framework Convention on Climate Change (UNFCCC)

As Parties to the UNFCCC and Annex 1 Parties to the Kyoto Protocol adopted in 1997, the Nordic countries are required to cut their GHG emissions and report annual greenhouse gas inventories of GHGs not controlled by the Montreal Protocol. The Paris Agreement adopted in 2015 introduces an enhanced transparency framework, including requirements for reporting annual GHG inventories.[90] The gases that require reporting are CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3[91]; HFOs are omitted. The Parties are encouraged to report on additional GHGs for which 100-year GWP values are available from the IPCC.[92]

10.2 EU Regulation with Relevance to HFOs

The first generations of F-gases are potent GHGs with high global warming potentials (GWPs). F-gases have, therefore, been regulated in the EU since 2006. Stricter regulations were imposed with the revised F-gas Regulation from 2014 and after the ratification of the Kigali Amendment in 2016. The 2014 F-gas Regulation mandates companies to report on their annual production, import, export, feedstock use and destruction of F-gases listed in Annexes I and II of the regulation. The reporting requirements only apply when the amounts of F-gases exceed a specific quantity.

EU is on track with the Kigali Amendment and the EU F-gas Regulation's prescription of the HFC phase-down. F-gas emissions are still a cause for concern. In 2021, F-gases were estimated to account for approximately 2.4% of the total GHG emissions in the EU, and HFCs account for most F-gas emissions in the EU.[93] The F-gas Regulation regulates substances according to their GWP values and uses ton CO_2eq as the quantitative measurement to set thresholds instead of the amount of substance by mass. Therefore, legislation seldom affects HFOs due to their low GWP. This section briefly describes the most relevant regulations and directives at the EU level.

89. EEA (2020)
90. EC (n.d.a) & UNFCCC (n.d.)
91. NH_3 was added to the list of Annex A Greenhouse Gases with the Doha amendment in 2012.
92. IPCC (2022)
93. EEA (2023)

10.2.1 The End-of-life Vehicles Directive

The most recent amendment of the EU Directive 2000/53/EC for end-of-life vehicles was in 2018.[94] Annex I describes the required treatment operations for depolluting EOL vehicles, including:

> "
>
> *Removal and separate collection and storage of fuel, motor oil, trans mission oil, gearbox oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, 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* [95]

10.2.2 The MAC Directive 2006/40/EC

The purpose of Directive 2006/40/EC on mobile air-conditioning systems (MAC Directive) is to reduce emissions of fluorinated greenhouse gases from air conditioning in passenger cars and light vans. The directive introduced a gradual ban on using F-gases with a GWP higher than 150 in all new vehicles. The directive was fully implemented in 2017. The directive does not provide guidance on what alternative refrigerants to use instead of those previously applied. As long as the substance of choice has a GWP below 150, it is up to the industry to decide which refrigerant to use. Due to the MAC Directive, the previous MAC refrigerant of choice, HFC-134a (GWP 1430), has been replaced mainly by HFO-1234yf in new passenger vehicles.[96] R-744 is also used in some new vehicles.

10.2.3 The Waste Framework Directive 2008/98/EC,

The Waste Framework Directive is the key legislative document on waste in the EU. The directive defines waste and provides the legislative framework for how it should be handled and establishes the waste hierarchy. The Waste Framework Directive also determines that hazardous waste may only be treated at treatment facilities that have obtained a special permit (required under Articles 23 to 25).

In the European List of Waste (LoW), CFCss, HFCFCs and HFCs are listed in Chapter 14 'WASTE ORGANIC SOLVENTS, REFRIGERANTS AND PROPELLANTS (except 07 and 08), and have the waste classification code 14 06 01*. They are classified as hazardous waste, as indicated by the asterisk.

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94. Directive (EU) 2018/849
95. Directive 2000/53/EC
96. Directive 2006/40/EC.

End-of-life vehicles from different means of transport (including off-road machinery) and waste from dismantling end-of-life vehicles and vehicle maintenance (except 13, 14, 16 06 and 16 08) have waste code 16 01.

Waste from electrical and electronic equipment has waste code 16 02. Entry 16 02 11* covers 'discarded equipment containing CFCs, HCFCs and HFCs.[97]

Whether HFOs are included in these categories or considered as hazardous wastes is unclear. Chapter 12 further elaborates whether the different countries that are a part of this study, considers HFOs as hazardous waste.

10.2.4 The WEEE Directive 2012/19/EU

HFOs are also used in products and equipment that fall under the definition of the WEEE Directive. The Directive on waste electrical and electronic equipment (WEEE) 2012/19/EU requires the separate collection and proper treatment of WEEE and implements the producer responsibility principle. The first WEEE directive entered into force in 2003; a revised WEEE directive went into force in 2012. Large household appliances such as refrigerators, freezers, electric heating appliances and air conditioner appliances etc., are covered by the EU WEEE directive: [98]

> ”
>
> *Article 8 Proper treatment:*
>
> *2. Proper treatment other than preparing for re-use, and recovery or recycling shall, as a minimum, include the removal of all fluids and a selective treatment in accordance with Annex VII.*

> ”
>
> *1. As a minimum the following substances, mixtures and components have to be removed from any separately collected WEEE: (...) chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC).*

97. Decision 2014/955/EU
98. Directive 2012/19/EU

"

2. The following components of WEEE that is separately collected have to be treated as indicated: (...) equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 1005/2009

10.2.5 The EU F-gas Regulation 2014/517/EU

The EU F-gas Regulation 517/2014 is the primary regulation of relevance for F-gases.[99] It prohibits intentional and unintentional emissions of F-gases in different ways and sets requirements for documentation of recovery and disposal. F-gases have been regulated in the EU since 2006. It aims to protect the environment by limiting the total amount of F-gases imported and produced in the EU, restricting the use of high GWP F-gases in certain types of equipment and appliances and totally banning the use of F-gases in certain appliances and preventing emissions from existing equipment and appliances by requiring qualified maintenance and installation. The regulation requires companies to report on produced, imported, and exported quantities of F-gases and mixtures.

The current F-gas Regulation 517/2014 went into force in 2015, replacing the former. Relevant measures from the preceding F-gas Regulation remain in place. The current F-gas Regulation aims to reduce F-gas emissions by two-thirds by 2030 compared to 2010, and the regulation introduced a phase-down timeline that started in 2015. The HFC phase-down is being implemented by annual quotas that are gradually being reduced; the quotas are putting quantitative limits on the placement of HFCs on the EU market by producers and importers.[100]

With the revised regulation, other fluorinated greenhouse gases, in addition to those listed in Annex I, became subject to reporting in accordance with Article 19 of the regulation. The other fluorinated greenhouse gases are listed in Annex II of Regulation 517/2014, including several HFO substances. The following HFOs (termed unsaturated hydro(chloro)fluorocarbons in the regulation) are listed in Annex II, section 1:

99. Regulation (EU) No. 517/2014
100.EEA (2020)

- HFC-1234yf
- HFC-1234ze
- HFC-1223zd[101]

Article 19 describes reporting requirements on the production, import, export, feedstock use, and destruction of the substances listed in Annex I and Annex II. Reporting is only required beyond the following listed quantities:

- *Each producer, importer and exporter that produced, imported, or exported one metric tonne or 100 tonnes of CO_2eq.*
- *Each undertaking that destroyed one metric tonne or 1000 tonnes of CO_2eq.*
- *Each undertaking that used 1000 tonnes of CO_2eq or more as feedstock.*
- *Each undertaking that placed 500 tonnes of CO_2eq or more contained in products or equipment on the market.*

Furthermore:

- *Each importer of equipment that is placed on the market pre-charged equipment where hydrofluorocarbons contained in this equipment have not been placed on the market prior to charging the equipment.*[102]

HFOs are only partly covered by Regulation 517/2014 as an Annex II gas, and due to the low GWP of HFOs, article 19 reporting requirements rarely step into force for POM equipment. For the import of bulk gas, the report threshold limit is 1 metric tonne or 100 t CO_2eq. Besides Article 19, Article 7 also includes Annex II gases. Article 7(2) prohibits placing any Annex I or Annex II substances on the market unless relevant producers and importers can provide evidence that any trifluoromethane (HFC-23: GWP 12,690) produced as a by-product in the manufacturing of the substance or the manufacturing of any feedstock used for their production has been either destroyed or recovered for other use in line with best available techniques (BAT).[103]

10.2.6 Potential Future Developments in the EU Regulation

The EU Commission has proposed a new F-gas Regulation that will repeal Regulation (EU) No 517/2014 to better align the regulation with the European Green Deal and the European Climate Law.[104] The proposal was published in April 2022 and is currently being negotiated by the EU Parliament and the Council. The impact assessment report that accompanied the new proposal highlighted a large gap for importers of HFO equipment, e.g., MAC systems, when the reporting threshold is defined in CO_2 equivalents.[105]

101. Regulation (EU) No. 517/2014
102. Regulation (EU) No. 517/2014
103. Regulation (EU) No. 517/2014
104. EC (n.d.b)
105. Gschrey et al (2022)

In the new proposal, HFOs listed in Annex II Section 1 are more extensively covered by the regulation and are, for instance, included in Article 4, Prevention of Emissions, Article 8, Recovery and Destruction and Article 10, Certification and Training. Furthermore, two new HFO substances are added to Annex II Section 1: [106]

- HFC-1132, a new MAC refrigerant
- HFC-1132a, part of new refrigerant blends

Barriers to effective implementation of Regulation 2014/517/EU identified in the impact assessment report include:

- Safety codes for climate-friendly alternatives have yet to be updated accordingly with technological progress, and this includes existing restrictions on flammable refrigerants that need to be updated.
- Technical barriers in building codes
- Lack of qualified service personnel to install climate-friendly alternatives
- Imports of HFCs outside of the quota system
- Since HFOs are listed in Annex II, they are not covered by the measures that aim at preventing their emissions. Annex II gases are not subject to emission controls
- The current regulation was considered less effective in preventing the leaking of other uses and substances than HFCs
- The requirement to prevent emissions during production, transport and storage applies to producers only and not any other actors.
- HFC recovery from foams at end-of-life is only required where it is 'technically feasible and does not entail disproportionate cost'. In practice, this has resulted in very little recovery, and the provision is difficult to enforce for authorities.

(European Commission (2022). Commission staff working document impact assessment report accompanying the document proposal for a regulation of the European Parliament and of the Council on fluorinated greenhouse gases amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014)

106.EC (2022a)

A potential ban on per- and polyfluoroalkyl substances (PFAS)

In January 2023, Denmark, Germany, the Netherlands, Norway, and Sweden submitted a proposal to restrict PFAS. Their suggested definition of PFAS: "Substances that contain at least one fully fluorinated methyl (-CF3) or methylene (-CF2-) carbon"[107] will extend the ban to cover at least the following market-available HFO substances:

- HFO1234yf
- HFO1234ze(E)
- HFO1336mzz(E)
- HFO1336mmz(Z)

ECHA has also submitted a proposal to restrict PFAS in fire-fighting foams.[108]

10.2.7 European Challenges

There are several obstacles to the phase-down of HFCs. According to the European Installers' Association AREA, only 3.5–7% of certified F-gas personnel were trained in alternatives such as natural refrigerants and HFOs, and only half of the training centres in the EU offer training on alternative refrigerants.[109]

10.3 Legislation in the countries covered by the study

This section provides a cross-country summary, presenting the key findings from the country studies and highlighting differences between the countries and where the countries have gone beyond the EU legislation, with a special focus on to what extent HFOs are included, explicitly excluded or whether it is not explicitly stated.

Most of the legislation across the Nordics is based on EU regulation, including for the non-member countries. Denmark, Finland, Germany, and Sweden are all members of the EU. Iceland and Norway are not EU members but are part of the EEA area. The Faroe Islands and Switzerland are neither an EU member nor part of the EEA area, Switzerland is a member of the European Free Trade Organisation (EFTA). Most of the legislation across the Nordics is based on EU regulation, including for the non-member countries.

The complete individual country studies are attached in Appendix 1. This section provides a cross-country summary, presenting the key findings from the country studies and highlighting differences between the countries and where the countries have gone beyond the EU legislation, with a special focus on to what extent HFOs are included, explicitly excluded or whether it is not explicitly stated.

107.ECHA (2023)
108.ECHA (2022)
109.EC (2022a)

10.3.1 F-gas Regulation

Denmark, Germany, Finland, Norway, and Sweden have all implemented the EU F-gas Regulation (517/2014). In Iceland, fluorinated GHGs are covered by Regulation No 1066/2019, which implements Regulation (EC) No 517/2014 for certain F-gases, HFOs not included.[110] Another notable exemption is that both Iceland and Norway have their own quota system and is not included in the EU Commission's quota system.[111]

The Faroe Islands do currently not have any legislation on F-gases. The Faroe Parliament are currently in the process of adopting a regulation on F-gases; however, HFOs are not explicitly included in the new proposed legislation.[112]

Finland

The Finnish training and certification scheme goes beyond the EU F-gas Regulation since all garages need to be certified, and the scheme covers all mobile equipment and activities such as recovery, installation, and repair.[113] A governmental decree from 2016 outlay required qualifications for handling vehicle equipment containing fluorinated greenhouse gases. The act describes the requirements for the operator and individuals working with the installation, maintenance, reparation, refilling, decommission and recycling of refrigerants. They are defined according to the definition of fluorinated greenhouse gases in the EU F-gas Regulation (517/2014), and HFOs are therefore not included. HFOs are not listed in the annex specifying different refrigerants. However, any blends containing fluorinated greenhouse gases are subject to the requirements. The requirements differ depending on whether the equipment contains less or at least 3 kg or more refrigerant. All require a certain level of education.[114]

Sweden

Sweden has also implemented Regulation (SE) No 2016:1128,[115] which complements the (EC) NO 517/2014 regulation. The regulation provisions that leakage check requirements and certified competence also apply to mobile equipment containing F-gases. Moreover, that upon disposal, those who supply refrigerants are required to take these back and provide containers for this purpose free of charge.[116] There is no refund for returning F-gases in Sweden.

Regulation 2016:1128 uses the same F-gas definition as in (EU) no. 517/2014 article 2.1. HFOs are, therefore, not covered by the regulation. However, the regulation states that if a system containing 14 tons CO_2eq or more is to be converted to another refrigerant than HFC, it needs to be reported to the authorities.[117]

110. Regulation (EU) No. 517/2014
111. Umhverfis Stofnun, n.d.
112. Umhvørvisstovan (2023)
113. Birchby et al (2022)
114. Tukes (2016)
115. SFS 2016:1128
116. SFS 2016:1128
117. SFS 2016:1128

Denmark

BEK nr. 1013 af 13/05/2021 prescribes further requirements in addition to the EU legislation. The regulation explicitly omits HFOs, including when part of a blend with other refrigerants covered by the legislation.[118] The Danish Environmental Protection Agency are responsible for enforcing the regulations.

Germany

Take-back facilities depend on the specific refrigerant and the type of systems, but it is often done via gas trades or waste management companies. Germany implemented a legally binding take-back scheme in 2009. Section 4 of the German Federal Chemicals Climate Protection Ordinance states that producers and distributors must take back HFC refrigerants after they have been recovered.[119] Distributors and producers can charge contractors a fee when they hand in HFC refrigerants, this has been identified as a limiting factor for the scheme since it discourages some from delivering recovered refrigerants since it is associated with a cost.[120]

Switzerland

In Switzerland, F-gases are regulated under the Chemical Risk Reduction Ordinance (ORRChem).

- Annex 1.5 ORRChem includes regulation for the import, export, and general use of F-gases.
- Annex 2.3 covers the use of solvents.
- Annex 2.9 covers the use of foams.
- Annex 2.10 covers the use of refrigerants.
- Annex 2.11 covers the use of extinguishing agents.
- Annex 2.12 covers the use of aerosols.

The manufacture, installation, maintenance or disposal of refrigeration, air conditioning or heat recovery appliances or systems requires a License. Licenses from EU and EFTA member states are considered equivalent to the Swiss certificate.[121] HFOs are not regulated in Switzerland only if they are contained in blends with other F-gases. However, there are reporting requirements for any equipment that uses more than 3 kg of refrigerant, no matter the type of refrigerant.[122]

118. BEK nr 1013 af 13/05/2021
119. Chemikalien-Klimaschutzverordnung (2008)
120. EIA (2016)
121. ORRChem (2005)
122. FOEN (2023)

10.3.2 End-of-life vehicle directive:

Denmark, Finland, Germany, Iceland, Norway and Sweden have all implemented the directive.

10.3.3 WEEE regulation

Denmark, Germany, Finland, Norway and Sweden have all transposed the EU Directive 2012/19 on WEEE into national law. Regulation 1061/2018 in Iceland is the primary regulation on waste electrical and electronic equipment. This largely adopts the EU Directive on WEEE (2012/19).[123] Appendix I in the Icelandic regulation 1061/2018 clearly defines the equipment relevant for the current compounds of interest – "heat exchangers". This is also the case for the EU 2012/19 regulation, but the Icelandic list is less comprehensive.

Switzerland has adopted The Ordinance on the Return, Take-back and Disposal of Electrical and Electronic Equipment (ORDEE), which requires Producer responsibility for the take-back of electrical and electronic equipment. The Ordinance came into force in 1998.

10.3.4 The Waste Framework Directive

The Danish, German, Finnish, Icelandic, Norwegian and Swedish waste regulation follows European legislation. In the Faroe Islands, waste handling is regulated by the Environment Protection Act, adopted in 1988 and the order on waste, which has been amended several times. The law encompasses activities from which liquid, solid or gaseous substances can pollute the Faroese territory's air, earth, and water bodies.[124]

10.3.5 The MAC Directive

The MAC directive is implemented by all countries EU and EEA countries.

10.3.6 Taxation and Refund Schemes

There are no taxes on HFC or other refrigerants in the Faroe Islands, Finland and Sweden or any other money-based take-back schemes.[125] In the Faroe Islands, the regulation on taxes on F-gases was in hearing in August 2023. The taxes are expected to come into force on January 1st 2024.

123. Directive (EU) 2012/19
124. Sæmundsdóttir (2021)
125. Sæmundsdóttir (2021)

Iceland

Icelandic Recycling fund

In Iceland, The Icelandic Recycling Fund aims to secure (economical) means for handling waste in Iceland[126] by leaning on the principle of "polluter pays". This is mandated through Law no. 162/2002 on processing fee.[127] Part of this legislation and taxation is directed at refrigerants, as described in Article 8, point 9. Appendix XV further extrapolates which specific refrigerants are taxed in which amount (even though every refrigerant on the list is currently taxed the same amount). HFOs are implied in this taxation under "3824.9006: Other refrigerants" in Appendix XV. The tax is collected as an expedition fee through import and is currently priced at 2,5 ISK/kg for every kind of refrigerant. The money is collected for The Icelandic Recycling Fund to pay for the waste handling this fund is responsible for. 0.5% is going to an administration fee to the Treasury. Before January 1st, 2003, it cost 98 ISK/kg in import duty for all refrigerants.[128] In other words, the tax has been lowered considerably. Some argue that this tax (regarding f-gases) costs more to upkeep administratively than it is worthwhile because few claims the fund to the degree it was planned for. The tax was lowered because of a significant operating profit for refrigerants accumulated; each year, a couple of hundred tons of F-gases were imported, but only a few tons were returned for waste disposal.[129]

Law on Environmental and Natural Resource Taxes, no. 129/2009

The newest, significant Icelandic regulation (with taxation as the primary instrument) is adopted through Law no. 135: the Act of Amendment of various laws regarding the budget for 2020.[130] This creates a new chapter in the Law on Environmental and Natural Resource Taxes, no. 129/2009[131] - Chapter III with articles 13–16. This is the legislative measure with the highest economically significant incitement for reducing the import of high GWP F-gases into Iceland. The amount of import duties to be paid is considerably more significant than the expedition fee for the Icelandic Recycling Fund. According to this legislation, the import duty to be paid for F-gases is between 30 ISK/kg–10,000 ISK/kg. The higher the GWP of the f-gas, the higher the tax is, up to a maximum of 10,000 pr. kg, similar to e.g., Denmark.[132] Article 13 provides a table for specific F-gases and their respective tax price and (UK) customs numbers. The list in the legislative document contains several commonly used HFCs, PFCs and blends. Article 13, §3 stipulates that:

126. Úrvinnslusjóður (n.d.).
127. Lög nr. 162/2002
128. Brynjarsson & Hilmarsson (2020)
129. Brynjarsson & Hilmarsson (2020)
130. Lög nr. 135/2019
131. Lög nr. 129/2009
132. Helgadóttir et al (2022)

"In the case of imports of fluorinated greenhouse gases other than those specified in paragraph 2. must pay tax based on the following criteria:

1. *For fluorinated greenhouse gases not specified in the 2nd paragraph. must pay tax in the amount of ISK 10,000/kg.*
2. *For mixtures not specified in paragraph 2. the amount of tax shall be calculated based on the proportions of the materials that make up the mixture.*
3. *For other mixtures not specified in paragraph 2. and the provisions of item 2 cannot be applied. a tax in the amount of ISK 10,000/kg must be paid." (Law no. 129/2009 [machine translated], 2009)."*

If the imported fluorinated GHGs are not listed in Article 13, the tax will be 10,000 ISK/kg. If it is a blend, the price will be determined based on the different components in the blend. Since HFOs are not classified as fluorinated greenhouse gases, there is no taxation on HFOs, and for any blends containing HFOs, that proportion does not count when calculating the price.

Norway

In 2003, Norway implemented an excise duty on the production and import of HFCs and PFCs, and in 2004 a refund scheme for the destruction of HFCs and PFCs was introduced. The tax is refunded to the party delivering the waste to an approved collection point, ensuring proper end-of-life treatment. The tax is NOK 0.952 per kg (2023) multiplied by the GWP potential of the refrigerant.[133] The excise duty covers the import and production of the following:

- *"Pure gas products in bulk and import of all types of combination of HFC and PFC, both as known mixtures and in combination with other substances.*
- *Products where the gases are integral components, include air conditioning and refrigeration units, vehicle air conditioning units, expanding foam insulation and aerosol propellants in spray cans."*[134]

The Norwegian Government plans to increase the taxes on HFCs as part of Norway's 2021–2030 Climate Action Plan.[135] The objective is to create stronger financial incentives for individuals and businesses to opt for climate-friendly alternatives. The tax level is currently set at NOK 952 per ton CO_2eq and is expected to be raised to around NOK 2,000 per ton CO_2eq by 2030. This will also result in a corresponding increase in tax refunds to the operator when handing in the refrigerant for analysis and destruction. The Government considers this

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133. Returgass (n.d.b)

134. The Norwegian tax administration (n.d.)
135. Norwegian Ministry of Climate and Environment (2020–2021)

substantial increase essential to ensure Norway fulfils their commitment under the agreement with the EU to reduce emissions by 40% by 2030.[136] There are currently no taxes on HFOs, and if they were to be included following the same method, the tax would be very low due to the very low GWP of HFOs.

Denmark

Law on taxation of CFC and certain Industrial greenhouse gases LOV nr 448 af 17/04/2020

There is a Danish tax on CFC and certain fluorinated greenhouse gases. The substance's GWP determines the tax for HFC, PFC and SF6. There is also a tax on HFO-1234ze and HFO-1234yf, currently at 0.17 €/kg.

Danish Refrigerant Installers Environmental Scheme (Kølebranchens Miljøordning (KMO))

KMO (Kørelbranchens Miljøordning) was established in Denmark in 1992, The KMO is a voluntary deposit-refund scheme to manage used refrigerants at end-of-life. In 2020, KMO established a return scheme for flammable refrigerants such as HFOs.[137] New refrigerants are sold with a KMO fee. To some extent, this fee covers the wholesaler's handling costs and the destruction or reuse of the recovered refrigerants. The customers who hand in used refrigerant will get a partial refund. The size of the refund depends on whether the refrigerant is clean or contaminated.

10.4 Use of HFOs in the Nordics

There is a general tendency in the Nordics to prefer and promote natural refrigerants, for instance, through joint Nordic initiatives such as "Nordic Criteria of Green Public Procurement",[138] a report published by the Nordic Council of Ministers that provides resources and guidance for the public administration to avoid the purchase or to find alternatives to appliances containing high GWP F-gases, as well as HFOs wherever possible. But HFOs are in use and are market available in all the Nordic countries.

The following section gives an overview of sectors where HFOs have been identified to be used in the Nordic countries, as well as Germany and Switzerland. HFOs are imported in bulk, and products, both pure HFOs and blends are being imported. Most notably, they are used in the majority of new passenger cars' AC systems. However, due to HFO's Annex II status in the current EU F-gas Regulation and not being subject to GHG reporting requirements by the UNFCCC, current monitoring of HFOs is limited, and data is limited. According to spokespersons from different organisations in the RACHP sector, some are generally, awaiting the upcoming EU F-gas Regulation and the potential ban on PFAS to consider future ventures.[139]

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136. Norwegian Ministry of Climate and Environment (2020–2021)
137. KMO (2020)
138. Poulsen & Pedersen (2020)
139. Svenska Kyl- & varmepumpforeningen (2023) & SKLL (2023)

10.4.1 Import of Bulk HFOs

- **Denmark:** The quantities of HFOs imported in Denmark are increasing. In 2019, 22.7 tonnes of HFOs were imported; in 2020, it was 30.2. tonnes. According to the Danish Tax Agency, the quantities of HFO-1234yf and HFO-1234ze substances imported in 2022 were 30.5 tonnes and 4.2 tonnes, respectively.[140]
- **The Faroe Islands**: There are no reporting requirements for HFOs in the Faroe Islands. However, all registered HFC importers are required to annually supply information to the Environmental Protection Agency. In the reporting format, it is possible to report on other F-gases than HFCs; here, both 1234yf and 1234ze have been reported. R-449 has also been imported, but in very small amounts.[141]
- **Finland:** There is both import and export of HFOs in Finland. The import consists of equipment containing HFO and HFO in bulk. HFOs are primarily imported in equipment, but there has been a significant increase in bulk import in recent years; most are expected to go to MAC applications. Import of the following HFO substances has been identified in Finland: HFO-1234yf, HFO-1234ze(E), HFO-1336mzz(Z) and HFO-1233zd(E).[142]
- **Iceland:** Very small amounts of pure HFOs are imported in Iceland annually (a few batches of a couple of kilos). HFOs are primarily imported in blends. The following blends have been identified in the import data since 2016: R-448A, R-449A, R-452A, R-454C, R-455A, R-513A, R-515B. R-449A constitutes the largest share; in 2021, 6.3 tonnes were imported.[143]
- **Norway:** The amounts of imported HFO-1234yf and HFO-1234ze have increased recently in Norway. The quantities of HFO-1234yf and HFO-1234ze substances imported in bulk in 2022 were 22 tonnes and 1.3 tonnes, respectively.[144] In addition to these, HFOs are imported in bulk in blends. Further, there are substantial amounts imported in products, particularly in MAC in passenger cars.

10.4.2 The use of HFOs in the Auto sector

In accordance with the MAC directive (Directive 2006/40/EC), it has been prohibited to use refrigerants with a GWP higher than 150 in new passenger vehicles' AC systems since January 2017. This has resulted in most new cars using HFO-1234yf in their AC system today. In the Nordics, HFO-1234yf first appeared in AC systems of new cars in 2011 and has rapidly increased since then. Car AC systems typically contain 400-1000 grams of refrigerant.[145] Due to the large

140. The Danish Tax Agency (2023)
141. Umhvørvisstovan (2023)
142. Syke (2023)
143. Umhverfis stofnun (2023)
144. Miljødirektoratet (2023)
145. Stiftelsen Returgass & Christonik ApS (2023)

number of AC systems, the auto sector is a significant source of emissions.[146] The regulated quality requirements for these AC systems accept an annual leakage of 40 g/year and 60 g/year for systems with multiple evaporators.[147] Continued refilling is necessary, and most HFO-1234yf imported is expected to be used for MAC systems.

- **Iceland:** Data obtained for the 2022 National Inventory Report in Iceland showed that all new vehicles imported during 2019 used R-1234yf in their AC system.
- **Finland:** HFO-1234yf has been the refrigerant in all new cars imported and registered in Finland since 2018. It has, however, still been possible to import used cars equipped with HFC-134a. Syke has estimated that of the used vehicles imported in 2020, 80% were equipped with HFC-134a, and 20% were equipped with HFO-1234yf, compared to 90% and 10% in 2018.[148]
- In Finland, light-duty vehicles equipped with HFO-1234yf were first reported in 2016, and in 2020, the share of light-duty vehicles using HFO-1234yf constituted 39%. For transport refrigeration, The HFC/HFO blend R-452A was introduced to the market in 2015 and is now widely used in new transport refrigeration equipment.[149]
- **Germany:** (cars). In Germany, they are currently testing using pure HFOs as a refrigerant in small vehicle refrigeration systems.[150]
- **Switzerland:** In Switzerland, HFO-1234yf is considered the state of art technology for AC systems in passenger cars, and new vehicles are not allowed to use HFC-134a for air conditioning.

10.4.3 The use of HFOs in RACHP

There is a general preference in the Nordics towards using natural refrigerants in cooling systems and heat pumps. But HFOs are in use and market available, both pure HFOs and HFC/HFO blends. Both pure HFOs and HFC/HFO blends are used. In commercial, industrial and transport refrigeration, practically only HFO/HFC blends are used. In stationary AC (incl. heat pumps), pure HFOs and blends are used.[151]

Larger RACHP (commercial and industrial use)

In Denmark, Germany, Finland, Norway, Sweden and Switzerland, HFOs have been identified to be used in larger heat pumps and chillers (>100 kWh) installed in commercial buildings and by industry.

146. NRF (2020)
147. EC (n.d.c)
148. Statistics Finland & Ministry of the environment (2022)
149. Statistics Finland & Ministry of the environment (2022)
150. Umwelt Bundesamt (2023)
151. Syke (2023)

- **Finland:** In Finland, there has been data on the instalment of large heat pumps containing HFO-1234ze since 2019, but only a small percentage of annually installed large heat pumps contained HFO-1234ze in 2019 and 2020 (less than 10%). Several other refrigerants are also reported to be used for this type of heat pump, including ammonia and the HFC/HFO blends R-450A and R-513A.[152]
- **Norway:** Due to the safety aspects, such as toxicity and flammability when working with ammonia, there is a tendency to use HFO refrigerants in newer plants in Norway. Some newer heat pumps for district heating use HFO1234ze. There are no restrictions on how large fillings the plants can have, and it is not unusual that the filling is several tonnes.[153]
- **Denmark:** In Denmark, a large part of imported HFO-1234ze is expected to be used for commercial refrigeration.[154]
- **Germany:** In commercial refrigeration, pure HFO-1234ze is used in condensing units as well as several HFO blends in central systems (R-448A, R-449A), condensing units (R-449A, R-452A, R-454C, R-455A, R-513A) and plug-in appliances (R-454C, R-455A).
- Numerous refrigerants are used in larger industrial refrigeration and air conditioning in Germany. In centrifugal chillers, it is mainly HFO-1234ze(E) and, to a minor extent, R-1233zd(E). Other chiller types, such as chillers with reciprocating or screw compressors, use R-1234ze(E) and other refrigerants. The blends R-513A and R-515B are also in centrifugal and other chillers.
- **Switzerland:** In Switzerland, it is not allowed to use HFCs in RACHP systems of more than 400 kW, and HFOs are primarily used instead.[155]

Domestic Heat pumps

- **Germany:** In domestic heat pumps in Germany, HFOs are not used pure, only in blends. The following blends are used for domestic heat pumps: R-448A, R-449A, R-452B, R-454B, R-454C, R-513A, and R-515B.
- **Switzerland:** In Switzerland, domestic heat pumps mainly use HFC or HFC/HFO blends. The use of hydrocarbons in heat pumps is increasing.

Fishing vessels

- **Iceland & the Faroe Islands:** In Iceland and the Faroe Islands, larger Industrial Fishing vessels mainly use ammonia as an on-ship refrigerant. Smaller fishing vessels use other refrigerants, HFCs or HFC blends. There are currently no natural refrigerant systems for smaller fishing vessels that are technically adequate, so there is a shift potential from HFCs to HFOs for this type of

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152. Syke (2023)
153. VKE (2023)
154. Danish Environment Protection Agency (2020)
155. Scecho AG (2023)

application.[156] However, there is a general shift towards using ammonia and CO_2 on fishing vessels.[157][158]

10.4.4 The use of HFOs as foam blowing agents

HFO-1234ze is known to be used as a foam-blowing agent, for instance, in XPS foams. In some of the investigated countries, it has been possible to confirm their use mainly in building and construction foams, but to what extent or in what quantities has not been possible to determine. As described in section 6.4.5. and 6.4.6, several natural refrigerants are also used as foam-blowing agents, and other HFO substances than HFO-1234ze are also expected to be used.

- **Iceland & the Faroe** Islands**:** No use of HFOs was identified in Iceland and the Faroe Islands
- **Finland:** In Finland, HFOs are known to be used as foaming agents.
- **Norway:** HFOs are used as foam-blowing agents in Norway. It has not been possible to gather any data on quantities.[159]
- **Sweden:** According to the latest Swedish national inventory report, an increasing proportion of XPS foams use other blowing agents than HFCs, such as CO_2 and HFOs. However, there is not any available data on the proportions.[160]
- **Germany:** HFO-1234ze is used as a foam-blowing agent for XPS foam. HFO-1336mzz(Z) is used for PUR foams. Foams in products have not been identified in Germany.
- **Switzerland:** In Switzerland, HFOs are used as a replacement for HFCs as a foaming agent in building and construction foams and foam products.

10.4.5 The use of HFOs as Aerosol propellants

HFO-1234ze is known to be used as an aerosol propellant, and their use in the countries studied has been confirmed through stakeholder interviews, but it has not been possible to determine in what quantities they are on the market.

- **Finland:** In Finland, imports of aerosol sprays containing HFO aerosol propellant have been identified and registered since at least 2018.[161]
- **Iceland & the Faroe Islands:** No use was identified in Iceland and the Faroe Islands

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156. Brynjarsson & Hilmarsson (2020)
157. Umhvørvisstovan (2023)
158. Iceland Recycling fund (2023)
159. Iceland Recycling fund (2023)
160. Naturvårdsverket (2022)
161. Syke (2023)

- **Sweden:** In Sweden, aerosol sprays with HFOs as aerosol propellants are only expected to be used in insignificant quantities so far. One expert estimates that HFOs will be used much more in the future.[162]
- **Denmark:** According to the Danish National Inventory Report, the previous aerosol propellant HFC-134a was phased out and substituted with HFO-1234ze in 2019 and so forth.
- **Germany:** In Germany, HFO-1234ze is used in aerosols. A blend of R-1234ze(E) and R-134a is used in rare cases, for instance, for electric cooling spray and filling of pressure cushions in heating and tank technology.[163]
- **Switzerland:** HFOs are in use as an aerosol propellant as a replacement for HFCs.[164]

162. Eco Scandic (2023)
163. Umwelt Bundesamt (2023)
164. Umwelt Bundesamt (2023)

11. Recovery, Collection and transport of F-gases & HFOs in the selected countries

HFOs and appliances containing HFOs are still relatively new on the market, meaning that many of the appliances containing HFOs are still in use and have not yet reached their end-of-life stage. It can take years or even decades before they are decommissioned and enter the waste stream. As an example, building insulation has a lifetime of decades, and heat pumps have an average lifetime of 10–15 years. At decommissioning, the initial amount is not always recoverable from all appliances as some are lost during use. For instance, aerosol propellants are released when used, and as described in the below section, there is continued leakage from cars' AC systems. However, closed circuit systems should not leak during their lifetime. Accidental leakages during the dismantling process or the following waste processing can happen. It is known to be a problem in the building sector that F-gases are not recovered accordingly during the demolition or renovation of buildings.[165]

The complete individual country studies are attached in Appendix 1. This chapter provides a cross-country summary, presenting the key findings from the country studies and highlighting differences between the countries. Sometimes, the countries are explicitly mentioned when the practice or findings differ from the other countries, but when the practices are the same, there will be a joint description.

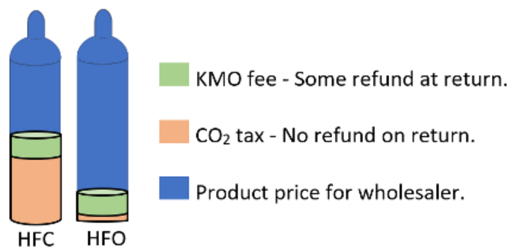
11.1 Collection of recovered refrigerants in bulk

- **Denmark** The collection of HFOs from the refrigeration and air-conditioning industry mainly occurs at the wholesalers. Wholesalers can participate in a voluntary KMO collection scheme for HFCs/HFOs. In 2020, KMO established a return scheme for flammable refrigerants such as HFOs.[166] New refrigerants are sold with a KMO fee. To some extent, this fee covers the wholesaler's handling costs and the destruction or reuse of the recovered refrigerants. The customers who hand in used refrigerant will get a refund. The size of the refund depends on whether the refrigerant is clean or contaminated.

165. Poulsen et al (2022)
166. KMO (2020)

- The price of refrigerants at the wholesaler depends on three elements. The KMO fee, the CO_2 tax, and the product's price. It is only possible to get a part of the KMO fee back. The KMO tax is found on all F-gases, both HFCs and HFOs. Figure 5 (below) shows a graphical price example of HFO and HFC. The size of the CO_2 tax is determined by law. For example, the current tax level on HFO is 0.17 €/kg and 36.2 €/kg for R134a.[167]

Figure 5



- The refrigerants are transported in approved service cylinders, and each wholesaler has their unique service cylinders. There is a distinction made between flammable and non-flammable substances. Service cylinders are either bought or rented. Most fluorinated refrigerants returned to the wholesalers are then exported to Germany, France, or the Netherlands. In some cases, the used refrigerants are purified through distillation, reimported to Denmark, and sold as regenerated refrigerants. Regenerated, reimported refrigerants do not count in the EU import quota system and are not subject to CO_2 taxation, as the refrigerants have already been taxed and registered previously. It is possible to regenerate up to 80% of a batch; this applies to both HFCs and HFOs. Chlorofluorocarbons and hydrochlorofluorocarbons (CFCs and HCFCs) are always destroyed.
- **The Faroe Islands** Industrial and commercial clients can purchase gas cylinders for F-gas recovery; these are then transported or picked up by the waste company and forwarded to a collection point where the cylinders are labelled and provided with a pictogram and later exported for destruction.[168] The Faroe Islands have two different waste and recycling companies, The IRF and KB. Both companies handle waste from private households and from institutions and companies. All F-gases are shipped to Denmark. There are no destruction or reclamation facilities for F-gases on the Faroe Islands.[169][170]

167. Skat (n.d.)
168. IRF (2023)
169. Dansk Affaldsforening (n.d.a)
170. IRF (2023)

- **Iceland** The Icelandic waste company Terra Efnaeyðing's facility, located in Hafnarfjörður, is the only waste company that handles F-gases.[171] F-gases are recovered and collected by servicing companies. Terra also collects from their customers, mainly companies and industry; they also gather from the municipal collection points. Terra has a local department in the North that collects before shipping to their facility in Hafnarfjörður. All collected F-gases are exported, and most are sent to Fortum in Denmark.[172]
- **Norway** Stiftelsen Returgass (SRG) is a nationwide company[173] that collects and handles used refrigerants in Norway. SRG has developed a system with collection points (Grønt Returpunkt (GRP)) where service tanks are handed in after recovery for proper disposal. After collection, the refrigerant is analysed to determine quantity and content, and the party who delivers the HFC-based refrigerant will receive a tax refund based on the analysis. Before payment, the waste handling costs are subtracted from the amount. The size of the payment is based on the refrigerant's GWP value. If the refrigerant type is not subject to a tax, which is the case for HFOs, then there is no payment and the associated costs for proper end-of-life treatment are charged to the customer. SRG sometimes refer to flammable HFCs, and they have made a separate procedure description for handling them safely. SRG is monitoring the collection and quantities of refrigerants. So far, HFOs only play a minor role in the return system. Other wholesalers do not regenerate, and the export is primarily for destruction. The price of refrigerants at the wholesaler depends on the F-gas tax and the product's price. It is possible to get a tax refund when the refrigerants are sent to processing at SRG. There are no taxes on HFOs and, therefore, no refund. Figure 6 (below) shows a graphical price example of HFO and HFC. The tax level is currently set at approximately NOK 590 per ton CO_2eq and is expected to be raised to around NOK 2,000 per ton CO_2eq by 2030.[174]

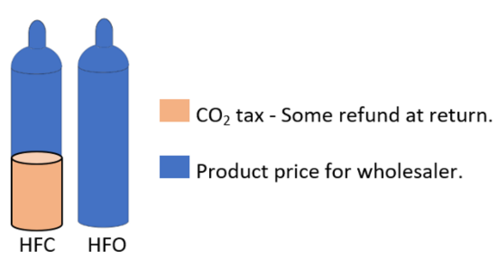


Figure 6

171. Brynjarsson & Hilmarsson (2020)
172. Terra Efnaeyðing (2023)
173. Returgass (n.d.d)
174. Norwegian Ministry of Climate and Environment (n.d.)

- **Sweden** The Swedish legislation (2016:1128, § 12) mandates that those who supply F-gases must take these back and provide containers for this purpose, free of charge.[175] There is no refund for delivering back F-gases in Sweden. According to a spokesperson for practitioners, HFCs and HFOs are treated the same in practice, even though there are no legal requirements for handling HFOs.
- **Germany** Take-back facilities depend on the specific refrigerant and the type of systems, but it is often done via gas trades or waste management companies. Germany implemented a legally binding take-back scheme in 2009. Section 4 of the German Federal Chemicals Climate Protection Ordinance states that producers and distributors must take back HFC refrigerants after they have been recovered.[176] Distributors and producers can charge contractors a fee when they hand in HFC refrigerants, this has been identified as a limiting factor for the scheme since it discourages some from delivering recovered refrigerants since it is associated with a cost.[177]
- **Switzerland** Recovering and delivering F gases back to the company for further treatment is obligatory. You pay a fee to cover recovery and recycling costs when buying equipment. Both private consumers and companies are required to pay. After handing in the recovered refrigerant, the contractor receives documentation for the delivery.[178]

11.2 Vehicles

The selling price of HFO is at a level where stakeholders in the market find it profitable to collect and recycle HFO.[179] It is, therefore, expected that HFO-1234yf will be reused after it has been recovered. The individual AC systems in cars typically contain 400–1000 grams of refrigerant.[180] Due to the large number of AC systems and the leakages from these, the Auto sector is a significant source of emissions.[181] Because of the continued reuse of refrigerants from MAC systems and the continued leakage during the car's lifetime, only small amounts of F-gases are expected to be recovered from this sector, and sources insinuate that only minor amounts are sent to destruction. However, according to EcoScandic Oy, which performs reclamation, they receive HFOs from car scrappers.

The Nordic countries of Denmark, Finland, Norway and Sweden have implemented extended producer responsibility for handling vehicles at end-of-life. Following the ELV directive, it is required to safely recover and store any fluids from the car, including air conditioning fluids. Furthermore, all personnel in auto repair shops need a training attestation to handle F-gases.

175. SFS 2016:1128
176. Chemikalien-Klimaschutzverordnung (2008)
177. EIA (2016)
178. FOEN (2023)
179. Dansk Autogenbrug & Christonik ApS (2023)
180. Stiftelsen Returgass & Christonik ApS (2023)
181. NRF (2020)

- **Iceland:** In the 2022 inventory report, the recovery of refrigerants from passenger cars was estimated to be 0.[182] However, this is illegal, and now car scrappers have begun to install the chambers necessary to recover refrigerants from the MAC systems during dismantling.[183] Terra does not receive any refrigerants from the auto sector.[184] This can either be due to a lack of recovery or that recovered refrigerants are recycled locally.
- **Germany:** In Germany, car producers have individual contracts with facilities handling collection and dismantling. Both car producers and importers must take back their own vehicle brand at an authorised facility designated by the car producer; the car owner is obliged to bring the car to the authorised, permitted facility and will be given the certificate of destruction after handing it in. Collection and dismantling facilities are organised in loose networks, but negotiations happen between the individual car producer or importer and the individual facility.[185] There are over a thousand authorised dismantling facilities and dozens of authorised shredding facilities in Germany to ensure the disposal of ELVs.[186]
- **Switzerland:** The disposal of end-of-life vehicles in Switzerland is based on the polluter-pays principle. The Swiss Auto Recycling Foundation was founded in 1992 and put an advance disposal fee on new vehicles at importation. Waste disposal companies that accept end-of-life vehicles need to require a permit from their local canton.[187]

11.3 WEEE

All countries have regulations for Extended Producer Responsibility (EPR) systems for Waste from Electrical and Electronic Equipment (WEEE), meaning that importers and producers are responsible for waste management after decommissioning. Numerous producer organisations administrate and are responsible for collecting, transporting, managing, and recycling WEEE for their members in the Nordic countries.

After WEEE is collected at waste collection points, it is usually transported to a centralised facility for dismantling, and here gases, oils and other fluids including refrigerants are recovered. After recovery, they are collected for further treatment, often incineration.[188] The country-specific infrastructure for the collection of WEEE is described below, but the recovery of refrigerants after the collection of WEEE generally happens as described above.

182. Keller et al (2022)
183. Umhverfis stofnun (2023b)
184. Terra Efnaeyðing (2023)
185. Monier et al (2014)
186. Zimmerman et al (2022)
187. FOEN (n.d.)
188. FOEN (n.d.)

- **Norway:** Stena Recycling and Revac handle WEEE in Norway. Stena Recycling exports its waste to Stena Recycling's facility in Sweden, where the refrigerants and the foam-blowing agents are recovered and destroyed. Revac delivers recovered refrigerants to the Norwegian Foundation for Refrigerant Recovery (SRG), while foam-blowing agents are sent to Germany for destruction[310].
- **The Faroe Islands:** The Faroe Islands practices extended producer responsibility, and the scheme is run by the two waste management facilities, IRF and KB. The fees for using waste facilities, transfer and sorting stations, landfills and incineration plants are decided at a national level.[189] Faroese companies pay a gate fee for waste; the price is higher for mixed waste and lower for clean, sorted fractions. For example, the gate fee for WEEE is 5 DKK/kg.[190] Used WEEE equipment is shipped to Denmark for destruction by Stena Recycling; both KB and IRF export to Stena Recycling in Denmark.[191]
- **Denmark:** The rules for extended producer responsibility for WEEE in Denmark are the same for importers and producers. All have to register their business at The Danish Producer Responsibility DPA. Importers and producers must take back or ensure a take-back scheme, e.g. by joining a compliance scheme operated by a producer organisation. The largest producer organisation in Denmark is Elretur.[192] Major Recycling companies in Denmark include Stena Recycling and H. J. Hansen.
- **Finland:** Finland has Extended Producer Responsibility (EPR) for WEEE, meaning that importers and producers are responsible for waste management after decommissioning and pay a fee for the equipment. Numerous producer organisations administrate and are responsible for collecting, transporting, managing, and recycling WEEE on behalf of their members.[193]
- **Iceland:** The Icelandic Recycling Fund does not actively collect WEEE but handles the administration and allocation of waste treatment fees.[194]
- **Germany:** The German Electrical and Electronic Equipment Act enforces that anyone who places electrical or electronic equipment on the market is responsible for its recycling. Since 2005, Germany has had a producer-led government-regulated system.[195]
- **Switzerland:** The Swiss authorities have approved three collective compliance schemes for WEEE; the SENS scheme deals with disused electrical and electronic appliances. Manufacturers, retailers, importers and collection

189. Swedish Competition Authority et al (2016)
190. Swedish Competition Authority et al (2016)
191. IRF (2023)
192. Elretur (n.d.)
193. Centre for Economic Development, Transport and the Environment (n.d)
194. Swedish Competition Authority (2016)
195. Ear (n.d.a)

points must create a take-back system and take back appliances from their product range free of charge. Consumers must hand in their WEEE at the retailer, manufacturer, importer, collection point or specialised recycling facility and not discard it as household waste. The scheme is financed by an advance recycling contribution (ARC). This financing scheme was introduced based on the ORDEE implemented in 1998, see section 1.1.1.[196]

11.4 Foam blowing agents

It has proven difficult to gather information on the use of HFOs as foam-blowing agents and if any foams containing HFOs yet have entered the waste stream. Informants are aware of one facility in the Nordics actively restructuring its current operations to recover and sort HFCs (which will be able to recover HFOs as well). The new F gas regulation includes further requirements for handling foams containing fluorinated greenhouse gases listed in Annex I and Annex II, section 1, including that building owners and contractors shall avoid emissions to the extent possible during renovation, refurbishing or demolition activities and the recovery needs to be carried out by qualified personnel. Furthermore, foams containing fluorinated greenhouse gases listed in Annex I and Annex II, section 1 cannot be placed on the market unless the fluorinated greenhouse gas is identified with a label.[197]

Sweden: In Sweden, insulation foams are processed at certain waste treatment facilities, and the F-gas is collected when the foam is shredded in a vacuum-sealed chamber.[198] Reclaiming these F-gases from the foam is not economically viable, so after being collected, they are typically sent to incineration.[199]

Iceland: In Iceland, foam-blowing agents from foams will likely not be recovered; the foam will probably end up in landfills or be incinerated without any recovery of the foam-blowing agent.[200] The Icelandic Recycling Fund covers foams, so a processing fee must be paid. The responsibility for collecting the foam at decommissioning, e.g., when a building is dismantled, befalls those responsible for dismantling.[201]

196. Sens eRecycling (n.d)
197. EC (n.d.b)
198. Poulsen (2022)
199. Eco Scandic (2023)
200. Umhverfis stofnun (2023a)
201. Iceland Recycling Fund (2023)

12. End-of-life treatment of HFOs in the selected countries

12.1 End-of-life treatmetns of HFOs

There has been an EU regulatory framework for waste management and handling since 1975.[202] While the regulatory framework pertaining to waste has been amended, expanded, and nuanced since 1975, and a wide range of measures and approaches are readily available today, all European countries still have more or less challenges with illegal dumping, even when overlooking unregistered illegal dumping.[203] Regarding HFO gases, the proposal for a regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014, clarify that the undertaking that uses a container with fluorinated greenhouse gasses shall immediately before disposal arrange for the recovery of any residual gases, ensuring that they are recycled, reclaimed, or destroyed.[204]

F-gases are classified as hazardous waste. Hazardous waste may only be processed or utilised by a facility with an environmental permit. All F-gases should be delivered for recycling or further treatment. In the European List of Waste CFCs, HFCFCs and HFCs have the waste classification code 14 06 01*. They are classified as hazardous waste, as indicated by the asterisk.

It differs or is unclear whether the respective countries actively and explicitly categorise pure HFOs under this code and, therefore, as hazardous substances. Germany and Finland consider unsaturated hydrofluorocarbons hazardous and refer to waste code 14 06 01*. Norway and Sweden do not consider HFOs to be hazardous wastes. According to the Danish KMO, all refrigerants will, per definition, be classified as hazardous waste according to the Danish Waste Act, but whether waste code 14 06 01* or 14 06 02* is most suitable can be discussed.[205]

12.1.1 Waste handling

Multiple waste handling companies are authorised to collect and transport waste with waste code 14 06 01* in the countries studied. It is unclear whether the respective countries actively and explicitly categorise pure HFOs under this code

202.EEC (1975)
203.Alves (2023)
204.EC (2022b)
205.KMO (2023)

and, therefore, as hazardous substances. The information in product safety sheets from retailers varies, and several of the companies operating in the countries in question link to the safety sheets from manufacturers, such as Honeywell and Chemours, that state to dispose of according to legal requirements while referring to the EU Waste Framework Directive.[206] One retailer lists waste code 16 05 04* in their safety sheet, which is gasses in pressure containers (including halons) containing hazardous substances.[207] Another merely states that the product is covered by the regulation on hazardous waste.[208] However, nothing from this study indicates that HFOs in practice during waste handling are handled differently from other F-gases.

12.1.2 Recycling

Companies and contractors working with refrigerants often do basic recycling that allows immediate reuse of the refrigerants. This is common practice in all the countries in this study.

Regarding practice, Sweden is a relevant example. In Sweden, WEEE facilities receive equipment containing F-gases at end-of-life (Fortum Waste Solution and Eco Scandic Oy do not handle F-gas-containing equipment but send it to the WEEE facility). Here, the F-gases are removed from the equipment and collected for further treatment, often destruction.[209] The F-gases that need simple recycling are typically treated in a facility in Sweden, while those that need more complex recycling are exported; typically to Finland.[210] The current procedure for end-of-life treatment of HFOs is the same as for HFCs, and as such the facilities can handle HFOs in the same way that HFCs are handled.[211]

According to The Swedish Refrigeration and Heat Pump Association, the four main recyclers operating in Sweden are Ahlsell, Kylma, Dahl and Ecoscandic. Several professional collectors buy recovered refrigerants, recycle them, and sell them back to operating companies. Many practitioners working with F-gases reuse and recycle the F-gases themselves.[212]

12.1.3 Reclamation

Eco Scandic is one of the few end-of-life treatment companies that are doing full reclamation throughout all the Nordic countries. They received a total of 67 tons of F-gas for reclamation in 2022. Of these, less than 2% were HFOs (1.34 tonnes), and the HFOs were mainly HFO-1234yf and HFO-1234ze. This is partly due to the relative novelty of HFOs in HVAC-R equipment, as the average lifetime for these

206.Honeywell (2022) & Chemours (2021)
207.Linde (2020)
208.Christonik (2013)
209.Poulsen (2022)
210.Svenska kyl- og varmepumpforeningen & Eco Scandic (2023)
211. Svenska kyl- og varmepumpforeningen, Eco Scandic & Fortum Waste (2023)
212. Svenska kyl- og varmepumpforeningen (2023)

appliances is approximately at least 5-7 years. Eco Scandic has a waste fee in Sweden and Finland of at least 4,5€/kg, as stipulated on their website.[213] However, waste fees can range from 18€/kg, depending on the service provider. Eco Scandic has agreements with several wholesalers, providing reclamation of their recovered F-gases and then selling them back to the wholesaler.

According to Eco Scandic Oy, the take-back models vary sporadically in the different sectors. Eco Scandic typically creates a specific take-back model in collaboration with the specific stakeholder. Eco Scandic reclaims HFC/HFO blends and pure HFCs and HFOs and sends unreclaimable F-gases to Fortum for destruction. The approach varies slightly when it is an A2L-classified refrigerant rather than a non-flammable refrigerant. Eco Scandic Oy processes both types.[214] In Finland, Darment also has an environmental permit for recycling refrigerants.

In Germany, the market situation is quite different, and there are several reclamation facilities that handle F-gases, including HFOs. However, there is currently no data on the amounts of HFOs recovered.[215]

In Switzerland, only private companies with an environmental permit can recycle and do reclamation.[216]

12.1.4 Destruction

Fortum has recycling and waste facilities in Denmark, Finland and Sweden. Fortum has facilities in Sweden and Finland that destroy recovered refrigerants; Fortum Sweden also imports recovered refrigerants from other countries for destruction. Fortum receives F-gases from waste companies that collect waste from different industries, from recyclers of products containing F-gases, from companies that service equipment containing refrigerants and from retailers of refrigerants. For destruction (as opposed to recycling/reclaiming), the technical barrier mostly consists of capacity limitations.[217] Regulations limit the levels of fluoride that can be emitted during the incineration process, and there is a limit to how fast you can decrease the fluoride levels in the gas; therefore, this is the immediate and general barrier and limiting factor for the destruction of F-gases. Fortum incinerates multiple fluorinated substances, not just F-gases. There are no technical differences in the methods for handling HFCs and HFOs. The distinction is drawn between HFC, SF6 and PFC. Fortum also receives F-gases used as aerosol propellants.[218] Fortum registers whom they receive F-gases from, allowing them to get information on sector uses, etc.

213. Eco Scandic (2023)
214. Eco Scandic (2023)
215. Umwelt Bundesamt (2023)
216. FOEN (2023)
217. Fortum Waste (2023)
218. Fortum Waste (2023)

Stena Recycling also has a centre in Halmstad, Sweden, with onsite destruction of F-gases collected in products or bulk from Stena Recycling's other sites across Europe. The applied destruction process is Regenerative Thermal Oxidizing (RTO).[219]

In Switzerland, nine waste treatment facilities are authorised to handle waste under code 14 06 01 or dispose of it. Some companies are also authorised to reclaim F gases.[220]

In Germany, there are 7 destruction facilities.[221]

12.1.5 Export

Waste exports from the countries covered in this study vary depending on whether the country has any destruction facilities. Iceland exports all refrigerants to Denmark. WEEE applications are shipped to H.J. Hansen in Denmark and Stena Recycling in either Denmark or Sweden. The Faroe Islands likewise exports all refrigerants and all WEEE equipment to Denmark.

Denmark exports all refrigerants primarily to Germany and France. Fortum Nyborg has previously destroyed F-gases but is currently not providing this service. Switzerland exports waste mainly to Germany. Germany has no regular waste export since the country has several destruction facilities.

Norway exports all refrigerants collected through SRG to France for destruction. Stena Recycling and Revac handle WEEE in Norway, and Stena Recycling exports its waste to Stena Recycling's facility in Sweden, where the refrigerants and the foam-blowing agents are recovered and destroyed. Foam-blowing agents are sent to Germany for destruction. Sweden exports refrigerants to Finland for reclamation. No waste export from Finland was identified.

12.2 Interlinkages Between Current Systems for EoL Handling of ODSes and HFCs and the Handling of HFOs

There are no treatment technical barriers for fitting HFOs into the existing systems for recovery, collection, recycling, reclamation and destruction of other fluorinated refrigerants, and HFOs are already handled through the existing infrastructure to a great extent. This is despite there being no or limited legal requirements for handling and monitoring HFOs.

Barriers to ensuring that the remaining HFOs are treated through the current systems are rather a lack of inclusion in the legislation, and some informants to this study also identified lack of knowledge among practitioners as a barrier.[222] Lack of

219. Asphjell et al (2023)
220. FOEN (2023)
221. Ludig et al (2022)
222. Naturvårdsverket (2023)

personnel educated in servicing the new low-GWP refrigerants is a Europe-wide problem, according to the Air Conditioning and Refrigeration European Association (AREA).[223]

Other challenges concerning proper HFO treatment are likely to be the same as those for handling HFCs. Specific technical know-how to reclaim HFOs and HFCs [224] is needed, which can be a barrier if end-of-life treatment facility operators are not sufficiently aware of this aspect of the F-gases life cycle.

Some HFOs are flammable refrigerants (A2L). As a consequence, different equipment is needed for leak detection and recovery. The cylinder needs to be approved for flammable refrigerants, and the recovered refrigerant needs to be labelled, showing it contains a flammable substance.[225] This type of equipment is available and required when handling other refrigerants, e.g., HFC-32, commonly used in RACHP applications, especially domestic heat pumps. However, the operators must be qualified to handle flammable refrigerants and their equipment.

The process for destroying HFOs is similar for HFCs, and companies that handle HFCs also typically handle HFOs. The reclamation process varies slightly since some are A2L-classified refrigerants. Still, there are no technical barriers to reclaiming HFOs, and the Nordic reclamation company Eco Scandic Oy is an example of a facility that reclaims both HFCs and HFOs.[226]

However, more research is recommended as more and new types of HFOs and HFO/HFC blends enter the market and, in time, will need to be properly treated. There are current efforts to address this. Swedish KTH Royal Institute is working on a 2-year project "Tank to grave management of new low GWP refrigerants" with EcoScandic Oy, Linde Gas AB, Ahlsell, HUURRE AB, and Thermia AB. The project will investigate low-GWP refrigerants throughout their entire lifetime and study whether low-refrigerant blends keep their original compositions throughout their lifetime, and if not, then what are the decompositions? Moreover, it will map the potential for recovery and recycling as well as the state-of-the-art of tank-to-grave management of new low-GWP. The project is scheduled to be finalised at the end of 2024.[227]

12.3 Challenges identified during the study for the safe recovery and end-of-life treatment of HFOs

A number of barriers to the handling of HFOs in existing systems have been identified and can be viewed in table 5. The barriers listed do not necessarily express uniquely national challenges, even though not explicitly identified while mapping the other respective countries.

223. AREA (2021)
224. Naturvårdsverket (2023)
225. AREA (2016)
226. Eco Scandic (2023)
227. KTH (n.d.) a

Table 5

Type of barrier	Technological	Regulatory	Financial	Educational	Behavioural
Country					
Denmark	None	Voluntary KMO take-back system instead of mandatory	Handing in HFOs outside the KMO scheme is associated with costs for the operators due to the loss of cylinders		
Sweden	None	HFOs are not covered by regulation 2016:1128, which mandates that suppliers are required to take back F-gases and provide containers free of charge.			
Norway	None	HFOs are not covered by the tax refund scheme	Handing in HFOs is associated with costs for the operators.		
Finland	None	HFOs are not included in the additional training and certification requirements (766/2016)		There is a decreasing interest in taking the education to become a refrigeration technician. Shortage of qualified practitioners.	

Iceland	None	There is no taxation on HFOs.	Proper equipment can be expensive for small operators. Handing in HFOs is associated with costs for the operators, as the cylinder is lost to the operator after it is handed in at a collection point. Lack of financial incentives to hand in refrigerants	Lack of education in alternative low GWP refrigerants	Long distances to collection points Lack of acknowledgement that releasing the refrigerants are of environmental concern
The Faroe Islands	None	No F-gas legislation is in place, and the upcoming legislation does not include HFOs	Proper equipment can be expensive for small operators.		Lack of official guidance on how to recover F-gases in construction demolitions
Germany	None	HFOs are not covered by regulation which mandates that suppliers are required to take back F-gases.	Distributors and producers can charge contractors a fee when they hand in HFC refrigerant		Many different types of refrigerants on the market lead to small amounts and mixing of refrigerants, which makes recovery difficult
Switzerland	None	HFOs are not covered by the Swiss regulation on F-gases. The Swiss cantons have different rules or interpret national regulations differently		Decreasing interest in the education for refrigeration technician.	

13. Discussion – Extended producer responsibility schemes

Based on existing relevant policy measures, the following section will discuss opportunities to apply end-of-life strategies for HFO gases in the Nordics.

13.1 Extended Producer Responsibility Schemes

Since the 2000s, Extended Producer Responsibility (EPR) adaptation has increased rapidly worldwide. In the EU, several directives refer to EPR as a recommended policy instrument for waste management to meet collection and recycling targets. In general, there are four broad categories of EPR instruments directed at policymakers, typically addressed as waste management aspects:[228]

- **Product-take-back requirements** – Take-back policies require the producer or retailer to collect the product at the post-consumer stage. Increased product-takeback can be achieved through collection and recycling targets of products or materials by incentivising consumers to return the used products to the selling point.
- **Economic and market-based instruments** – Economic and market-based instruments include measures such as deposit-refund schemes, Advanced Disposal Fees (ADF), material taxes, and an upstream combination of taxes and subsidies. In South Korea, ADFs are imposed on producers and importers of hazardous products and/or more difficult to recycle.
- **Regulations and performance standards** – For example, requirements for minimum recycled content. Standards can be mandatory or applied by industries through voluntary programs.
- **Accompanying information-based instruments** – These policies are developed to indirectly support EPR schemes by raising public awareness. Measures include imposing information requirements on producer responsibility and waste separation.[229]

Some general benefits of implementing EPR schemes can be highlighted,[230] including:

- Increased reuse and recycling
- Increased green product design or eco-design

228.OECD (2014b)
229.OECD (2014b)
230.Hogg et al (2020)

- Financing of waste collection and processing systems
- Reduced cost of utilising recycled materials
- Job creation
- Reduced potential health risks from landfills[231]

EPR schemes often have the fundamental environmental goal to incentivise producers to design more resource-efficient products with reduced environmental impacts,[232] in line with the Eco-design Directive,[233] and to ensure effective end-of-life collection and environmentally efficient treatment of the waste collected, to increase recycling and preparation for reuse rates.[234] The latter will be the central focus of the following subsections. Further, there will be a particular focus on take-back solutions and deposit-refund schemes.

13.1.1 Product Take-Back Solutions

Product take-back requirements are the most common EPR scheme, with almost three-quarters of all EPR schemes based on this instrument globally. Take-back solutions can be implemented with different intentions, configurations, and outcomes.[235] In the last two decades, many countries have enacted product take-back legislation that holds manufacturers responsible for collecting and environmentally sound treatment of end-of-life-span products. In most cases, the main objectives of take-back legislation are to reduce the amount of waste going to landfill by increasing product take-back and creating incentives for environmentally friendly product design.[236] The main objective of take-back systems developed to facilitate an increased collection, recycling, and proper disposal of HFO substances would most likely be to reduce the amount released to the atmosphere from illegal or improper waste handling, making it slightly different from the typical take-back systems for solid waste. This means that new configurations of take-back solutions might need to ensure an actualised increase in the collection, recycling, and handling of HFO substances. While some take-back solutions are implemented voluntarily to reverse supply chains to facilitate remanufacturing, reuse, recycling, or zero-waste production, voluntary agreements are rarely seen as an efficient approach to create prompt national action. Nonetheless, voluntary and required take-back solutions are considered crucial to closed-loop manufacturing.[237] If prompt action is the objective of addressing end-of-life solutions for HFO substances, concrete legislative requirements for take-back might be necessary.

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231. Watkins & Gionfra (2020)
232. Watkins & Gionfra (2020)
233. Directive (EU) 2009
234. Watkins & Gionfra (2020)
235. Watkins & Gionfra (2020)
236. Esenduran et al (2015)
237. Andersen et al (2021)

To support prompt actions on take-back solutions, governments can offer take-back incentives to manufacturers or retailers under a given collection target to minimise environmental pollution, whether the take-back systems are required or voluntary. With an incentivising approach, studies identify that manufacturers will act to increase the number of returned products through investments responding to governmental offers.[238] By controlling the collection rate appropriately, the manufacturers can achieve production and inventory levels that can be managed economically, and minimum total costs can be achieved.[239] Challenges are typically addressed using industry 4.0-related technology and planning and scheduling methods.[240] Take-back incentives provided by the government are proven to be an effective policy to increase product reuse. However, in the case of HFOs, the economic incentive must be determined. If there are no incentives for customers (both business-to-consumer (B2C) and business-to-business (B2B)) to return HFO substances (whether it be penalties, subsidies, or other rewards), they will be less likely to assist in the increase of collection, recycling and disposal. In some cases, where handing in containers with HFOs is associated with costs, it might be cheaper for the practitioner to simply 'free' the superfluous gas, as this is an 'efficient' way to free the container. To what extent such practices are used in the Nordics is unclear. However, such practices are an intentional release of gas, which is prohibited according to the EU F-gas regulation.

Implementing take-back solutions, regardless of the product, will require manufacturers to invest money to increase the product return rate. The investments will be compensated through material cost savings long-term, which will further increase the incentive for take-back systems. However, optimal economic configurations for take-back systems often rely on efficient closed-loop supply chain systems, where the collaborative action of all members engaged in the system is necessary.[241] Ensuring assistance with the facilitation of new supply chain configurations and facilitating an increased understanding of the overall potential benefits of take-back systems for HFO substances from an economic point of view (whether it is based on penalties or rewards) would likely increase the willingness to participate among manufacturers and retailers.

13.1.2 Deposit-Refund Systems

Deposit-refund systems combine product taxation with a rebate when the product or its packaging is returned for recycling or appropriate disposal. This is usually done by applying a tax per unit of product sales with a subsidy per unit returned for recycling. The deposit-refund approach can address many environmental challenges beyond waste disposal by imposing an up-front fee on production or consumption, using the fee revenues to rebate 'green' inputs and mitigation activities.

238.Jauhari et al (2021)
239.Jauhari et al (2021)
240.Andersen et al (2021)
241. Jauhari et al (2021)

Deposit-refund systems go beyond bottle-collection and recycling schemes and have been established for lead-acid batteries, motor oil, tires, various hazardous materials, electronics, etc. The deposit-refund scheme can address air and water pollution caused by illegally dumping hazardous waste materials or non-point source pollution. Further, evading taxation is difficult when applied to production or consumption activities. Deposit-refund systems can generally be applied in two ways:[242]

- **Downstream deposit-refund systems**, where the consumers returning the materials to collection centres are paid the refund. Downstream deposit-refund systems have been shown to transform non-recyclers into diligent recyclers;
- **Upstream deposit-refund systems**, where the refund is paid to collectors or directly to re-processors. The upstream approach is considered the most innovative, as these systems are likely to have lower transaction costs and may be less inclined to lead to situations where materials are collected for recycling but are not actually recycled.[243]

Downstream deposit-refund systems are mostly relevant for products out of the B2C market due to the incentive mechanisms whereby consumers are rewarded for product return and circular behaviour.

On the other hand, upstream deposit-refund systems are relevant for B2B and B2G markets, but will often require additional policy measures or incentive structures to ensure increased waste collection. A combination of take-back solutions and upstream deposit-refund systems could enable the desired incentive, as retailers are put in the role of collectors and manufacturers as re-processors. Retailers and manufacturers are incentivised by regulatory requirements on take-back efforts and rewarded with refunds when collecting or recycling/properly disposing of the substance in question.

13.1.3 Developing an EPR Scheme

There is a wide range of aspects to consider when it comes to designing and developing an EPR scheme, hereunder take-back solutions and deposit-refund systems. In developing EPR schemes, all the products covered by an EPR scheme must be clearly defined to ensure the best options for compliance. Product definitions should include the following:

- Types of products
- Categories and sub-categories where appropriate
- Materials
- Consumer type (household and/or commercial)[244]

242.Walls (2011)
243.Walls (2011)
244.Monier et al (2014)

In the case of the included HFO-containing product groups, it would beneficially clarify all product types covered by the EPR, differentiate products into subcategories based on the type of gas utilised for coolant (including natural alternatives), materials not related to HFO gases in the EPR covered products, and the consumer type.

To ensure that EPR schemes reflect the reality of a given society and ensure a general understanding of responsibilities among EPR-affected producers, it is essential to organise a dialogue with involved and co-responsible stakeholders.[245] The following should be taken into consideration:

- Producers and other stakeholders affected by the EPR scheme must face the same obligations.
- It can be reasonable to support SMEs and micro-enterprises to ensure a continuous market development flow.[246]

As HFOs come from different manufacturing sectors and are oriented towards different consumer markets, multiple EPR schemes should be developed based on the product type. This would ease the stakeholder dialogues, as different sectors likely would have differentiating concerns with implementation of EPR schemes.

EPR involves a shift in responsibility (administrative, financial, and/or psychical) from governments or municipalities to producers or Producer Responsibility Organisations (PROs). From a polluters-pays perspective, the definition and role of the polluters (i.e. consumers) shift from an individual directly causing pollution to an economic agent (producers) in EPR schemes, playing a decisive role in reducing pollution.[247] The shift in responsibilities is commonly facilitated through individual compliance schemes or Individual Producer Responsibility (ICS/IPR) or collective compliance schemes or Collective Producer Responsibility (CCS).[248][249] ICSs/IPRs are a rare approach in the EU and are limited to instances where one producer sells its products to a limited number of users.[250] CCSs/CPRs are much more common than individual schemes and are organised by specific organisations (PROs) that take responsibility for waste collection and treatment on behalf of their members and implement EPR principles. PROs' responsibility perimeter differs based on the type of waste producers. Often, there is a relevance in distinguishing between household, commercial and industrial waste.[251] CPRs tend to be more efficient regarding waste collection and treatment and cost-effective due to pooled resources, economies of scale, etc.[252] If EPR schemes target total products (all components) or multiple product groups, CCSs or CPRs would be the most suited, as PROs would be able to facilitate proper collection, separation and recycling/disposal of all materials.

245. Monier et al (2014)
246. Watkins & Gionfra (2020)
247. Monier et al (2014)
248. Watkins & Gionfra (2020)
249. Monier et al (2014)
250. Monier et al (2014)
251. Monier et al (2014)
252. Watkins & Gionfra (2020)

The costs of waste management, collection, and treatment of the products covered by an EPR scheme should be covered. In the case of IPR, it is recommended that standard contracts and fee calculation guidelines are set out to ensure fair and equal treatment of the producers. In the case of CPR, PROs should ideally set fees to cover the entire net waste management costs for the products included in the EPR scheme. Any revenue from sales of secondary raw materials or reusable products, both in the case of IPR and CPR, should be subtracted from the costs paid by the producers.

- Fees may include a fixed element, e.g., a producer membership fee, typically paid annually.
- If appropriate, product-related fees should be established per product, category, subcategories, and/or material. With this approach, a fee can be paid annually based on the number of products a producer places on the market.
- Fees can also be modulated based on specific product features, such as recyclability, hazardousness, utilisation of renewable resources, etc. EPR schemes that target product characteristics directly provide the most directive incentives for eco-design increments.[253]

Obligations placed on producers should be clearly defined to ensure the best options for compliance. The clarification of obligations can be made, utilising a variety of approaches:

- Producers can be obliged to finance the current waste management system based on an average cost, KPIs, and production output. Cost determination can be based on national, regional, or local waste management costs. Alternatively, producers can be obliged to set up waste management contracts with the regional or municipal waste manager. Contract templates can be developed to ensure easy compliance and implementation.
- The partial organisational approach, whereunder regional or municipal organisations still are responsible for waste collection, but with financial support from the producers. In some cases, this approach further obliges producers to participate in or facilitate waste activities such as the sorting and selling of secondary raw materials.
- The full organisational approach obliges producers to take responsibility for waste collection and treatment. This is typically done with direct contracts with waste operators, and the producers keep ownership of the waste and, thereby, any recyclable secondary raw materials.[254]

253.Watkins & Gionfra (2020)
254.Watkins & Gionfra (2020)

While all organisation approaches are valid, utilising the infrastructure already available in the Nordic or other European countries would be beneficial. Measurable targets or KPIs should be set for waste management, collection, and treatment. These targets should be reviewed periodically to ensure a continuation of an increase in recycling and preparation for reuse. Target should consider legislative and supranational mandatory waste collection and treatment targets. Furthermore, measurable targets or KPIs should consider technical and economic feasibility, existing/needed infrastructure, and geographic and demographic characteristics.[255] KPIs should be differentiated based on the lifespan of the applications where HFOs are used.

13.1.4 Transparency, Monitoring and Enforcement

Transparency of an EPR scheme is crucial in ensuring that EPR targets are met, and so are monitoring EPR schemes' contribution to national and supranational waste management targets. To provide transparency in EPR processes, an adequate monitoring system should be in place, and public authorities must enforce legislative obligations. Publicly available information, e.g., annual PRO reports, can contribute to adequate transparency of the EPR scheme. Such reports should include information on collection methods and amounts, recycling and reuse rates achieved through the EPR scheme, fees charged to producers, costs incurred, revenue from the resale of secondary raw material, and recommendations to consumers and stakeholders on how to increase proper collection and treatment of waste. An adequate monitoring system for EPR schemes is not only beneficial when it comes to determining the net costs of collection and treatment. A monitoring system can further function as an input to the assessment of national waste management targets, contribute to a transparent EPR scheme, and, if relevant, identify any iterations needed for the EPR scheme.[256] A monitoring system should, at least, entail the following:

- Detection of free riders, in the form of producers, benefitting but not contributing to the EPR scheme
- Detection of unfair commercial practices by producers, PROs, and waste management companies
- Detection of compliance or nonconformity with EPR targets[257]

Enforcement of regulative and legislative requirements is crucial, not only in the context of identifying free riders or stakeholders with unfair commercial practices, but also to ensure that citizens trust the waste management system. Enforcement practices related to EPR schemes should entail the following:

255.Watkins & Gionfra (2020)
256.Watkins & Gionfra (2020)
257.Watkins & Gionfra (2020)

- Penalties for free riders
- Punishment of unfair commercial practices
- Fair and sound financial management of EPR schemes
- Compliance with legislation by all stakeholders involved[258]

Establishing a transparent and well-monitored scheme would as well contribute to remedy the current lack of valid HFO market-, use-, and disposal data that this study has experienced.

258.Watkins & Gionfra (2020)

14. Conclusion

HFOs are the fourth generation of synthetic refrigerants and differ from earlier generations of fluorinated refrigerants by having a low GWP and no ODP. HFOs are used in RACHP, cars' AC systems, foam-blowing agents, and aerosol propellants. Since HFOs are technically HFCs, it is possible to modify some of the existing HFC systems to HFOs. Furthermore, some HFC/HFO blends can work as drop-ins in existing systems, unlike natural refrigerants which require entirely new systems and have high construction costs.

The use of HFOs is increasing and is expected to continue to increase in the foreseeable future. Due to the longevity of the products where they are in use, they are expected to continuously enter the waste stream in the coming decades. But HFOs are the cause environmental and potential health concerns, as HFOs degrade to TFA, a PFAS substance which can end up in water bodies where they are highly persistent. Studies show a continued increase in TFA concentrations in water bodies across Europe.

HFOs are listed as Annex II gases in the European F-gas Regulation No 517/2014 and are only partly covered by the regulation. HFOs are currently subject to the reporting requirements described in Article 19. Still, the reporting requirements rarely step into force due to the low GWP of HFOs with reporting only being required beyond thresholds of 100 tonnes of CO2eq or 1 metric tonne. However, this will likely change with the upcoming update of the F-gas Regulation. The proposed update includes HFOs in Article 4 (prevention of emissions) and 8 (recovery and destruction). ECHA is currently treating a proposal to ban PFAS, which, if adopted, can greatly impact the future use of HFOs since the most common HFOs are categorised within the proposed definition for PFAS.

The countries mapped in this study have all implemented the EU F-gas Regulation or equivalent regulation, except for the Faroe Islands. The Faroe Islands are currently in the process of adopting their first legislation on F-gases, but HFOs are not included. Denmark, Iceland and Norway have all implemented refund schemes for HFCs. There is no refund for HFOs in Norway. On the contrary, it is associated with costs to hand in HFOs after recovery. The Danish refund scheme is voluntary. Denmark, Iceland, and Norway have all placed a tax on fluorinated refrigerants. HFOs are exempt in Norway and Iceland. In Denmark, the tax on HFO-1234yf and HFO1234ze is as low as 0.17 €/kg, as the substance's GWP determines the fee. Sweden has implemented a regulation that mandates that those who supply F-gases must take these back and provide containers for this purpose, free of charge. HFOs are not covered by the regulation.

There are no treatment technical barriers to fitting HFOs into the existing systems for recovery, collection, recycling, reclamation and destruction. HFOs are already to some extent handled through the existing infrastructure. HFOs generally enter the waste stream through three main channels: Refrigerants recovered by a technician from RACHP equipment, WEEE and car scrapping. All the Nordic countries have Extended producer responsibility for WEEE, and all car scrappers must have a training attestation to handle F-gases. The Faroe Islands and Iceland export WEEE to H. J. Hansen in Denmark and Stena Recycling in Denmark and Sweden. Norway also exports WEEE to Stena Recycling in Sweden. Many practitioners working with F-gases reuse and recycle the F-gases themselves, and several professional collectors buy recovered refrigerants, recycle them, and sell them back to operating companies.

The only companies in the Nordics with an environmental permit for reclaiming refrigerants are Darment and Eco Scandic Oy, both located in Finland. Eco Scandic Oy receives refrigerants from Sweden and Finland. So far, the amounts of HFOs Eco Scandic Oy receives are minor.

Fortum has destruction facilities in Sweden and Finland with the necessary permits to handle fluorinated refrigerants. Denmark, The Faroe Islands, Iceland and Norway all export refrigerants for destruction elsewhere, primarily to France and Germany.

15. Recommendations

15.1 Recommendations for the Nordic Council of Ministers

Based on the findings and conclusions of the study, the following cross-Nordic recommendations are given to the Nordic Council of Ministers:

- Initiate an information campaign to create awareness of the detrimental environmental impacts when fluorinated refrigerants are emitted instead of being correctly recovered and disposed of accordingly, as well as any potential health risks from direct exposure.
    - Consider making the campaign threefold. The first should focus on the practitioners and ensure they are aware of the environmental impacts of improper disposal as well as any potential health risks.
    - The second part of the campaign should target private citizens to discourage the unauthorised handling of domestic RACHP appliances.
    - The third part of the campaign should target practitioners in other sectors to raise awareness of the necessity of ensuring qualified and educated personnel are involved in the process and ensuring that they are responsible for the recovery of refrigerants, e.g., in demolition and renovation projects.
- Encourage development and implementation of a voluntary labelling scheme to explain and raise awareness about HFOs and HFCs being PFAS. Introducing a voluntary labelling scheme that informs consumers and industry stakeholders about the PFAS content in HFOs and HFCs is a significant step towards promoting transparency, informed decision-making, and responsible product usage. The scheme can encourage manufacturers and suppliers to provide detailed information about the presence of PFAS in their products, allowing end-users to make more sustainable choices.
    - The Nordic countries can collaborate with experts, industry representatives, and environmental organisations to develop comprehensive labelling guidelines that accurately reflect PFAS content in HFOs. In the engagement with relevant industries, positive impacts on market reputation and consumer trust can be emphasised to encourage participation. By working together to establish and promote the labelling scheme, Nordic countries can set a positive example for international collaboration on addressing the challenges of HFOs.

- Commission a study to examine ultra-short PFAS, such as TFA, to increase the knowledge of environmental and health exposure risks associated with these substances. Ultra-short PFAS has not yet been well studied and is accumulating in water bodies while the consumption of HFOs is continuously increasing. The study can provide valuable insights into the sources, distribution, and accumulation patterns of ultra-short PFAS, enabling informed decisions about their management and providing a foundation for effective policy-making and proactive measures to mitigate the potential risks associated with these substances. Moreover, by undertaking this research, the Nordic countries can assume a leadership role in addressing a knowledge gap that has implications beyond our region, influencing global research priorities and fostering international cooperation.

EU Perspective

- Await upcoming EU legislation and ensure knowledge sharing concerning implementation practices across Nordic countries. This will also provide an opportunity to align our national frameworks with these regulations and engage in collaborative efforts that bolster the understanding, strategies, and solutions related to these substances. A consistent approach will help prevent regulatory arbitrage and ensure a level playing field for industries.
- Consider unifying the term for HFOs with what the EU legislation applies to ensure better transparency and consistency, so instead of Hydrofluoroolefins/HFOs, they are termed unsaturated hydrocarbons/uHFCs. This will also make it more transparent that HFO technically is an HFC. Unifying the terminology ensures a uniform understanding of the substances in question. A consistent term enhances stakeholder communication, ranging from policymakers and industries to researchers and consumers.

15.2 Recommendations for the Nordic countries respectively

Operational

- In line with the Nordic countries' stance on climate-friendly refrigerants, look into whether safety codes and existing restrictions on flammable refrigerants are updated accordingly with technological progress.

- Ensure adequate information and guidelines on climate-friendly refrigerants are readily available for practitioners. This can be inspired by the Danish Environmental Agency's establishment of a knowledge centre for Climate-Friendly Refrigerants (Videncenter for Klimavenlige Kølemidler) or through encouragement of stakeholders such as industry associations and manufacturers to create industry initiatives, e.g., guidelines and best practices specifically focusing on HFOs.

Map the use of HFOs

- Encourage branch organisations to conduct member surveys to uncover which types of refrigerants are being used on the market and in which kind of appliances. This can be based on the Swedish Refrigeration & Heat Pump Association's survey on the type of heat pumps their members install and which refrigerant type they use.
- Consider lowering the threshold value for reporting requirements to cover low GWP substances better. The Swedish Refrigeration and Heat Pump Association has recommended setting this value to 3 kg CO_2e instead.[259]

Include HFOs in current policies and systems

- Realign HFOs with current systems for HFCs to ensure no extra costs are associated with handing in recovered HFOs.
    - Consider including HFOs in current take-back schemes if they are currently exempt.
    - If the refund share is based on GWP, consider other parameters to ensure that there is economic incitement to recover and hand in recovered HFO instead of releasing it to the environment.
- Clarify the current waste status of HFOs and encourage including HFOs in the list of hazardous wastes. Furthermore, the Nordic countries can jointly encourage HFOs to be explicitly included in the EU list for hazardous waste to ensure a uniform understanding and approach across the EU.
- Apply a combination of voluntary and mandatory measures to ensure that HFOs are recovered and collected for proper waste handling.
    - Voluntary Measures. Promote Take-Back schemes in collaboration with manufacturers, retailers and service providers. A partnership-based approach encourages industry players to actively participate in the responsible disposal of HFOs.
    - Consider financial incentives or rewards for actors who hand HFOs for proper disposal. Financial incentives acknowledge the potential cost

259.Svenska Kyl- & varmepumpforeningen (2023) and effort associated with proper disposal. By offsetting these costs, individuals and businesses are more likely to opt for responsible disposal methods rather than engaging in improper disposal practices.

- Develop labels or certifications that can be earned when participating in organised end-of-life treatment programs.
- Engage retailers to ensure proper disposal by providing collection points at their facilities or providing information on authorised disposal facilities.
- Mandatory Measures. EPR legislation that explicitly includes HFOs (combined take-back and deposit-refund system).
- Require that servicing, refilling, recovery and decommissioning are journaled and reported. If not already, then consider establishing a national database for recording. Transparent record-keeping ensures traceability and enables regulatory bodies to monitor compliance effectively.
- Consider establishing a centralised national database for recording HFO-related activities. This database would provide a comprehensive overview of HFO waste management efforts, aiding in assessing the effectiveness of strategies and identifying areas for improvement.
- Collaborate with waste management companies to establish the necessary infrastructure for proper collection, transportation and disposal and make sure that collection points are easily accessible on a nationwide scale.

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Zimmermann, T., Sander, K., Memelink, R. (Ökopol Institute for Environmental Strategies GmbH, Hamburg), Knode, M. Freier, M. (RETEK AG, Ihlow), Porsch, L. (VVA Brussels SPRL, Brussels), Schomerus, T. (Leuphana Universität, Lüneburg), Wilkes, S., Flormann, P. (TSR Recycling GmbH & KG., Düsseldorf) (2022). Executive summary Illegal treatment of end-of-life vehicles Assessment of the environmental, micro- and macro-economic effects. German Environment Agency. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/texte_130-2022_illegal_treatment_of_end-of-life_vehicles.pdf

17. APPENDIX 1: The complete country studies

17.1 Denmark

17.1.1 Country regulations with relevance

Legal (obligations, requirements, or prohibitions, including (but not limited to) acts, laws, regulations, and administrative or executive orders)

Denmark has implemented several regulations to reduce the usage of fluorinated greenhouse gases. Denmark's primary F-gas legislation is the EU F-gas Regulation (517/2014). The law aims to reduce HFC usage by phasing down production and consumption by 79% by 2030. The regulation limits the amounts of HFCs that can be placed on the market in the EU and requires companies to report their HFC usage and emissions. As a supplement, Denmark has implemented national legislation, which is updated continuously. The latest update is from May 13th, 2021, with Bekendtgørelse 1013.[260] The legislation prescribes further strictures than the EU legislation; the regulation explicitly omits HFOs, including when part of a blend with other refrigerants covered by the legislation. The Danish Environmental Protection Agency (EPA) (Miljøstyrelsen) enforces the regulations. Under the regulation, companies must keep records of their HFC usage and provide them to the EPA. Companies must also ensure their employees are qualified to handle and recover HFCs.

The Danish Environmental Protection Agency has appointed the organisation "Kølebranchens Miljøordning", (The Danish Refrigeration Installers' Environmental Scheme (KMO),[261] to issue authorisations and keep track of which companies and individuals have permission to educate, trade and handle HFCs, including HFOs.

Soft regulatory instruments

The Danish Environmental Agency has established a knowledge centre for Climate-Friendly Refrigerants (Videncenter for Klimavenlige Kølemidler). The knowledge centre provides information, advice, and guidelines on refrigerants to technicians, manufacturers, and developers.

260.F-gas bekendtgørelsen (2021)
261. KMO (n.d.a)

Education and Documentation Requirements

Denmark has different training and documentation requirements, depending on the refrigerant type and on the amount of refrigerant. In rough terms, it is possible to categorise the documentation requirements in three groups.

- **MAC:** Individuals and companies must be certified according to Directive 2006/40/EC (MAC-directive)[262] to work with air conditioning systems on all types of vehicles. The authorisation is only relevant for the auto sector and systems below a 2.5 kg filling charge.[263]
- **Category II requirements:** Companies and personnel working with heat pumps and air conditioning systems with a refrigerant charge under 2.5 kg[7] must meet Category II requirements.[264] The educational requirements are more extensive, and all usage of HFC is ideally reported to KMO.
- **Category I requirements:** The Category I requirements for working with systems larger than 2,5 kg coolant are more comprehensive. The Danish Working Environment Authority (WEA) sets educational requirements and restrictions. Category I companies are met with requirements of using a quality assurance system according to ISO 9001 with reference to BEK nr 1977 of 27/10/2021, appendix 7[265] and annually third-party control.

17.1.2 Monitoring

KMO was established in 1992, and in addition to the mandate mentioned above, another goal of KMO is to track the usage of HFCs and HFOs in Denmark. Originally the intention was that all authorised companies should report their use of refrigerants in KMO's database. In practice, it has become a voluntary system that allows companies to register their refrigerant consumption. Companies have different systems for monitoring their consumption and not all refrigerant consumption is reported to KMO. Due to a database crash in January 2022,[266] submitting any usage data has been impossible for a period of time. As a consequence, there is a lack of overview of which companies and persons are currently approved to work with HFC substances.[267]

In practice, sales and imports are recorded by each wholesaler and refrigeration company. This results in decentralised tracking, and mapping the amount of F-gas handled nationally can be difficult.

262. Directive 2006/40/EC
263. Christonik ApS (2023)
264. KMO (n.d.b)
265. BEK nr 1977 af 27/10/2021
266. KMO (2022)
267. KMO (2023)

17.1.3 Use of HFO Substances in Denmark

The Danish F-gas consumption is well described in the report "Danish consumption and emission of F-gases in 2020", from the Danish Environmental Protection Agency.[268] The report lists the import and consumption of F-gases in Denmark, including some information and data on HFOs. The quantities of HFOs imported are increasing. In 2019, 22.7 tonnes of HFOs were imported, which increased to 30.2 in 2020. According to the Danish Tax Agency, the quantities of HFO substances imported in 2022 were 34.7 tonnes. It is expected that there has been and will be a growth in the usage of HFOs in recent years due to the low GWP factor.

Table 6 Danish HFO-1234yf and HFO-1234ze import in 2022 (The Danish Tax Agency (2023))

Year	Refrigerant	Quantity (Tonnes)
2022	HFO-1234yf	30.5
2022	HFO-1234ze	4.2
	Total:	34.7

There is no overview of the amount of HFOs exported.

The usage of HFOs can be divided into different sectors based on their usage. This section describes the following: MAC in cars, RACHP equipment, products which use HFOs as blowing agents, such as insulation materials, and as an aerosol propellant in spray cans.

According to the latest data reported to the EU, the following number of Danish companies reported activities in the field of F-gas refrigerants. This includes all types of F-gases and not just HFO; a company can report on more than one activity:[269]

268.The Danish Environment Protection Agency (2020)
269.Ludig et al (2022)

Importers	13
Exporters	3
Equipment importers	16
Destruction companies	0
Quota authorisers	1

The Auto sector

It has not been possible to determine the exact quantities of the auto sector related HFOs imported, recycled, or disposed of in Denmark. Sources insinuate that they find it likely that only a minor amount of HFO from cars is sent to destruction. The selling price of HFO is at a level where stakeholders in the market find it profitable to collect and recycle HFO.[270]

RACHP

There is a general preference in Denmark towards using natural refrigerants in cooling systems and heat pumps. This shift is driven by the desire to reduce the environmental impact of traditional synthetic refrigerants and move towards more sustainable and climate-friendly alternatives. The trend for using HFOs is not as strong as in other European countries, but they are used in some commercial refrigeration and heat pump installations.[271] A large part of imported HFO-1234ze is expected to be used for commercial refrigeration.[272]

Aerosol propellants

HFO-1234ze has substituted HFCs in aerosols for specific industrial purposes since 2019.[273]

17.1.4 Existing systems for collection and end-of-life treatments of HFOs

KMO

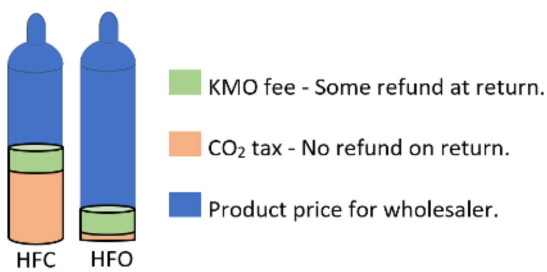
The collection of HFOs from the refrigeration and air-conditioning industry mainly occurs at the wholesalers. Wholesalers can participate in a voluntary KMO collection scheme for HFCs/HFOs. In 2020, KMO established a return scheme for flammable refrigerants such as HFOs.[274] New refrigerants are sold with a KMO

270. Danish Car Recycling Association (2023)
271. Ahlsell (2023)
272. Danish Environment Protection agency (2020)
273. Danish Environment Protection agency (2020)
274. KMO (2020)

fee. To some extent, this fee covers the wholesaler's handling costs and the destruction or reuse of the recovered refrigerants. The customers who hand in used refrigerant will get a refund. The size of the refund depends on whether the refrigerant is clean or contaminated.

The price of refrigerants at the wholesaler depends on three elements: The KMO fee, the CO_2 tax, and the product's price. It is only possible to get a part of the KMO fee back. The KMO tax is found on all F-gases, both HFCs and HFOs. The figure below shows a graphical price example of HFO and HFC. The size of the CO_2 tax is determined by law. For example, the current tax level on HFO is 0.17 €/kg and 36.2 €/kg for R134a.[275]

Figure 7



The refrigerants are transported in approved service cylinders, and each wholesaler has their unique service cylinders. There is a distinction made between flammable and non-flammable substances. Service cylinders are either bought or rented.

Most fluorinated refrigerants returned to the wholesalers are then exported to Germany, France, or the Netherlands. In some cases, the used refrigerants are purified through distillation, reimported to Denmark, and sold as regenerated refrigerants. Regenerated, reimported refrigerants do not count in the EU import quota system and are not subject to CO_2 taxation, as the refrigerants have already been taxed and registered previously. It is possible to regenerate up to 80% of a batch; this applies to both HFCs and HFOs. Chlorofluorocarbons and hydrochlorofluorocarbons (CFCs and HCFCs) are always destroyed.

Some wholesalers don’t regenerate, and the export is primarily for destruction.[276]

Another option for disposing of HFOs and HFCs is at recycling sites. These are municipal and are not part of KMO's voluntary return scheme. If return cylinders with refrigerants are handed in at a recycling site, a fee must be paid, and the return cylinders are lost to the recycling site. Due to the waste fee and the cost associated with the purchase of a new one return cylinder, the quantity that is returned at the recycling sites is very limited. Return cylinders are pressure tanks and are, therefore, handled as hazardous waste and sent to destruction. It is

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275. Skat (n.d.)
276. Ahlsell (2023)

typically Stena Recycling that handles refrigerants from the recycling sites. Previously, Fortum in Nyborg received fluorinated refrigerants for destruction. However, currently, they do not offer this service.[277]

HFO is exported for reclamation and as waste for incineration to other EU countries, primarily Germany, France or the Netherlands. Sources indicate that the exported quantity is considerably lower than the imported quantity.[278]

In some cases, the used refrigerants are purified through distillation, reimported to Denmark, and sold as regenerated refrigerant. Regenerated, reimported refrigerants do not count in the EU import quota system and are not subject to CO_2 taxation, as the refrigerants have already been taxed and registered previously. As mentioned above, it is possible to regenerate up to 80% of a batch of HFCs or HFOs, whereas CFCs and HCFCs are always destroyed. Other wholesalers do not regenerate, and the export is primarily for destruction.[279]

End-of-Life Vehicles

Both new and second-hand imported vehicles are covered by producer responsibility in Denmark. To import vehicles in Denmark, it is required to register at The Danish Producer Responsibility (DPA). DPA is established under the Danish Environmental Protection Act and administers the national register and Danish legislation on producer responsibility. At end-of-life, the producer, company or private person who has imported the vehicle is required to hand over the car to either the importer or to an ELV reception site. In Denmark, the last owner receives a car scrapping premium when the car is handed over to the car breaker. Stena Recycling has established a collaboration on a return system with Danish car scrappers.[280]

WEEE

The rules for extended producer responsibility for WEEE in Denmark are the same for importers and producers. All must register their business at DPA. Importers and producers are required to take back or ensure a take-back scheme, e.g., by joining a compliance scheme operated by a producer organisation. The largest producer organisation in Denmark is Elretur.[281]

Products

In waste where the HFO is included as a component (as a blowing agent, for example), the product is treated as waste concerning the product as a whole. The waste is usually treated as a small combustible fraction or sent to landfill.[282]

277. Fortum Waste Solutions A/S (2023)
278. Ahlsell (2023)
279. Ahlsell (2023)
280. Stena Recycling (n.d.)
281. Elretur (n.d.)
282. Stena Recycling (2023)

17.2 The Faroe Islands

The Faroe Islands are a part of the Danish kingdom, but The Faroe Islands have had their own home rule act since 1948, the first paragraph stating that the Faroe Islands are a home-ruling society. Umhvørvisstovan – the Environmental Agency of the Faroe Islands – is the national environmental authority. In 1988, the first act on Environmental Protection was put in force. The Faroe Islands is not a member of the European Union or the EEA area. Denmark initially ratified the Montreal Protocol without making a territorial exclusion of the Faroe Islands, but in 1991, Denmark expressed reservations about the application of the Montreal Protocol to the Faroe Islands. In 1997, however, Denmark lifted the reservation again. The Faroe Islands have also been excluded from some of the subsequent amendments to the Montreal Protocol. These reservations have been lifted again as well. The Faroe Islands are not territorially excluded from the ratification of the Kigali Amendment.[283] The Faroe Islands, therefore, need to phase down their consumption of HFCs due to the high GWP of HFCs, even though the Faroe Islands are not under any legal commitment to meet the Kyoto Protocol. However, the Faroese government have signed the United Nations Framework Convention on Climate Change (UNFCCC). The Faroese Environment Agency report their GHG emissions annually to the IPCC as a part of the inventory for the Kingdom of Denmark, with HFCs and other f-gases being included in the list of GHG emissions that the Faroe Islands report on.[284]

17.2.1 Country regulations with relevance

Legal (obligations, requirements, or prohibitions, including (but not limited to) acts, laws, regulations, and administrative or executive orders)

The Faroe Islands do currently not have any legislation on F-gases. The Faroe parliament is currently in the process of adopting a regulation on F-gases. However, HFOs are not explicitly included in the new proposed legislation.[285] General waste handling is regulated by the Environment Protection Act.[286]

Fiscal (subsidies, taxes, or charges)

The Ministry of Finance and the Ministry of Environment, together with Umhvørvisstovan (the Environmental Protection Agency), have made a proposal to change the bill on tax on production and import and custom regulation in order to put a tax on the import of F-gases. The tax will be based on the gases' GWP values, and the size of the tax will be similar to the Icelandic taxes. HFOs are not included in the new taxation.[287]

283.UNEP ozone secretariat (n.d.)
284.Nielsen et al (2022)
285.Umhvørvisstovan (2023)
286.Sæmundsdóttir (2021)
287.Umhvørvisstovan (2023)

The Faroe Islands practice extended producer responsibility, and the scheme is run by the two waste management facilities, IRF and KB. The fees for using waste facilities, transfer and sorting stations, landfills and incineration plants are decided at a national level.[288] Faroese companies pay a gate fee for waste; the price is higher for mixed waste and lower for clean, sorted fractions. For example, the gate fee for WEEE is 5 DKK/kg.[289]

Soft regulatory instruments (recommendations, technical standards, voluntary bottom-up initiatives (self-regulation), legislation-induced co-regulatory actions)

None were identified.

17.2.2 Use of HFO Substances in the Faroe Islands

The Faroe Islands have ratified the Kigali Amendment, and they need to phase down the use of HFCs. There is some information available concerning HFC consumption that can serve as an indicator for future HFO needs. The recently submitted emission inventory report for Denmark, Greenland, and the Faroe Islands for 1990-2020 also maps HFC emissions on the Faroe Islands.[290]

- Most F-gases that are emitted are HFCs (nearly 99%)
- There is no production of HFCs on the Faroe Islands.
- Four types of HFCs are in use on the Faroe Islands, namely the HFC gas blend HFC-507a that has substituted HCFC-22. HFC-507a has no ODP but has a high GWP; it is mainly used for refrigeration both domestically, commercially and in the industry; this also includes fishing vessels that previously also used HCFC-22.
- There has been an increase in HFC emissions in recent years due to the rise in the use of HFC-125 and HFC-143a, both components in the HFC-blend HFC-507a.

The auto sector

No data on the use of HFOs in the auto sector were obtained, but considering the European market, there is no doubt that most new passenger vehicles imported to the Faroe Islands from Europe will contain HFO-1234yf in their MAC system.[291]

Refrigeration, Air Conditioning and Heat Pumps (RACHP)

There is an increase in heat pump installations on the Faroe Islands, and the authorities generally recommend shifting to heat pumps. Heat pumps are also being installed in newly constructed buildings. Several of the installed heat pumps use HFC/HFO blends. Students at the Faroese Vocational School receive information about HFOs as part of their education.[292]

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288. Swedish Competition Authority et al (2016)
289. Swedish Competition Authority et al (2016)
290. Nielsen et al (2022)
291. Umhvørvisstovan (2023)
292. Vinnuháskúlin (2023)

Larger Industrial Fishing vessels mainly use ammonia as an on-ship refrigerant. Smaller fishing vessels use other refrigerants, HFCs or HFC blends. But there is an ongoing shift towards using ammonia and CO_2 on fishing vessels.[293]

Foaming agents

No use of HFOs was identified. Isolation foams are generally incinerated on the Faroe Islands.[294]

Aerosol propellants

No use of HFOs was identified. Spray cans are exported to Stena Recycling in Denmark.[295]

17.2.3 Existing systems for collection and end-of-life treatments of HFOs

Industrial and commercial clients can purchase gas cylinders for F-gas recovery. These are then transported to- or picked up by the waste company and forwarded to a collection point where the cylinders are labelled and provided with a pictogram and later exported for destruction.[296]

The system for shipping vessels is different. Shipping vessels purchase chemicals, including refrigerants, via global suppliers (e.g., Unitor or Drew Marine) that deliver to ports across the globe. They can then pick up the gas cylinders at a prespecified port and return them to a port as well,[297] and there exist different cylinder exchange programs using standardised cylinders. Typically, the fishing vessel's engineer handles and maintains the equipment on the fishing vessels instead of a refrigeration technician.[298]

The Faroe Islands have two different waste and recycling companies; both companies handle waste from private households as well as waste from institutions and companies:

- Interkommunali Renovatiónsfelagsskapurin L/F (IRF) is a Faroese inter-municipal waste and recycling company owned by 29 Faroese municipalities. Their activities include the collection of industrial waste in all the municipalities and the collection of hazardous waste.[299] The IRF handles the waste from appr. 11 000 households.
- The other company is Kommunala Brennistøðin (KB) and covers the capital of Tórshavn. The KB handles approximately the waste of 7 500 households.[300] KB also handles vehicle scrappage on the Faroe Islands and the prior environmental treatment of cars for scrapping. IRF have a collaboration with KB regarding vehicle scrapping.[301]

293.Umhvørvisstovan (2023)
294.IRF (2023)
295.IRF (2023)
296.IRF (2023)
297.Vinnuháskúlin (2023)
298.Vinnuháskúlin (2023)
299.Dansk Affaldsforening (n.d.a)
300Dansk Affaldsforening (n.d.b)
301.IRF (2023)

The IRF and KB are responsible for waste collection and treatment. Each company has facilities, including incinerators, landfills (for non-combustible waste) and reuse or recycling centres. Recycling infrastructure in The Faroe Islands is limited, and recyclables are exported[302] Two companies operate waste shipments and must report their waste transfers annually.

All F-gases are shipped to Denmark. There are no destruction or reclamation facilities for F-gases in the Faroe Islands. Used WEEE equipment is also shipped to Denmark for destruction by Stena Recycling; both KB and IRF export to Stena Recycling in Denmark. IRF does currently not receive any HFOs.[303]

Further guidelines and instructions from a governmental level concerning how to handle construction waste, the risks of improper handling of systems or appliances containing refrigerants when renovating, and how to handle hazardous substances that are being phased out are requested by practitioners. There is also a need for further action to implement circular economy ambitions better.[304]

Monitoring systems

There are no existing monitoring systems in place for HFOs, but all registered HFC importers are required annually to supply information to the EPA. The reporting form has an option to report on other F-gases than HFCs; here, both 1234yf and 1234ze have been reported.

17.3 Finland

17.3.1 Country regulations with relevance

Legal (obligations, requirements, or prohibitions, including (but not limited to) acts, laws, regulations, and administrative or executive orders)

The main legal requirements in Finland are the EU F-gas Regulation (517/2014) and the EU WEEE Directive (2012)/19/EU). Both have been implemented in national law.[305] Furthermore, the Finnish waste legislation follows the EU waste legislation.

The Finnish training and certification scheme goes beyond the EU F-gas Regulation since all garages need to be certified, and the scheme covers all mobile equipment and activities such as recovery, installation, and repair.[306] A government decree from 2016 outlays required qualifications for handling vehicle equipment containing fluorinated greenhouse gases. The act describes the requirements for the operator and individuals working with the installation, maintenance, reparation, refilling, decommission and recycling of refrigerants. They are defined according to the

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302.Papineschi et at (2019)
303.IRF (2023)
304.IRF (2023)
305.Ymparisto (2023)
306.Birchby et al (2022)

definition of fluorinated greenhouse gases in the EU F-gas Regulation (517/2014), and HFOs are therefore not included. HFOs are not listed in the annex specifying different refrigerants. However, any blends containing fluorinated greenhouse gases are subject to the requirements. The requirements differ depending on whether the equipment contains less or at least 3 kg or more refrigerant. All require a certain level of education.[307]

The Finnish Environment Institute Syke is responsible for the market surveillance of refrigerants and equipment containing refrigerants.[308] A data collection system also collects data on F-gas quantities used in bulk and equipment. Syke is responsible for collecting annual data on F-gases for Finland's GHG emission inventory and also collects data on HFOs. According to the Environmental Protection Act (517/2014) 165§, companies must report requested data on fluorinated greenhouse gases to Syke.[309] HFOs are reported in the GHG inventory as additional information and not included in the national total.[310]

The Finnish Chemicals Agency Tukes is the responsible authority supervising that the refrigeration branch complies with the qualification requirements. There are currently (2023) no qualification requirements for handling HFOs, so the following description for required qualifications concerns HFCs.[311]

There are no refrigerant storage reporting requirements to the emergency services by the Chemical Safety Act unless the refrigerants are highly flammable. Tukes lists HFO-1234yf to be such a substance, so if more than 1 ton of HFO-1234yf is stored in cylinders or contained in appliances, it needs to be reported to the authorities.[312]

Tukes

Companies and individuals that install equipment containing fluorinated greenhouse gases (F-gases) need to be approved and qualified by Tukes before starting their operations if they provide any of the following tasks:

- Connect or open refrigerant circuits of equipment containing F-gases.
- Recover F-gases or F-gas-based solvents from equipment.
- Carry out leak checks on the equipment.

All RACHP companies and individuals are publicly listed, making it possible to check for certified personnel, and the listings can be found on Tukes' website. The register also holds information on companies that service mobile air conditioning and the waste management companies that treat F-gases. Only companies registered by Tukes are allowed to buy refrigerants that contain F-gases and equipment containing them,[313] except the following actions do not require any qualifications

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307.Tukes (2016)
308.Ymparisto (2023); Syke (2023)
309.Miljöskyddslag (2014)
310.Syke (2023)
311. Ymparisto (2023); Syke (2023)
312. Tukes (n.d.a.)
313. Tukes (n.d.b)

regarding F-gases:

- For buying for resale
- To sell
- For collection, transport, and delivery.[314]

There are currently no qualification and approval requirements from Tukes relevant to handling HFOs[315]

Hazardous waste

The Finnish waste legislation is based on the EU Waste Framework Directive. F-gases are classified as hazardous in the Government decree on waste (179/2012) and must, therefore, be treated as hazardous waste. They are listed under 14 06 waste organic solvents, refrigerants, and foam/aerosol propellants with waste code number 14 06 01* Chlorofluorocarbons, HFCFC, HFC.[316]

Taxation

F-gases are recovered, reclaimed, and destroyed in Finland, but no official scheme supports the practice. There are no taxes on HFC or other refrigerants in Finland, nor are there any money-based take-back schemes.[317]

17.3.2 Use of HFO Substances in Finland

According to the latest data reported to the EU, the following number of Finnish companies reported activities in the field of F-gas refrigerants. This includes all types of F-gases and not just HFO; a company can report on more than one activity:[318]

Importers	5
Exporters	1
Equipment importers	15
Destruction Companies	2
Quota Authorisers	1

314. Ymparisto 2023
315. Syke (2023)
316. Ministry of the environment (2012)
317. Ministry of the environment (2012)
318. Ludig et al (2022)

Finland has both import and export of HFOs. The import consists of equipment containing HFO and HFO in bulk. HFOs are primarily imported in equipment, but there has been a significant increase in bulk import in recent years; most are expected to go to MAC applications.

Import of the following HFO substances has been identified in Finland: HFO-1234yf, HFO-1234ze(E), HFO-1336mzz(Z) and HFO-1233zd(E).[319]

The auto sector

HFO-1234yf has been the refrigerant in all new cars imported and registered in Finland since 2018. Only pure HFOs are used for this application. The first passenger vehicles in Finland equipped with HFO-1234yf were imported and registered in 2012. Light-duty vehicles equipped with HFO-1234yf were first reported in 2016, and in 2020 the share of light-duty vehicles constituted 39%. It has, however, still been possible to import used cars equipped with HFC-134a. Syke has estimated that of the used vehicles imported in 2020, 80% were equipped with HFC-134a, and 20% were equipped with HFO-1234yf, compared to 90% and 10% in 2018.[320] There is one car manufacturing plant in Finland that mainly exports its products. There is, therefore, also some export of R1234yf out of Finland in passenger cars.[321]

For transport refrigeration, The HFC/HFO blend R-452A was introduced to the market in 2015 and is now widely used in new transport refrigeration equipment.[322]

RACHP Sector

HFOs are used in all RAC equipment except domestic refrigeration. Both pure HFOs and HFC/HFO blends are used in applications. In commercial, industrial and transport refrigeration, practically only HFO/HFC blends are used. In stationary AC (incl. heat pumps), pure HFOs and blends are used, while in MAC, only pure HFOs are used.[323]

- **Larger refrigeration and air conditioning equipment:** In Finland's 5th Biennial Report under the UNFCCC from 2022, it is projected that the use of F-gas refrigerants in commercial refrigeration (food retail stores and professional kitchens) will be fully phased out and replaced by natural refrigerants such as CO_2 and hydrocarbons by 2035.[324] According to a spokesperson from the industry, CO_2 is mainstreamed in commercial refrigeration. Industrial refrigeration mainly uses ammonia, and propane and butane are used for smaller equipment.

319. Ymparisto (2023)
320. Statistics Finland & Ministry of the environment (2022)
321. Syke (2023)
322. Statistics Finland & Ministry of the environment (2022)
323. Syke (2023)
324. Statistics Finland & Ministry of the environment (2022)

- In Finland, HFOs are used in larger heat pumps and chillers (100 kWh) installed in commercial buildings and by industry.
- **Large heat pumps (0.1 MW- 20 MW):** It is estimated that until 2019, all installed heat pumps of this size contained R-134A. Since 2019, there has been data on the instalment of large heat pumps containing HFO-1234ze, but only a small percentage of annually installed large heat pumps contained HFO-1234ze in 2019 and 2020 (less than 10%). Several other refrigerants are also reported to be used for this type of heat pump, including ammonia and the HFC/HFO blends R-450A and R-513A.[325]

Foaming agents and aerosol propellants

In Finland, HFOs are known to be used as foaming agents and aerosol propellants. Imports of aerosol sprays containing HFO aerosol propellant have been identified and registered since at least 2018.[326]

17.3.3 Existing Systems for Collection and End-of-life Treatments of HFOs

F-gases are classified as hazardous waste in Finland. Hazardous waste may only be processed or utilised by a facility with an environmental permit. All F-gases should be delivered for recycling. Several waste handling companies are authorised to collect and transport waste with waste code 14 06 01*. The companies are listed below, some operate in the entire country, and some in specific regions:[327]

- Eco Scandic Oy
- EKA-Palvelut
- Kaeser Kompressorit Oy
- Kuljetusliike Harry From Oy
- Lahti Minikonepalvelu Oy
- Liedon kunta, Kisälli
- Mantilan Kuljetus Oy
- MEK-Trans Oy Ab
- Kuljetusliike Nykänen Oy
- Salon
- Salon Hyötykäytto Oy
- Stena Recycling Oy
- Kuljetusliike J. Pääaho Oy
- Transkivimäki Oy
- Mj Salmela Oy
- Veikko Lehti Oy[328]

325.Statistics Finland & Ministry of the environment (2022)
326.Syke (2023)
327.Avfallshanteringskollen (n.d.)
328.Syke (2023)

Recovery

According to a spokesperson from the industry, even though HFOs are not covered by the current legislation, HFOs are handled in the same way as HFCs. HFOs are, therefore, often also included in reporting required for fluorinated greenhouse gases. While the recovery practice started slowly, it is now working well, and several recovered refrigerants are being reclaimed.[329]

Foam-blowing agents in foam products are generally not considered recyclable, so they are incinerated after recovery.

- **Maintenance and decommissioning of MAC:** In 2012, Tukes published a guide on handling R1234yf in MAC systems. They refer to the safety sheets from Honeywell and DuPont, describe R1234yf as highly flammable, and state it may cause frostbite and cause suffocation if not handled correctly. People are required to wear personal protective equipment gear, including protective eyewear and heat-insulating protective gloves. Furthermore, HFC refrigerants, for instance, R134a, must not be added to MAC systems that work with R1234yf, and R1234yf may not be added to AC systems meant for R134a. It is also required to purchase new maintenance equipment to handle R1234yf. Service- and test equipment for HFC refrigerants must not be used for R1234yf.[330]
- **Collection of WEEE:** Finland has Extended Producer Responsibility (EPR) for Waste from Electrical and Electronic Equipment (WEEE), meaning that importers and producers are responsible for waste management after decommissioning and pay a fee for the equipment. Numerous producer organisations administrate and are responsible for collecting, transporting, managing, and recycling WEEE on behalf of their members.[331]

End-of-life Treatment Options

Permits for destruction and reclamation go through the local municipalities.[332]

- **Destruction:** Fortum is the only company that destroys refrigerants in Finland. They incinerate refrigerants and are required to report the amounts to Syke. Fortum does not export refrigerants for destruction elsewhere.[333]
- **Recycling/ reclamation:** Two companies in Finland have an environmental permit for refrigerant recycling: Eco Scandic Oy and Darment. Eco Scandic Oy receives refrigerants from both Sweden and Finland. They are currently testing a new business model that is partly based on providing reclamation as a service, meaning that the recovering entity buys back the reclaimed refrigerant at a fixed lower price lower than the market price. But they also

329.SKLL (2023)
330.Tukes (2012)
331. Centre for Economic Development, Transport and the Environment (n.d)
332.Syke (2023)
333.Syke (2023)

sell reclaimed refrigerants to third parties that do not recover or collect refrigerants. Reclaimed refrigerants are generally cheaper than virgin.[334] They received a total of 67 tons of F-gas for reclamation in 2022. Of these, less than 2% were HFOs (1.34 tonnes), mainly composed of HFO-1234yf and HFO-1234ze. This is considered to be partly due to the relative novelty of HFOs in HVAC-R equipment since the average lifetime for these appliances is approximately at least 5-7 years. Eco Scandic Oy has a waste fee in Sweden and Finland of at least 4,5€/kg, as stipulated on their website. However, waste fees can range from 18€/kg, depending on the service provider. Eco Scandic has agreements with several wholesalers, providing reclamation of their recovered F-gases and then selling them back to the wholesaler. According to Eco Scandic Oy, the take-back models vary sporadically in the different sectors. Eco Scandic Oy typically creates a specific take-back model in collaboration with the specific stakeholder. Eco Scandic Oy reclaims HFC/HFO blends and pure HFCs and HFOs. Eco Scandic Oy sends unreclaimable F-gases are sent to Fortum for destruction. The approach varies slightly when it is an A2L-classified refrigerant rather than a non-flammable refrigerant, Eco Scandic Oy processes both types.[335]

- **Export of Waste:** No waste export of HFO substances was identified.

17.3.4 Other Findings

- Natural refrigerants are widely used for several applications, but adequate natural alternatives are not available for certain applications. Flammability is especially an issue. Some companies in Finland are working on research and development on natural refrigerant applications.[336]
- The industry is generally waiting for the upcoming legislation, both the forthcoming revised F-gas Regulation and what a potential ban on PFAS can entail, waiting to see the best way to proceed.[337]
- There is a need for more qualified personnel to install equipment because of increased demand, while there is a decreasing interest in education. There was a university education programme, but it has been closed. It is expected that there will soon be a lack of engineers with system design expertise. However, another university has opened a new research field on heat pumps.[338]
- There is a general concern for TFA in Finland, but no studies have been conducted.

334. Eco Scandic (2023)
335. Eco Scandic (2023)
336. Syke (2023)
337. SKLL (2023)
338. SKLL (2023)

17.4 Iceland

17.4.1 Country regulations with relevance

Legal (obligations, requirements, or prohibitions, including (but not limited to) acts, laws, regulations, and administrative or executive orders)

Iceland has signed the Montreal Protocol and accepted the Kigali Amendment.[339] Iceland is not part of the EU but is part of the internal European market via the EEA agreement.

Icelandic F-gas Regulation

The current Icelandic F-gas Regulation is from 2019; HFOs are currently not covered by the regulation since fluorinated greenhouse gases in the Icelandic regulation are defined as:

Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride and other greenhouse gases that contain fluorine and ***are listed in Annex I to Regulation (EU) no. 517/2014*** *or mixtures containing any of these substances.* (Article 3, point 2)

This definition excludes HFOs since HFOs only are listed in Annex II of the EU F gas regulation.

The regulation: 1066/2019: Reglugerð um flúoraðar gróðurhúsalofttegundir[340] has repealed earlier legislation with the same focus area, including[341]

- Regulation No 230/1998 prohibited importing, producing, and selling HFCs for uses other than refrigeration systems, air conditioning and drugs (MDIs).
- Regulation No 834/2010 repealed 230/1998 and became a regulation specifically targeting F-gases (instead of all gases contributing to the greenhouse effect). This regulation did, to a large extent, implement regulation (EC) No 842/2006 as dictated by the EEA agreement. This regulation also prohibited the production, import and sale of HFCs or products containing HFCs, except for HFCs used in refrigerants, air conditioning equipment and MDIs.
- Regulation 1279/2018 amended 834/2010 by implementing import quotas according to the Kigali Amendment.

The current Icelandic Regulation 1066/2019 combined 843/2010 and 1279/2018 into the Icelandic legislative system and does largely adopt the rules articulated in Regulation (EU) No. 517/2014 on fluorinated greenhouse gases.[342] The main difference is regarding the import quota.[343] Iceland has its own quota system in place, as they are not included in the EU Commission's quota system.

339. Ozone Secretariat (n.d.)
340. Reglugerð nr. 1066/2019
341. Keller et al (2020)
342. Regulation 517/2014/EU
343. Umhverfis Stofnun, n.d.

The Icelandic Regulation 1066/2019 states that 89% of the total allowed import quota each year is allocated to companies already on the market in the years leading up to the allocation. These actors will get a license with quotas corresponding to their average market share from the earlier period. The remaining 11% is allocated to actors who have applied for an import license. These actors will then be allocated a share of the 11%. As the EU regulation stipulates, Icelandic Regulation 1066/2019 Appendix I stipulates a step-by-step phasedown on imports of all hydrofluorocarbons to Iceland.[344] This means that currently (2023), only 35% of the original quantity (from the mean of the baseline years 2011-2013) can be imported to Iceland. In other words, the percentage of the baseline is currently set 10%-points lower in Icelandic legislation than what the EU regulation 517/2014 mandates.[345] Likewise, the Icelandic regulation stipulates a percentage of baseline lower than the EU regulation in 2030. This outlines the overall framework for how to phase down HFCs (and certain other f-gases), which will influence how HFOs are continuedly treated in the future.

WEE regulation, no. 1061/2018

Besides Regulation 1066/2019, which is central to the general rule of F-gases in Iceland, Regulation 1061/2018 on Waste Electrical and Electronic Equipment[346] (WEEE) is relevant for the end-of-life treatment of F-gases. In short, this is an adoption of EU Directive 2012/19 on WEEE.[347] Regarding F-gases, two appendixes to Regulation 1061/2018 are relevant: Appendix I(b) and II 188, also represented in the EU Regulation.[348]

Appendix I in Icelandic regulation 1061/2018 clearly defines the equipment relevant for the current compounds of interest – "heat exchangers". This is also the case for the EU 2012/19 regulation, but the Icelandic list is less comprehensive.

Appendix II of Regulation 2012/19 specifies how the WEEE should be handled. By point 1i, chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, and hydrocarbons must be removed from the electric and electronic equipment. These must be recycled or disposed of by the relevant law on waste. It must again be highlighted that HFOs are not currently explicitly addressed. Appendix II further stipulates that any ODS or gas with a GWP higher than 15 must be properly separated from the equipment and treated correctly in accordance with the regulation on F-gases. This includes gases contained in foam and cooling circuits. However, no pure HFOs have a GWP above 15; this is, therefore, only relevant for HFOs that are part of a blend.

344.Reglugerð nr. 1066/2019
345.Regulation 517/2014/EU
346.Reglugerð nr. 1061/2018
347.Directive (EU) 2012/19
348.Directive (EU) 2012/19

The MAC directive, no. 822/2004

EU MAC Directive 2006/40/EC prohibits F-gases with a GWP higher than 150 from filling in mobile air-conditioning equipment.[349] This has been implemented into Icelandic regulation 822/2004 through amendments introduced after 2006.[350]

Potential future developments

Iceland is awaiting the upcoming revision of the EU F-gas legislation. This will likely decide any future updates of the Icelandic F-gas legislation.[351] There is generally a shift towards using natural refrigerants rather than towards HFOs; the transition to natural refrigerants is also officially supported, for instance through joint Nordic initiatives such as "Nordic Criteria of Green Public Procurement",[352] a report published by the Nordic Council of Ministers that provides resources and guidance for the public administration to avoid the purchase or to find alternatives to appliances containing f-gases with a high GWP.

17.4.2 Fiscal (Subsidies, Taxes or Charges)

Icelandic Recycling fund

In Iceland, The Icelandic Recycling Fund aims to secure (economical) means for handling waste in Iceland[353] by leaning on the principle of "polluter pays". This is mandated through Law no. 162/2002 on processing fee.[354] Part of this legislation and taxation are directed at refrigerants, as described in Article 8, point 9. Appendix XV further extrapolates which specific refrigerants are taxed in which amount (even though every refrigerant on the list is currently taxed the same amount). HFOs are implied in this taxation under "3824.9006: Other refrigerants" in Appendix XV.

The tax is collected as an expedition fee through import and is currently priced at 2,5 ISK/kg for every kind of refrigerant. The money is collected for The Icelandic Recycling Fund to pay for the waste handling this fund is responsible for. 0.5% is going to an administration fee to the Treasury. Before January 1st, 2003, it cost 98 ISK/kg in import duty for all refrigerants.[355] In other words, the tax has been lowered considerably. Some argue that this tax (regarding F-gases) costs more to upkeep administratively than it is worthwhile because few claim the fund to the degree it was planned for. The tax was lowered because of a significant operating profit for refrigerants accumulated; each year, a couple of hundred tons of F-gases were imported, but only a few tons were returned for waste disposal.[356]

349.Directive (EC) 2006/40
350.Reglugerð nr. 822/2004
351. Umhverfis stofnun (2023)
352.Helgadóttir et al (2022)
353.Úrvinnslusjóður (n.d.).
354.Lög nr. 162/2002
355.Brynjarsson & Hilmarsson (2020)
356.Brynjarsson & Hilmarsson (2020)

Not all types of appliances are part of the Icelandic Recycling Fund's jurisdiction. WEEE, refrigerants, foam, vehicles and fire extinguishing equipment are all part of their jurisdiction.[357]

Law on Environmental and Natural Resource Taxes, no. 129/2009

The newest, significant Icelandic regulation (with taxation as the primary instrument) is adopted through Law no. 135: the Act of Amendment of various laws regarding the budget for 2020.[358] This creates a new chapter in the Law on Environmental and Natural Resource Taxes, no. 129/2009[359] - chapter III with articles 13–16. This is the legislature measure with the highest economically significant incitement for reducing the import of high GWP F-gases into Iceland. The amount of import duties to be paid is considerably more significant than the expedition fee for the Icelandic Recycling Fund. According to this legislation, the import duty to be paid for F-gases is between 30 ISK/kg–10.000 ISK/kg. The higher the GWP of the F-gas, the higher the tax is, up to a maximum of 10.000 pr. Kg, like it is in, e.g., Denmark.[360] Article 13 provides a table for specific F-gases and their respective tax price and (UK) customs numbers. The list in the legislative document contains several commonly used HFCs, PFCs and blends. Article 13, §3 stipulates that:

> "
>
> *In the case of imports of fluorinated greenhouse gases other than those specified in paragraph 2. must pay tax based on the following criteria:*
>
> *1. For fluorinated greenhouse gases not specified in the 2nd paragraph. must pay tax in the amount of ISK 10,000/kg.*
>
> *2. For mixtures not specified in paragraph 2. the amount of tax shall be calculated based on the proportions of the materials that make up the mixture.*
>
> *3. For other mixtures not specified in paragraph 2. and the provisions of item 2 cannot be applied. a tax in the amount of ISK 10,000/kg must be paid.*
>
> (Law no. 129/2009 [machine translated], 2009)

357.Iceland Recycling Fund (2023)
358.Lög nr. 135/2019
359.Lög nr. 129/2009
360.Helgadóttir et al (2022)

If the imported fluorinated GHGs are not listed in Article 13, the tax will be 10,000 ISK/kg; if it is a blend, the price will be determined based on the different components in the blend. Since HFOs are not classified as fluorinated greenhouse gases, there is no taxation on HFOs, and for any blends containing HFOs, that proportion does not count when calculating the price.

It is expected that import taxation rather than the quota system is responsible for the decrease in imports since imports are way below the allowed quotas. The import tax has received a mixed reception from the industry; some argue that HFCs should be even more expensive so that natural refrigerants would gain an economic advantage.[361]

17.4.3 Monitoring

There are no requirements to monitor HFOs; therefore, there is no official monitoring of HFOs in Iceland. Some information can be collected through the following:

- The National Inventory Report (published by The Environment Agency of Iceland).
- The Montreal Protocol and related amendments (Kigali amendment).
- UNFCCC (e.g., Climate Action Plans).
- EU f-gas working groups and EFTA.

Relevant stakeholders/actors with information on HFOs (and F-gases in general):

- The Icelandic Recycling Fund
- Terra Efnaeyding F-gas waste handling).
- Umhverfis stofnun (The Environment Agency of Iceland)

17.4.4 Use of HFO Substances in Iceland

Very small amounts of pure HFOs are imported into Iceland; according to data from customs, it is only a few batches of a couple of kilos.[362] HFOs are primarily imported in blends. The following blends containing HFOs have been identified in the import data since 2016:

- **R-448A** 20% HFO-1234yf + 7% HFO-1234ze(E)
- **R-449A** 25.3% HFO-1234yf
- **R-452A** 30% HFO-1234yf
- **R-454C** 78.5% HFO-1234yf

361. Umhverfis stofnun (2023)
362. Umhverfis stofnun (2023)

- **R-455A** 75.5% HFO-1234yf
- **R-513A** 56% HFO-1234yf
- **R-515B** 91.1% HFO-1234ze(E)

The imported amounts of the different blends in kilograms can be seen in table 7, the amounts; the data from 2022 have not yet been confirmed.

Table 7

	R-448A	R-449A	R-452A	R-454C	R-455A	R-513A	R-515B
2016		110					
2017		110					
2018		825	110				
2019		3661	250				
2020	358	6161	1178				
2021		6298	440	20		193	120
2022		5555	286		30	22	

The general trend in choosing refrigerants is natural ones rather than newer synthetic ones, such as HFOs.[363]

The Auto sector

In connection with collecting data and information for the 2022 National inventory report, data obtained from the largest car importers in Iceland showed that all new vehicles they imported during 2019 used R-1234yf in their AC system. Since 2016 there has been a rapid increase in the proportion of passenger cars containing R-1234yf instead of R-134a. All vehicles imported from Europe are estimated to contain R-1234yf, and most cars imported into Iceland come from Europe. According to the Transport Authority, of all newly registered vehicles, only 3% were imported from outside Europe; individuals imported all these. Most of these cars were imported from North America, where R-134a still are in use.[364] It is estimated that most pure HFOs imported into Iceland are to maintain MAC in passenger cars.[365]

363.Umhverfis stofnun (2023)
364.Keller et al. (EAI), 2022
365.Umhverfis stofnun (2023)

RACHP

It is estimated that the amount of pure HFOs used in this sector is small, the food industry uses the HFC/HFO blend R449, but the amounts are small. There has been a significant shift in the fishing industry within the last 5–6 years. Several large refrigeration systems used in the fishing industry have been changed, and many new ones use ammonia or CO_2. Many fishing vessels use ammonia as well.[366] However, in smaller fishing vessels, there are currently no natural refrigerant systems that are technically adequate, so there is a shift potential from HFCs to HFOs for this type of application.[367]

Few heat pumps are used in Iceland, but it is a growing market.[368]

Foaming agents, Fire Protection and Aerosols

Identifying any use of HFO substances for these applications has not been possible.[369]

17.4.5 Existing Systems for Collection and End-of-life Treatments of HFOs

The Icelandic municipalities are responsible for F-gases while they are in use. The environment agency of Iceland (Umhverfis stofnun) is responsible for tracking the import and export of F-gases and enforcing legislation on waste treatment. There is no recycling, reclamation, or destruction of F-gases in Iceland. There is one incineration plant in Iceland, but it does not handle F-gases. Some companies and contractors working with refrigerants do basic recycling that allows immediate reuse.[370] Properly handled refrigerants are returned to authorised facilities in Iceland, Terra Efnaeyðing, for further deposition, and the Icelandic Recycling Fund repays a fee to companies after reporting how much is sent to recycling/destruction.[371] Only qualified personnel are allowed to handle refrigerants, and they need to be qualified according to § 7 in regulation 1066/2019 on fluorinated greenhouse gases. Again, HFOs are not covered by this legislation. Being a refrigerant technician in Iceland is not an isolated job description but is usually part of another job description, e.g., mechanic or electrician; the refrigeration industry would like this to change and make it an independent education.[372] It has not been possible to determine the recovery rates of HFOs; it is generally estimated that some amounts of refrigerants are lost during waste management, in addition to what is lost during the use phase.[373]

366. Iceland Recycling fund (2023)
367. Brynjarsson & Hilmarsson (2020)
368. Iceland Recycling fund (2023)
369. Umhverfis stofnun (2023)
370. Terra Efnaeyðing (2023)
371. Poulsen et al (2022)
372. Umhverfis stofnun (2023)
373. Iceland Recycling fund (2023)

Terra Efnaeyðing

Terra Efnaeyðing is the only waste company that handles F-gases at their facility located in Hafnarfjörður.[374]

The f-gases are recovered and collected by servicing companies and handed over to a specialised company dealing with waste, such as Terra Efnaeyðing. Terra also collects from their customers, mainly companies and industry; they also gather from the municipal collection points. Terra has a local department in the North that collects before shipping to their facility in Hafnarfjörður.[375] All Collected F-gases are exported, and most are sent to Fortum in Denmark. There are documentation requirements for exporting refrigerants and fire extinguisher gas, and they require a permit.

The Auto sector

In the 2022 inventory report, the recovery of refrigerants from passenger cars was estimated to be 0.[376] However, this is illegal, and now car scrappers have begun to install the chambers necessary to recover refrigerants from the MAC systems during dismantling.[377] Terra does not receive any refrigerants from this sector.[378] This indicates no recovery or that recovered refrigerants are recycled locally.

RACHP

Refrigerants in large stationary equipment are filled onto gas cylinders when stationary equipment is decommissioned or emptied. Refrigerants in smaller equipment are recovered through vacuum chambers when the equipment is shredded, and then the refrigerant is shipped to Denmark. Almost all WEEE equipment is sent to Stena Recycling in Denmark or Sweden.

Foaming Agents and Aerosol Propellants

Foam-blowing agents from foams are likely not to be recovered; the foam will likely end up in landfills or be incinerated without any recovery of the foam-blowing agent.[379] The Icelandic Recycling Fund covers foams, so a processing fee must be paid. The responsibility for collecting the foam at decommissioning, e.g., when a building is dismantled, befalls those responsible for dismantling.[380]

17.4.6 Strengths and Weaknesses

- One significant barrier is that cylinders are not returned to importers when the refrigerant+ container is exported out of Iceland after decommissioning, meaning that the investment in the cylinder is lost when handed in at collection points.

374. Brynjarsson & Hilmarsson (2020)
375. Terra Efnaeyðing (2023)
376. Keller et al (2022)
377. Umhverfis stofnun (2023b)
378. Terra Efnaeyðing (2023)
379. Umhverfis stofnun (2023a)
380. Iceland Recycling Fund (2023)

- There are currently very few collection points, and the distance to collection points is often identified as a barrier to handing in refrigerants; more locally located collection points and take-back centres will make it easier to return refrigerants for proper end-of-life treatment.
- Equipment for proper decommissioning is expensive, and the cost for a small operator can be significant.
- There is a need for education in alternative refrigerants.
- According to the Icelandic Environment Agency, adequate control and certification have been lacking for many years[25]. It is recommended that more resources are put into the general enforcement of end-of-life F-gas Regulation and treatment.

17.5 Norway

17.5.1 Country regulations with relevance

Legal (obligations, requirements, or prohibitions, including (but not limited to) acts, laws, regulations, and administrative or executive orders)

Norway is a party to the Montreal Protocol and has ratified the Kigali amendment, which went into force in 2019.[381] Norway is not part of the EU, but Norway is a member of the European Economic Area (EEA). Norway adopted the EU F-gas Regulation, no 517/2014, in 2018, before that, the predominant F-gas Regulation in Norway was the EU F-gas Regulation no 842/2006, which was implemented into Norwegian legislation in 2010.[382] Norway does not participate in the EU import regime for HFCs since it is not considered to be EEA-relevant.[383] The EU WEEE directive is also implemented into Norwegian legislation, as is the EU MAC directive (Directive 2006/40/EC).[384] The Norwegian Environment Agency is responsible for enforcing the regulations on F-gases, except for the MAC directive that the Norwegian Public Roads Administration administers.

In accordance with the F-gas Regulation, you need a certification to work with F-gases. Isovator is the authorised certification body in Norway. They certify both companies and personnel. Isovator is also responsible for certifying operators working with vehicle AC.[385] Furthermore, Norway has implemented national regulations relevant to F-gases through the Norwegian Pollution Control Act[386] and the Norwegian regulation on handling certain fluorinated greenhouse gases. Norway aims to be carbon neutral by 2030.[387] According to Emissions Database for Global Atmospheric Research, EDGAR, the CO_2 emissions from Norway were 37,45 Mtonnes in 1990 and 42,33 Mtonnes in 2021.[388]

381. UNEP Ozone Secretariat (n.d)
382. EEA Suppl. No 7 (2020)
383. Norwegian Ministry of Climate and Environment (2020-2021)
384. EEA Suppl. No 69 (2009) & EEA Suppl. No 18 (2018)
385. Returgass (n.d.a)
386. Forurensningsloven (1981)
387. Norwegian Ministry of Climate and Environment (2020-2021)
388. Crippa et al (2022)

Due to the low global warming potential of HFO1234yf and HFO1234ze and according to EU F-gas Regulation (517/2014) Annex II, the gases are not subject to be reported unless the quantum is larger than 1000 tonnes of CO_2 equivalent.[389] [390] Because of that, it has only been possible to quantify the imported bulks of HFO. In addition to bulk imports, HFOs are imported as part of blends or equipment, e.g., MAC systems. Obtaining an overview of imported HFO to the auto sector has not been possible.

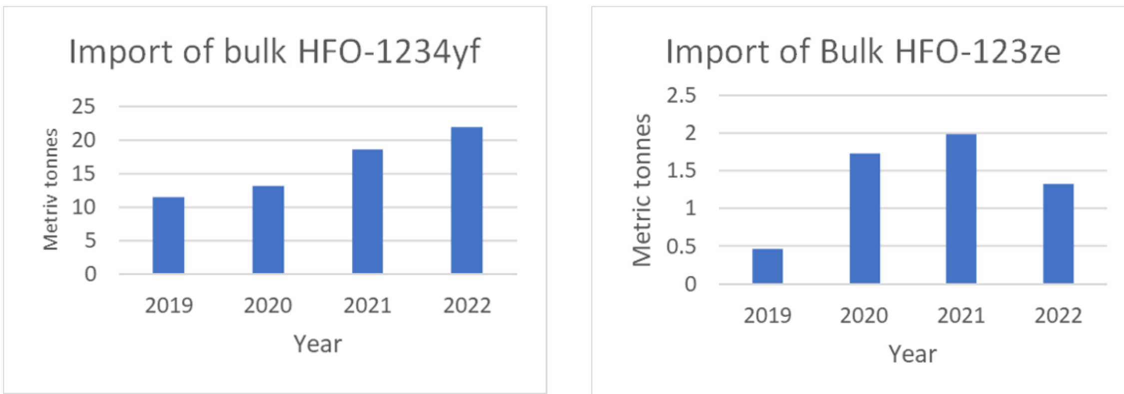

Figure 8 Norway's bulk import of the two HFO substances, HFO-1234yf and HFO-1234ze, in Metric tonnes (Miljødirektoratet, 2023)

The primary objectives of the HFC regulation in Norway are to:

- Minimise the environmental impact of HFCs, including their contribution to global warming.
- Encourage the transition to alternative refrigerants with lower global warming potential (GWP) and improved energy efficiency.
- Promote the adoption of sustainable technologies and practices in refrigeration, air conditioning, and foam insulation sectors.
- Ensure proper handling, management, and disposal of HFCs to prevent their release into the atmosphere.
- Establish quotas that gradually decrease over time to effectively control HFC production and import. Norwegian companies importing HFCs in bulk must obtain licenses from the Norwegian Environment Agency. These licenses come with reporting obligations, necessitating companies to provide detailed annual reports on their HFC imports.

389.Miljødirektoratet (2023)
390.Regulation (EU) 517/2014

Norway actively participates in international efforts to address the global impact of HFCs. The country aligns its regulatory framework with international agreements such as the Montreal Protocol and the Kigali Amendment, which aim to phase down the production and use of HFCs globally. Through these collaborations, Norway contributes to a unified approach to mitigate the environmental impacts of HFCs on a global scale.

The regulation of HFCs in Norway is critical to the country's commitment to environmental sustainability and combating climate change. Through comprehensive legislation, quotas, reporting obligations, financial incentives, and proper handling practices, Norway aims to minimise the use and impact of HFC. Due to the low CO_2 potential, HFO is not regulated by the Norwegian authorities.

Taxes and refund

In 2003 Norway implemented an excise duty on the production and import of HFCs, and in 2004 a refund scheme for the destruction of F-gases was introduced. The tax is refunded to the party delivering the waste to an approved collection point, ensuring proper end-of-life treatment. The tax is NOK 0.952 per kg (2023) multiplied by the GWP potential of the refrigerant.[391] The excise duty covers the import and production of the following:

- Gas in bulk and import of all types of combination of HFC and PFC, both as known mixtures and in combination with other substances.
- Products containing gas, for example, smaller air conditioning and refrigeration units, vehicle air conditioning units, expanding foam insulation and spray cans with HFC propellants.'[392]

The Norwegian Government plans to increase the taxes on HFCs as part of Norway's 2021–2030 Climate Action Plan.[393] The objective is to create stronger financial incentives for individuals and businesses to opt for climate-friendly alternatives and ensure recovery and proper end-of-life treatment of refrigerants. The tax level is currently set at approximately NOK 590 per ton CO_2eq and is expected to be raised to around NOK 2,000 per ton CO_2eq by 2030; this will also result in a corresponding increase in tax refunds to the operator when handing in the refrigerant at a collection point. The Government considers this substantial increase essential to ensure Norway fulfils their commitment under the agreement with the EU to reduce emissions by 40% by 2030.[394] There are currently no taxes on HFOs, and if there were according to the existing method, the tax would be very low due to the low GWP of HFOs.

391. Returgass (n.d.b)
392. The Norwegian tax administration (n.d.)
393. Norwegian Ministry of Climate and Environment (2021)
394. Norwegian Ministry of Climate and Environment (2021)

Penalties

The Norwegian Environment Agency is responsible for enforcing the regulations related to HFCs. Non-compliance with the regulatory requirements can lead to penalties, fines, or other legal consequences. The agency conducts inspections, monitors reported data and collaborates with stakeholders to ensure compliance and proper implementation of the regulations.[395]

17.5.2 Use of HFO Substances in Norway

The largest consumers of HFOs are the automotive market, large-scale heat pumps for district heating e.g. in Oslo, refrigerant blends in smaller heat pumps, dryers, commercial and industrial refrigeration and blowing agents in various types of foams. Each industry has a different way of handling the end-of-life treatment of HFOs.

The Auto sector

Most newly registered cars in Norway use HFO-1234yf in their MAC system.[396] According to the MAC directive, mobile air conditioning (MAC) systems, including those in cars, are defined in terms of maximum allowable leakage rates. The specific leakage rates permitted depend on the type of the system. The systems must not contain gases with a GWP higher than 150. The leakage rate must not exceed 40 grams of refrigerant per year for one evaporator system and 60 grams per year for systems with dual evaporator systems.[397]

Therefore, air conditioning systems in the car industry are known to have a continuous emission rate to the atmosphere. Service in the auto sector uses refrigerant recovery and filling machines to recover HFO from the air conditioning systems. The filling machines usually measure the refrigerant retracted from the systems, reuse the HFO and add the amount that the A/C system has lost during the service interval. Because of refrigerants' reuse and the systems' leaks, only a small amount is recovered from the auto sector and send for destruction. Refrigerants from scraped cars are often sold for reuse. The individual A/C systems in cars typically contain 400–1000 grams of HFO.[398] Due to the large number of A/C systems, the Auto sector is a major source of emissions.[399] Some car brands and models sold in the European market use the natural refrigerant R744 (carbon dioxide). R744 operates at a much higher pressure and partly with lower energy efficiency. Therefore, the transition to R744 is expected to have long prospects, and HFO1234yf will be the primary refrigerant in the auto sector. Collection and recycling sites for end-of-life treatment of vehicles need permits from the Norwegian County governors.[400]

395.Miljødirektoratet (2023)
396.Miljødirektoratet (2023)
397.EC (n.d.c)
398.Returgass (2023) & Christonik ApS (2023)
399.NRF (2020)
400Asphjell et al (2023)

RACHP

In Norway, there is a growing trend to use natural refrigerants and HFO refrigerants in cooling systems and heat pumps. This shift is driven by the desire to reduce the environmental impact of traditional synthetic refrigerants and move towards more sustainable and climate-friendly alternatives.

Natural refrigerants, such as carbon dioxide (CO2), ammonia (NH3), and hydrocarbons (HCs) like propane (R290) and isobutane (R600a), have gained significant attention due to their excellent environmental properties. These substances have no ozone depletion potential (ODP) and no or very low global warming potentials (GWPs), making them an attractive alternative to fluorinated refrigerants. This includes HFOs, which have negative effects related to PFAS and TFA. Natural refrigerants are increasingly utilised in various cooling systems and heat pumps in Norway. Carbon dioxide is commonly used in commercial refrigeration systems due to its low environmental impact. It has become popular for supermarkets, cold storage facilities, and industrial refrigeration. Ammonia is another natural refrigerant widely used in larger industrial cooling and heat pump systems. Its excellent thermodynamic properties make it highly efficient for large-scale refrigeration and air conditioning applications. In addition to systems with natural refrigerants, cooling systems and heat pumps using HFOs are also being introduced in Norway. HFOs, such as HFO-1234yf and HFO-1234ze, have significantly lower GWPs than traditional hydrofluorocarbons (HFCs). Although HFOs are synthetic refrigerants, their lower GWPs contribute to reducing greenhouse gas emissions and addressing climate change concerns. Commercial and industrial systems typically contain large amounts of refrigerant. Due to the safety aspects, such as toxicity and flammability when working with ammonia, there is a tendency to use HFO refrigerants in newer plants. Some newer heat pumps for district heating use HFO1234ze. There are no restrictions on how large fillings the plants can have, and it is not unusual that the filling is several tonnes. [401]

Using natural refrigerants and HFOs in cooling systems and heat pumps aligns with Norway's sustainability and environmental protection commitment. In collaboration with industry stakeholders, the Norwegian government promotes adopting these alternatives to synthetic refrigerants with higher GWPs. In Norway, there are some apprehensions of using HFO due to PFAS concerns.

Proper training and certification of technicians and professionals are essential to ensure the safe and efficient use of natural refrigerants and HFOs. Regulations and standards govern these substances' installation, maintenance, and disposal, protecting human health and the environment. It has not been possible to determine whether HFO is exempt from the education requirements.

401.VKE (2023)

Stena Recycling and Revac handle WEEE in Norway. Stena Recycling exports its waste to Stena Recycling's facility in Sweden, where the refrigerants and the foam-blowing agents are recovered and destroyed. Revac has up to 2022 delivered recovered refrigerants to the Norwegian Foundation for Refrigerant Recovery (SRG), while foam-blowing agents are sent to Germany for destruction.[402] From 2023 Revac also sends recovered refrigerants to Germany for destruction.[403]

Foam-blowing Agents

HFOs are introduced as foam-blowing agents in some applications across the EU and Norway. It has not been possible to gather any data on quantities.[404]

17.5.3 Existing Systems for Collection and End-of-life Treatments of HFOs

Stiftelsen Returgass (SRG) is a nationwide company[405] that collects and handles used refrigerants in Norway. SRG has developed a system with collection points (Grønt Returpunkt (GRP)) where service tanks are handed in after recovery for proper disposal. After collection, the refrigerant is analysed to determine quantity and content, and the party who delivers the refrigerant will receive a tax refund based on the analysis. Before payment, the waste handling costs are subtracted from the amount. The size of the payment is based on the refrigerant's GWP-value. If the refrigerant type is not subject to a tax, which is the case for HFOs, then there is no payment and the associated costs for proper end-of-life treatment are charged to the customer. See the flowchart below.

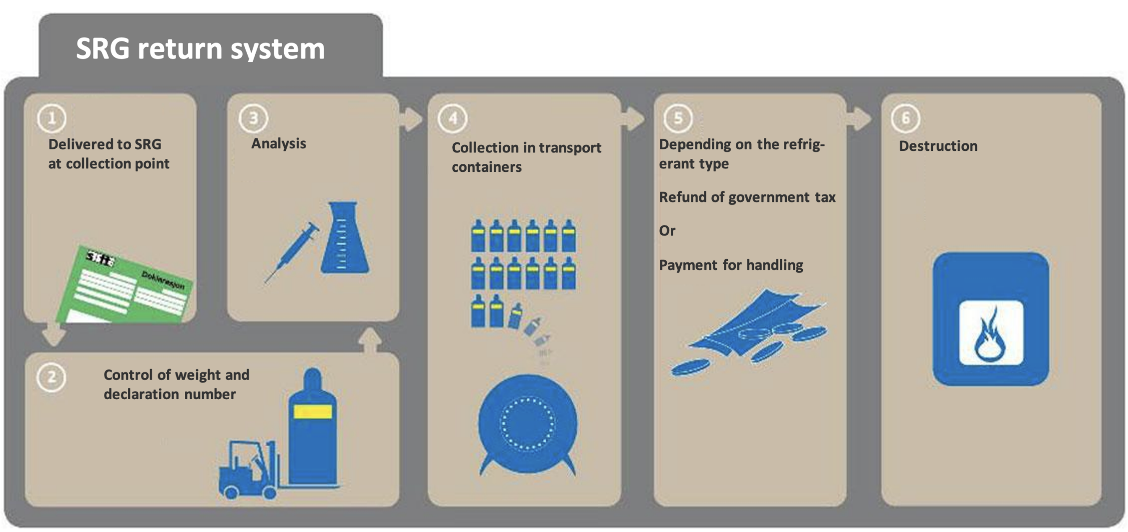

Figure 9 The handling of used refrigerants at Isovator/ReturGass (Returgass (n.d.a)

402.Asphjell et al (2023)
403.Miljødirektoratet (2023)
404.Asphjell et al (2023)
405.Returgass (n.d.d)

SRG sometimes refer to flammable HFCs, and they have made a separate procedure description for handling them safely. SRG is monitoring the collection and quantities of refrigerants, and as shown in the bar chart, it is evident that HFO so far plays a minor role in the return system. This is likely because HFOs do not yet constitute a significant market share and while stationary products like heat pump and refrigeration plants haven't been decommissioned. Another factor is that submitting HFO to the return system is associated with costs for the customer.[406] SRG has so far registered three types of HFOs:

- HFO-1234yf, HFO1234ze and HFO-1233zd[407]

The sources are not known precisely, but it is presumably refrigerant mixtures from heat pumps, dryers, the auto sector, and refrigeration systems.

None of the refrigerants delivered to SRG are recycled or reclaimed. All collected refrigerants are sent to France for destruction.[408]

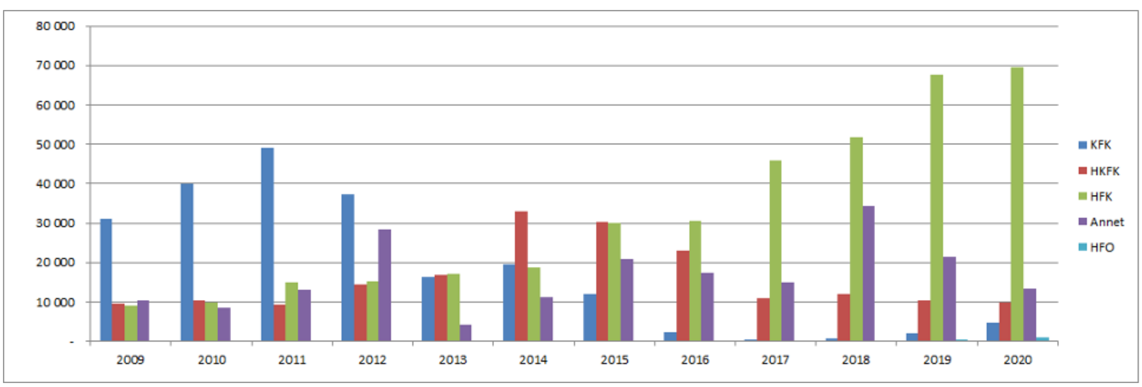

Figure 10 In 2020, SRG received the following amounts of refrigerant gases, halon, SF6, oil and glycol measured in kg (Returgass (n.d.c)

Pricing of refrigerants

The price of refrigerants at the wholesaler depends on the F-gas tax and the product's price. It is possible to get a tax refund when the refrigerants are sent to processing at SRG. There are no taxes on HFOs and, therefore, no refund. Figure 11 (below) shows a graphical price example of HFO and HFC. The tax level is currently set at approximately NOK 590 per ton CO_2eq and is expected to be raised to around NOK 2,000 per ton CO_2eq by 2030.[409]

406.Returgass, & Miljødirektoratet (2023)
407.Returgass (2023)
408Asphjell et al (2023)
409.Norwegian Ministry of Climate and Environment (n.d.)

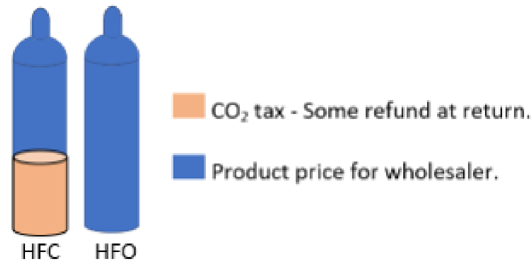

Figure 11

Current end-of-life treatment options

The collecting system for HFC gasses in Norway is very efficient and has a high collection rate. HFO gasses are mainly unregulated due to their low GWP and the lack of environmental taxation, and they have not been completely implemented in the regulatory system yet.

17.6 Sweden

17.6.1 Country regulations with relevance

Legal (obligations, requirements, or prohibitions, including (but not limited to) acts, laws, regulations, and administrative or executive orders)

Overall, the primary legislation regarding F-gases in Sweden is Regulation (EU) No. 517/2014[410] and Regulation (SE) No 2016:1128.[411] The WEEE directive is also of relevance.[412]Naturvårdsverket is the competent authority on F-gases in Sweden. Sweden had national legislation in place for controlling refrigerants before joining the European Union. The first Refrigerants Order was issued in 1988, controlling CFCs, HCFCs and later HFCs were added. Refrigeration Foundation in consultation with the Swedish Environmental Protection Agency developed Swedish Refrigeration Code of Best Practice (Svenska Kylnorm) and supplementary Fact Sheets were linked to the Refrigerants Order. The Code of Best practice is updated and still effective,[413]

The Swedish regulation 2016:1128 is a complement to the EU regulation 517/2014 and is stricter primarily because it includes mobile equipment in the certificates and leakage control requirements and generally has a few additional reporting requirements. Furthermore, the Swedish legislation (2016:1128, § 12) mandates that those who supply F-gases must take these back and provide containers for this purpose, free of charge.[414] There is no refund scheme for taking back F-gases in Sweden.[415]

410. Regulation (EU) No. 517/2014
411. SFS 2016:1128
412. Directive (EU) 2012/19
413. Naturvårdsverket (2022)
414. SFS 2016:1128
415. Poulsen (2022)

Like the legislation in the other Nordic countries, Swedish legislation mandates that equipment and appliances (mobile and stationary) containing HFCs are journaled. According to paragraph 15 in the Swedish legislation an operator must if:

> ”
>
> *...there are at least 14 tonnes of carbon dioxide equivalents in a stationary facility, in a facility on a ship or in mobile equipment that is subject to leakage control according to § 11 or according to Article 3.3 second paragraph and 4.1-4.3 of the EU regulation on f-gases.*

report at the latest 31 March every year to the supervisory authority the following:

"The report must contain

1. *the results of the leak checks carried out during the calendar year,*
2. *information on equipment scrapped during the calendar year,*
3. *the information specified in Article 6.1 of the regulation on f-gases,*
4. *the operator's organisation number, postal address, and billing address,*
5. *address and property designation of the property where the equipment is located, if the equipment is stationary,*
6. *a list of the equipment, and*
7. *in the case of equipment on a ship, the ship's name, signal letters or the like."*

This means that on top of the details required by EU regulation 517/2014 (like quantities and type of F-gas), information on a facility containing the equipment, with organisation, location, etc., must also be journaled if the collective amount contained in equipment equals or is greater than 14 tons CO_2e. Furthermore, the undertaker is required to submit these records to the supervisory authority in Sweden. In case less than 14 tons of CO2e are present in the facility but more than 5 tons of CO_2e in a single piece of equipment, only the details stipulated in the EU regulation 517/2014 must be journaled and kept for at least five years.[416]

Regulation 2016:1128 uses the same F-gas definition as in (EU) no. 517/2014. HFOs are, therefore, not covered by the regulation. However, the regulation states that if a system that contains 14 tons CO_2eq or more is to be converted to another refrigerant than HFC, it needs to be reported to the authorities.[417]

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416. Svenska kyl- og varmepumpforeningen (2023)
417. SFS 2016:1128

Penalties

The penalties with relevance for end-of-life treatment of F-gases especially concern documentation and correct recycling/reclamation/destruction. The actors with supervisory responsibility can, in general, impose environmental penalty fees:

"Whoever has supervisory responsibility according to the Environmental Supervision Ordinance (2011:13) can impose environmental penalty fees. There is currently no supervisory responsibility for f-gases in mobile equipment other than motor vehicles, aircraft or trains."

More specifically, the penalties identified of relevance are listed below according to different regulations and fees, etc:[418]

Table 8

Delayed report to the EU registers in case of production, import, **export** or **destruction**, or late review by an auditor.	EU 517/2014 Art 19.1-19.5, 19.6	Environmental sanction fee MSA regulation ch. 9 § 7
Recycling has not been carried out by certified or trained personnel.	EU 517/2014 article 8.1 or 8.3	Indictment MB 29 ch. 3 § item 7
MSA Ordinance = Ordinance (2012:259) on Environmental Sanction Fees, the Ordinance has been updated for the new f-gas Ordinances 2017 under Ordinances 2016:1130 and 2016:1305 **MB** = Environmental Code, regulation (1998:808)		

The Requirements under Article 8 in (EU) no 517/2014 do not extend to Annex II gases.

Fiscal Subsidies

A fee for F-gases (and other chemicals listed in Swedish legislation) must be paid annually:
§ 5 of Swedish Ordinance 1998:940 stipulates that:

418. Naturvårdsverket (n.d.)

"The chemical fee must be paid annually for the calendar year and must consist of

1. *a registration fee of SEK 600 for each product or organism subject to notification, but no more than SEK 70,000 per year, and*
2. *a quantity fee of SEK 12 per ton of products and organisms subject to notification, but no more than SEK 70,000 per year."*

However, HFOs are not listed in SFS 2008:245 and are not subject to a fee.

Soft regulatory instruments (recommendations, technical standards, voluntary bottom-up initiatives (self-regulation), legislation-induced co-regulatory actions)

No special soft regulation from authorities in Sweden has been identified. There are some examples of industry initiatives trying to create circular business models for the use of F-gases. The Finnish reclamation company Eco Scandic work on promoting the recycling and reclamation of F-gases throughout EU.[419] Eco Scandic is based in Finland and collects F-gases (from designated collection points) for end-of-life treatment from Sweden and Finland. Eco Scandic sees great potential in reclaiming and using reclaimed F-gases to close the loop around the EU F-gas market. Another initiative is creating an alternative (turnkey) business model for F-gases. Instead of users/operators of F-gases sending them to reclamation or destruction during their end-of-life and then buying back either reclaimed or virgin F-gases, they suggest a leasing model. You can lease F-gases from Eco Scandic, which then maintains them and makes sure the operators have what F-gas they need during their contract. This model is still new and in its early phases.

Monitoring

In accordance with Article 19, any undertaking that has destroyed at least 1 metric tonne of F-gases is obliged to report to the Commission by 31 March each year, Sweden does not have a national database for collecting these data. According to the NIR modelling, all F-gases are assumed destroyed, which is not what happens in practice, as at least some F-gases are being reclaimed and reused.[420] Currently, the limit for monitoring is at 5 kg CO_2e pr. System. The Swedish Refrigeration and Heat Pump Association have concretely recommended setting the value at 3 kg CO_2e instead to ensure proper monitoring of HFOs.[421] As stated earlier, HFOs often slip through the regulation today, mainly because the CO_2e of HFOs is so low.

419. Eco Scandic (2023)
420. Eco Scandic (2023)
421. Svenska Kyl- & varmepumpforeningen (2023)

17.6.2 Use of HFO Substances in Sweden

According to the latest data reported to the EU, the following number of Swedish companies reported activities in the field of F-gas refrigerants. This includes all types of F-gases and not just HFO; a company can report on more than one activity:[422]

Importers	12
Exporters	3
Equipment importers	26
Destruction companies	1
Quota authorisers	3

Import and Export of HFOs

HFO-1234yf, HFO-1234ze and HFO-1336mzz have CN code 2903 51 00. The following quantities were reported imported and exported in 2022:[423]

Table 9

CN code	Import of goods, adjusted for non-response, Metric ton	export of goods, adjusted for non-response, Metric ton
290351	454	38

The Auto sector

Around 2012, HFO-1234yf was introduced into Sweden's MAC sector in passenger cars due to the EU MAC directive.[424] An agreement was made between Svenska miljöemissions data (SMED) and Kemikalieinspektionen (KemI) to have the MAC sector journal and report on the stock of HFO-1234yf. Data shows that HFOs have quickly risen since their introduction in Sweden.[425] In 2015, 26,8 tonnes of the HFO

422.Ludig et al (2022)
423.SCB (2023)
424.Gustafsson (2011)
425.Naturvårdsverket (2023)

1234yf was imported; in 2016, it was 82,3 tonnes.[426] The majority of HFO-1234yf imported is expected to be used for MAC. A recent paper reveals that in 2018, there was estimated to be 145,4 tonnes of (total) HFO in the MAC sector, and in 2019 this was at 314,5 tonnes.[427]

An informant reports that most HFOs received for end-of-life treatment are HFO-1234yf from the MAC sector, whereas the rest are of insignificant quantities.[428]

RACHP

Most larger refrigeration systems in Sweden already use natural refrigerants, which requires entirely different systems than those using F-gases.[429] HFO-1234ze appears to be the HFO refrigerant of choice for these types of applications, if used.[430]

- **Heat pumps:** According to the Swedish Refrigeration & Heat Pump Association (kyl & värmepumpforeningen), the demand for heat pumps is rapidly increasing in Sweden. It is uncertain how many new heat pumps use HFOs or HFO/HFC blends. The Swedish Refrigeration & Heat Pump Association sent out a questionnaire asking their members about how they perceive the increase in demand, as well as what type of refrigerant is used in the heat pumps they install, but HFOs were not a possible response option in the questionnaire.[431]

Foaming Agents, Fire Protection and Aerosols

According to the latest Swedish national inventory report, an increasing proportion of XPS foams use other blowing agents than HFCs, such as CO_2 and HFOs. However, there is not any available data on the proportions.[432] HFO-1234ze is known to be a suitable aerosol propellant, but it is probably only in insignificant quantities so far. An expert estimate that HFOs will be used much more in the future.[433]

17.6.3 Existing Systems for Collection and End-of-life Treatments of HFOs

According to a spokesperson for practitioners, HFCs and HFOs are treated the same in practice, even though there are no legal requirements for handling and monitoring HFOs. The technical barriers for HFOs are generally the same as for HFC's existing barriers.[434] Furthermore, HFOs, as listed in EU regulation 517/2014 Annex II, have not yet been discussed in detail in the Swedish Environmental Agency.[435] Therefore, it is still uncertain how exactly HFOs should optimally be treated for end-of-life treatment.

426.KEMI (n.d.)
427.Poulsen (2022)
428.EcoScandic Oy (2023)
429.Svenska kyl- & värmepumpforeningen (2023)
430.Eco Scandic (2023)
431. Svenska kyl- & värmepumpforeningen (2022)
432.Naturvårdsverket (2022)
433.Eco Scandic (2023)
434.Svenska Kyl- og Varmepumpforeningen & Eco Scandic (2023)
435.Naturvårdsverket (2023)

From what can be derived from accessible reports (mainly NIR), it points to the fact that take-back systems for F-gases in Sweden generally are very effective. Combined with the fact that HFOs are largely treated the same way as HFCs, this means good opportunities exist for fitting HFOs into the existing end-of-life treatment system. However, more research into the actual practice is recommended as more and new types of HFOs are being recovered for end-of-life treatment, and following new regulations is being mandated.

Recycling

The four main recyclers operating in Sweden, according to The Swedish Refrigeration and Heat Pump Association, are:

- Ahlsell
- Kylma
- Dahl
- Eco Scandic

Several professional collectors buy recovered refrigerants, recycle them, and sell them back to operating companies. Many practitioners working with F-gases reuse and recycle the F-gases themselves.[436]

Foam blowing agents

Regarding F-gases in foam, insulation foam is processed at certain waste treatment facilities, and the F-gas is collected.[437] Reclaiming these F-gases from the foam is not economically viable, therefore almost all of this is sent to destruction.[438] According to EcoScandic at end-of-life, the foam is shredded in a vacuum-sealed chamber, where the gases are collected (at a WEEE plant) and typically sent to incineratio). Only one plant in the Nordics is actively restructuring its current operations to recover and sort HFCs (which will be able to recover HFOs as well).

WEEE

In practice, "WEEE" facilities receive equipment containing F-gases at end-of-life. Here, the F-gases are removed from the equipment and collected for further treatment, often for destruction.[439] The F-gases that need simple recycling are typically treated in a facility in Sweden, while those that need more complex recycling are exported (typically to Finland). [440]Again, the current procedure for end-of-life treatment of HFOs is the same as for HFCs so that the facilities can handle HFOs in the same way that HFCs are handled.[441]

436.Svenska kyl- og varmepumpforeningen (2023)
437.Poulsen (2022)
438.Eco Scandic (2023)
439.Poulsen (2022)
440.Svenska kyl- og varmepumpforeningen & Eco Scandic (2023)
441. Svenska kyl- og varmepumpforeningen, Eco Scandic & Fortum Waste (202

Reclamation

Eco Scandic is one of the few end-of-life treatment companies that are doing full reclamation throughout all the Nordic countries. They received a total of 67 tons of F-gas for reclamation in 2022. Of these, less than 2% were HFOs (1.34 tonnes), mainly composed of HFO-1234yf and HFO-1234ze. This is partly due to the relative novelty of HFOs in HVAC-R equipment since the average lifetime for these appliances is approximately at least 5-7 years. Eco Scandic has a waste fee in Sweden and Finland of at least 4,5€/kg, as stipulated on their website. However, waste fees can range from 18€/kg, depending on the service provider. Eco Scandic has agreements with several wholesalers, providing reclamation of their recovered F-gases and then selling them back to the wholesaler. According to Eco Scandic Oy, the take-back models vary sporadically in the different sectors. Eco Scandic typically create a specific take-back model in collaboration with the specific stakeholder. Eco Scandic reclaims HFC/HFO blends and pure HFCs and HFOs. Eco Scandic sends unreclaimable F-gases are sent to Fortum for destruction. The approach varies slightly when it is an A2L-classified refrigerant rather than a non-flammable refrigerant, Eco Scandic Oy processes both types.[442]

Destruction

Fortum is the only destruction company in Sweden that destroys recovered refrigerants; Fortum also imports recovered refrigerants from other countries for destruction in Sweden. Fortum also receives F-gases from waste companies that collect waste from different industries, from recyclers of products containing F-gases, from companies that service equipment containing refrigerants and from retailers of refrigerants. For destruction (as opposed to recycling/reclaiming), the technical barrier mostly consists of capacity limitations.[443] Regulations are limiting the levels of how much fluoride that can be emitted during the incineration process. During the "washing/scrubbing" process, which is part of the destruction of F-gases, restrictions exist on how much fluoride you can run through the system and emit. There is a limit to how fast you can decrease the fluoride levels in the gas; therefore, this is the immediate and general barrier and limiting factor for the destruction of F-gases. Fortum incinerates multiple fluorinated substances, not just F-gases. There are no technical differences in the way of handling HFCs and HFOs. Whereas there is a difference between HFCs/HFOs and other fluorinated substances such as SF6 and PFC. Fortum also receives F-gases used as aerosol propellants.[444]

Fortum registers whom they receive F-gases from, allowing them to get information on sector uses etc.

442.Eco Scandic (2023)
443.Fortum Waste (2023)
444.Fortum Waste (2023)

17.7 Germany

17.7.1 Country regulations with relevance

The legislation with relevance for F-gases in Germany is based on EU legislation. The current German Chemicals Climate Protection Ordinance (Chemikalien-Klimaschutzverordnung) is based on the EU F-gas Regulation and uses the same definitions.

The EU Waste Framework Directive (2008/98/EC) is enacted in Germany by the Waste Management Act (Kreislaufwirtschaftsgesetz - KrWG). The German federal states (Bundesländer) are responsible for any waste management scheme. All waste treatment bodies must be authorised and be permitted to treat any waste with the respective waste code number.[445]

HFOs are considered hazardous waste, and the waste code number must be identified with the regional waste management company; one possible code is 140601* CFC, HCFC, HFC.

The End-of-life Vehicle Act transposes Directive 2000/53/EC into national law, and the German Electrical and Electronic Equipment Act (ElektroG) transposes the EU WEEE Directive into national law. The regulation has been amended twice, in 2015 (ElektroG2) and in 2022, when the German Electrical and Electronic Equipment Act (ElektroG3) and the Ordinance on Requirements for the Treatment of Waste Electrical and Electronic Equipment came into force. Part of the scope is to expand the network for return points to increase the collection rate of WEEE.[446] Manufacturers are required to register with the foundation 'Stiftung Elektro-Altgeräte Register' (stiftung ear) as well as make a monetary contribution to WEEE collection, treatment, and recycling.[447]

Soft regulatory instruments

There are some funding programmes for new RACHP equipment where HFCs and HFOs are excluded or funded less to promote the use of natural refrigerants.

Associations provide standards for how to deal with refrigerants after decommissioning, for instance, in schooling materials for the climate service in vehicles or guidelines of service employers' liability insurance associations. The German Environment Agency (UBA) strongly supports using non-halogenated substances (natural refrigerants) whenever it is technically feasible and has done so since the 1990s.[448]

445.Umweltbundesamt (2023)
446.Ecosistant (2022)
447.Ear (n.d.a)
448.Umweltbundesamt (2023)

17.7.2 Use of HFO Substances in Germany

According to the latest data reported to the EU, the following number of German companies reported activities in the field of F-gas refrigerants. This includes all types of F-gases and not just HFO; a company can report on more than one activity:[449]

Producers	3
Importers	50
Exporters	18
Equipment importers	114
Destruction companies	7
Feedstock users	1
Quota authorisers	11

Data from 2021 on the amounts of HFO-1234yf and HFO-1234ze and the type of application where they are deployed:

Table 10 Amount of HFO-1234yf and HFO-1234ze in metric tons and the types of applications where it is in use, From Umwelt Bundesamt (2023)

	Amount (part of blends included) in applications	2021 (metric tons)
1233zd	2 F 1 f, Stationary Air-Conditioning	21.3
1234yf	2 F 1 a, Commercial Refrigeration	301.7
	2 F 1 d, Transport Refrigeration	58.0
	2 F 1 e, Mobile Air-Conditioning	9611,6
	2 F 1 f, Stationary Air-Conditioning	160.3
1234ze	2 F 1 a, Commercial Refrigeration	27.6
	2 F 1 f, Stationary Air-Conditioning	710.2

449.Ludig et al (2022)

The auto sector

HFO-1234yf is used in the MAC system in almost all new vehicles (cars).

The RACHP sector

In commercial refrigeration, pure HFO-1234ze is used in condensing units as well as several HFO blends in central systems (R-448A, R-449A), condensing units (R-449A, R-452A, R-454C, R-455A, R-513A) and plug-in appliances (R-454C, R-455A).

In vehicle refrigeration, there are current attempts to use pure HFOs in small refrigeration systems. Besides, some HFO blends are used increasingly, e.g., R-452A in all size classes of refrigerated vehicles and reefer containers and the blend R-513A only in reefer containers.

In larger industrial refrigeration and stationary air conditioning, numerous refrigerants are used. In centrifugal chillers, it is mainly HFO-1234ze(E) and, to a minor extent, R-1233zd(E). Other chiller types, such as chillers with reciprocating or screw compressors, use R-1234ze(E) and other refrigerants. The blends R-454B, R-513A, and R-515B are also in centrifugal and other chillers.

In domestic heat pumps, HFOs are not used pure, only in blends. The following blends are used for heat pumps: R-450A, R-448A, R-449A, R-452B, R-454B, R-454C, R-513A, and R-515B.

Foaming agents:

- Building and Construction: HFO-1234ze is used for XPS foam, and HFO-1336mzz(Z) for PUR foams.
- Foaming agents in products: Identifying any use of HFOs in this sector has not been possible.

Aerosol Propellants:

HFO-1234ze is used in aerosols. A blend of R-1234ze(E) and R-134a is used in rare cases, for instance, for electric cooling spray and filling of pressure cushions in heating and tank technology.[450]

17.7.3 Existing Systems for Collection and End-of-life Treatments of HFOs

Take-back facilities depend on the specific refrigerant and the type of systems, but it is often done via gas trades or waste management companies. Germany implemented a legally binding take-back scheme in 2009. Section 4 of the German Federal Chemicals Climate Protection Ordinance states that producers and distributors must take back HFC refrigerants after they have been recovered.[451] Distributors and producers can charge contractors a fee when they hand in HFC

450.Umwelt Bundesamt (2023)
451. Chemikalien-Klimaschutzverordnung (2008)

refrigerants, and this has been identified as a limiting factor for the scheme since it discourages some from delivering recovered refrigerants since it is associated with a cost.[452]

End-of-life Vehicles

In Germany, car producers have individual contracts with facilities handling collection and dismantling. Both car producers and importers must take back their own vehicle brand at an authorised facility designated by the car producer; the car owner is obliged to bring the car to the authorised, permitted facility and will be given the certificate of destruction after handing it in. Collection and dismantling facilities are organised in loose networks, but negotiations happen between the individual car producer or importer and the individual facility.[453] There are over a thousand authorised dismantling facilities and dozens of authorised shredding facilities in Germany to ensure the disposal of ELVs.[454]

WEEE

The German Electrical and Electronic Equipment Act enforces that anyone who places electrical or electronic equipment on the market is responsible for its recycling. Since 2005, Germany has had a producer-led government-regulated system.

The take-back concept differs depending on whether the equipment is business-to-consumer (b2c) or business-to-business (b2b). Since 2022, producers of b2b equipment are obligated to create a reasonable system for returning WEEE; this cannot be passed on to the customer. The customer can be imposed with the financial obligation of disposing of WEEE, but the producer has to set up the system and submit the take-back concept to EAR.[455] For b2c equipment, the public waste disposal authorities have set up collection sites where WEEE from private households can be delivered. When the containers at the collection sites are full, it is reported to the EAR that notifies the producer or authorised representative, who must pick up and replace the container with an empty one.[456] The producers are responsible for financing the provision and pick-up of containers.

Reclamation & Destruction

- Several destruction and reclamation facilities in Germany handle F-gases, including HFOs. However, there are currently no data on the amounts of HFOs recovered.
- There is no regular waste export of F-gases out of Germany.

Barriers

There is a shortage of pressure vessels that, combined with the many different

452.EIA (2016)
453.Monier et al (2014)
454.Zimmerman et al (2022)
455.Ear (n.d.b)
456.Ear (n.d.c)

types of refrigerants on the market, lead to small amounts and mixing of refrigerants, which makes recovery difficult.[457]

17.7.4 Monitoring systems

The use of HFOs must be reported as part of the Environmental Statistics Act (Umweltstatistikgesetz) to the Federal Statistical Office (Statistisches Bundesamt, destatis.de).[458]

17.7.5 Other

The uncertainty of the effects of breakdown products from F-gases that end up in the environment is of great concern, partly due to their persistence in the environment and their impact on the environment and human health. Germany has carried out a country-wide measurement programme to determine the quantities of TFA (trifluoroacetate) in precipitation, which is a breakdown product of HFCs and HFOs. TFA is a very mobile substance, and it ends up via precipitation in the water bodies. There are no currently known environmental conditions in which TFA degrades. In drinking water production, no practicable and economical method exists for its removal.[459] TFA is very stable (several decades) and will, therefore, accumulate over time.[460]

17.8 Switzerland

17.8.1 Country regulations with relevance

Switzerland has ratified the Montreal Protocol and all subsequent amendments. HFOs are not regulated in Switzerland only if they are contained in blends with other F-gases. F-gases are regulated under the Chemical Risk Reduction Ordinance (ORRChem).

- Annex 1.5 ORRChem includes regulation for the import, export, and general use of F-gases.
- Annex 2.3 covers the use of solvents.
- Annex 2.9 covers the use of foams.
- Annex 2.10 covers the use of refrigerants.
- Annex 2.11 covers the use of extinguishing agents.
- Annex 2.12 covers the use of aerosols.

457.Umweltbundesamt (2023)
458.Umweltbundesamt (2023)
459.Umweltbundesamt (2021)
460.Behringer et al (2021)

HCFOs, however, are regulated under Annex 1.4: Substances that deplete the ozone layer, and the abovementioned annexes since HCFOs are classified as ozone-depleting substances. F-gases are considered special waste under the Ordinance on Lists for the Transport of Waste (waste code 14 06 01) and must be disposed of accordingly.

It is stated in ORRCHEM that "*Any person who receives appliance or systems containing refrigerants for disposal must remove the refrigerants contained and dispose of them separately and appropriately*".

The manufacture, installation, maintenance or disposal of refrigeration, air conditioning or heat recovery appliances or systems requires a License. Licenses from EU and EFTA member states are considered equivalent to the Swiss one.[461]

The Basel Convention and OECD agreement regulates the export of waste. It is implemented into the Swiss Ordinance on the Movement of Waste. Switzerland only exports waste to other countries in Europe, mainly to Germany. Switzerland does not have a quota system like in the EU. Import permits are granted for all HFCs for applications with authorised use.[462]

Switzerland has not adopted the EU WEEE directive. Switzerland has adopted The Ordinance on the Return, Take-back and Disposal of Electrical and Electronic Equipment (ORDEE), which requires Producer responsibility for the take-back of electrical and electronic equipment. The Ordinance came into force in 1998.[463]

Soft regulatory instruments

- There is an officially communicated preference for natural refrigerants and general encouragement of the industry, partly due to possible future regulations on HFOs in Europe.
- Numerous funding opportunities exist in Switzerland (+200) for low GWP alternatives. However, there exist several challenges:
  - The funding application schemes are considered to be complicated.
  - Another barrier is that some outdated rules and regulations concerning flammability still exist that hinder new technical systems that deploy natural refrigerants.[464]

17.8.2 Use of HFO Substances in Switzerland

HFOs are used across all the below-mentioned sectors, and the shift to low GWP refrigerants, including HFOs, is considered important for reaching the Swiss climate target.[465]

461. ORRChem (2005)
462. BAFU (2023)
463. BAFU (n.d.1)
464. Schecho AG (2023)
465. Schecho AG (2023)

The auto sector

As in the EU, HFC-134a has not been allowed as a refrigerant in new vehicles' AC equipment since 2017. In new vehicles, HFO-1234yf is considered the state of the technology.[466]

RACHP sector

HFOs are specially used in larger RACHP types of equipment or systems. In Switzerland, it is not allowed to use HFCs in RACHP systems of more than 400 kW, and HFOs are primarily used instead.[467]

Domestic heat pumps mainly use HFC or HFC/HFO blends. The use of hydrocarbons in heat pumps is increasing.[468]

Foaming agents

HFOs are used as a replacement for HFCs as a foaming agent in building and construction foams and foam products.

Aerosol propellants

HFOs are in use as an aerosol propellant as a replacement for HFCs.

17.8.3 Existing Systems for Collection and End-of-life Treatments of HFOs

Recovery, collection and end-of-life treatment of refrigerants

Only private companies with an environmental permit can recycle and do reclamation. 9 waste treatment facilities are authorised to handle waste under code 14 06 01 or dispose of it. Some companies are also authorised to reclaim F-gases.[469]

Recovering and delivering F-gases back to the company for further treatment is obligatory. You pay a fee to cover recovery and recycling costs when buying equipment. Both private consumers and companies are required to pay. After handing in the recovered refrigerant, the contractor receives documentation for the delivery.[470]

WEEE

The Swiss authorities have approved three collective compliance Schemes for WEEE; the SENS scheme deals with disused electrical and electronic appliances. Manufacturers, retailers, importers and collection points must create a take-back system and take back appliances from their product range free of charge. Consumers must hand in their WEEE at the retailer, manufacturer, importer, collection point or specialised recycling facility and not discard it as household

466.BAFU (2023)
467.BAFU (2023)
468.BAFU (2023)
469.BAFU (n.d.2)
470.Schecho AG (2023)

waste. The scheme is financed by an advance recycling contribution (ARC). This financing scheme was introduced based on the ORDEE implemented in 1998, see section 1.1.1.[471]

End-of-life vehicles

The disposal of end-of-life vehicles in Switzerland is based on the polluter-pays principle. The Swiss Auto Recycling Foundation was founded in 1992 and put an advance disposal fee on new vehicles at importation. Waste disposal companies that accept end-of-life vehicles need a permit from their local canton.[472]

Data on waste elimination in Switzerland

Waste under the code 14 06 01 in the European Waste Catalogue includes CFCs, HCFCs, HFCs and HFOs and blends, so the numbers below are a total for category.[473] The quantity of pure HFOs is unknown.

Table 11 Waste statistics for waster under code 14 06 01*, data from BAFU, available at: https://www.bafu.admin.ch/bafu/en/home/topics/waste/state/data.html

	2020	2021
Export for recycling and reclamation (tonnes)	93	89
Export for incineration (tonnes)	12	0
Domestic Incineration (tonnes)	43	81
Domestic recycling (tonnes)	11	5
Import of waste (tonnes)	0	0

17.8.4 Monitoring systems

There are numerous reporting requirements in Switzerland, including:

- Import and Export of HFCs
- Commissioning and decommissioning of stationary equipment with more than 3 kg of refrigerant, no matter the kind of refrigerant.
- Keeping a maintenance log for equipment or systems containing more than 3 kg of refrigerant.[474]

471. Sens eRecycling (n.d)
472. BAFU (n.d.3)
473. BAFU (2023)
474. BAFU (Hrsg) (2022)

17.8.5 Other

- Switzerland is aware of the potential environmental risks of TFA, a degradation product of some HFOs. FOEN has commissioned an ongoing study investigating the contribution of different emission sources. The study findings shall help evaluate possible future regulation.[475]
- Some practitioners experience a lack of transparency and coherence between the different cantons (member states) in Switzerland. The different cantons can have different rules or interpret national regulations differently. This means that if you apply for an, e.g., plant building permit in one canton and get permission and then apply for the same in another region, you might not get permission there.[476]
- There is a decreasing interest in the education to become a refrigeration technician.[477]

475. BAFU (2023)
476. Schecho AG (2023)
477. Schecho AG (2023)

About this publication

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