Activating Circular Economy for Sustainable Cooling

Legislation and Practices for End-of-Life Management of Refrigerants and other F-gases in Norway and the EU

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About the report: This case study on *Legislation and Practices for End-of-Life Management of Refrigerants and other F-gases in Norway and the EU* is part of a series of publications on "Activating Circular Economy for Sustainable Cooling" through lifecycle refrigerant management in India under the INDEE+ project. The series offers a comprehensive analysis of refrigerant management practices in India and globally, including this case study of Norway's legislation and practices, proposals for effective implementation in India, and innovative business models.

Organisations: The **Norwegian Environment Agency (NEA)** is a government agency under the Ministry of Climate and Environment, Government of Norway. The NEA employs over 700 personnel across two offices stationed in Trondheim and Oslo and at the Norwegian Nature Inspectorate's (SNO) sixty local offices. NEA's primary tasks are to reduce greenhouse gas emissions, manage Norwegian nature, and prevent pollution.

Future Refrigeration India (INDEE+) is an umbrella project, focused at enhancing the use of natural refrigerants, and lifecycle management of refrigerant gases having ozone depletion and high global warming potential. Overall, this project aims to achieve the goals of the ratified Kigali Amendment of the Montreal Protocol. Under this project, CEEW and NEA have collaborated to support the lifecycle management of highly potent refrigerants and other gases in an environmentally sound manner in India.

The **Council on Energy, Environment and Water (CEEW)** is one of Asia's leading not-for-profit policy research institutions. The Council uses data, integrated analysis, and strategic outreach to explain – and change – the use, reuse, and misuse of resources. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. In 2021, CEEW once again featured extensively across ten categories in the *2020 Global Go To Think Tank Index Report*, including being ranked as South Asia's top think tank (15th globally) in our category for the eighth year in a row. The Council has also been consistently ranked among the world's top climate change think tanks. Follow us on Twitter @CEEWIndia for the latest updates.

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Preface

The Montreal-protocol on Substances that Deplete the Ozone Layer had substantial effects on the use of CFC and HCFC refrigerants and other ozone-depleting substances. The Kigali amendment to the protocol agreed upon in 2016 introduced similar constraints on the use of HFC refrigerants based on their contribution to climate change.

In 2019 Norway and India finalized a cooperation project on policy options for phasing down HFC refrigerants in India. It was agreed to follow-up this project by a new project focusing on end-of-life management of ozone-depleting substances, HFCs and other strong greenhouse gases.

At the same time there was another project between Norwegian University of Science and Technology (NTNU) and Indian educational and research institutions on the use of natural refrigerants, and it was decided to merge these two projects into the "Future Refrigeration India" or INDEE+ project.

This report is the Norwegian contribution to the work package on "Support recovery, recycling, reclamation and disposal of refrigerant gases in India" of the INDEE+ project, which is performed jointly between Council on Energy, Environment and Water (CEEW) and Norwegian Environment Agency (NEA). We have decided to widen the scope of gases and usages covered to include SF_6 and some usages outside of the refrigeration sector.

The report has been written by NEA, with input from external resources. We would especially like to thank Norwegian Foundation for Refrigerant Recovery (SRG)/Isovator, Revac AS, Stena Recycling, Norcem AS and Trédi Saint-Vulbas for their contributions.

Torgrim Asphjell

Norwegian Environment Agency

Oslo, 15th February 2023

From the launch of the phase I project on phasing down of HFCs in India.

Chapters

More information about the INDEE+ research project can be found at: https://www.ntnu.edu/indee/indee.

Executive Summary

This report is the Norwegian contribution to the work package on "Support recovery, recycling, reclamation and disposal of refrigerant gases in India" of the "Future Refrigeration India" or "INDEE+" project, which is performed jointly between Council on Energy, Environment and Water (CEEW) and Norwegian Environment Agency (NEA).

The main purpose is to give an overview on how waste refrigerants are handled in practice in Norway and describe the legal framework underpinning this infrastructure. Focus will be on recovery of gases from equipment taken out of service and the subsequent handling of this gas or other stockpiles of gas in terms of collection and destruction or reuse. We have decided to widen the scope of gases and usages covered to include SF_6 and some usages outside of the refrigeration sector.

The Montreal-protocol on Substances that Deplete the Ozone Layer had substantial effects on the use of CFC and HCFC refrigerants and other ozone-depleting substances. The Kigali amendment to the protocol agreed upon in 2016 introduced similar constraints on the use of HFC-refrigerants based on their contribution to climate change. However, these global agreements focus on restrictions on production and use, and consequently Norway has implemented additional legislation and measures on collection and destruction of waste refrigerants and other gases to avoid atmospheric release.

Norway has followed the usual Montreal-protocol path of phasing out CFCs, the transitional substances in the HCFC group and other ozone-depleting substances. We are now in a situation where the climate gases in the HFC group are gradually being replaced by natural refrigerants or synthetic refrigerants with lower contribution to global warming. However, there will for many years to come be large quantities of waste HFCs, and also considerable amounts of ozone-depleting substances, that need to be recovered and destructed.

In this report we will use the main gas categories Ozone-depleting substances (ODSes) and other fluorinated greenhouse gases (F-gases). The latter group includes HFCs and SF_6. Focus will be on the use as refrigerant in refrigeration- and air-conditioning equipment, including heat pumps.

Norway is not a member of the European Union but is connected to the union by the European Economic Area (EEA) Agreement. A consequence of this is that most EU legislation is also implemented in Norway. The EU regulations and directives on ODSes, F-gases, waste and industrial pollution are incorporated into Norwegian national regulation. In addition, Norway has implemented some domestic only regulation and measures.

Norway introduced the first regulations to limit the import and use of CFCs in 1979. Subsequent legislations were adopted to include the other ODSes. These had requirements that the used ODSs can be handed in for safe destruction free of charge. This resulted in the establishment of the Norwegian Foundation for Refrigerant Recovery (SRG). As of the year 2002, Norway implemented the EU regulations on ozone depleting substances, including the

Regulation No 2037/2000[1] in 2002 and the revised Regulation No 1005/2009[2] in 2013. This latter regulation introduced further restrictions on the use of all ozone depleting substances controlled under the Montreal Protocol to ensure full phase out of the substances according to the obligations under the Protocol.

The EU F-gas regulation[3] was adopted by the EU in 2006 and implemented in national Norwegian legislation in 2010. The intention behind the regulation is to limit the emissions of HFCs, PFCs and SF_6 through containment, recovery, and restrictions of use in products, equipment, and applications. The regulation is supplemented by implementing regulations on topics such as leakage checking, labelling, reporting and certification.

According to the F-gas regulation HFC refrigerants shall be properly recovered by certified personnel from all stationary refrigeration and air conditioning equipment and SF_6 shall be recovered from gas insulated switchgears (GIS). Recovery is also mandatory for most other gases and uses, with foam blowing agents being the most notable exception.

A revised EU F-gas regulation entered into force in the EU in 2015. This regulation introduced further measures to reduce emission, including a phase-down scheme for HFCs. Norway implemented this regulation in 2018, as well as its own phase-down scheme in accordance to its compliance obligations with the Montreal protocol.

While the F-gas regulation constitutes a strong legal basis for recovery of gas, Norway has also established a domestic incentive by a tax and refund scheme for HFCs and PFCs. All import of HFCs and PFCs in bulk and in products is taxed.

The tax also applies to production, but since Norway has no domestic production of HFCs and PFCs (or any other F-gas) it is in practice a tax on import. The level of the tax is according to the global warming potential (GWP) of the gas and is tied to the CO_2-tax for mineral oils and was 766 NOK (appr. 6000 INR) per GWP weighted tonnes in 2022. The tax is refunded to those who deliver HFCs or PFCs for destruction. There is no documentation requirement that the tax was paid. But there are requirements as regards documentation of the amount and composition of the gas destructed.

The requirements as regards treatment of the waste gases after recovery from products and equipment is found in the national waste regulation, which covers collection, recycling, destruction, export and other aspects as regards all types of waste. This is largely based on the EU Waste Framework directive[4] and implementing acts.

The waste regulation includes a separate chapter om hazardous waste. Waste CFCs, HCFCs and HFCs in bulk or in waste electric or electronic products (WEEE) are classified as hazardous waste and specific requirements for storage, transport and treatment apply. Personnel handling the waste shall have documentable adequate skills and undertakings shall

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[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32000R2037&from=EN

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1005&from=EN

[3] For an overview of EU legislation to control F-gases, see: https://ec.europa.eu/clima/eu-action/fluorinated-greenhouse-gases/eu-legislation-control-f-gases_en

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN

have a permit to handle hazardous waste and deliver the waste to an approved undertaking at least once a year.

A system for collection, recycling and other treatment of WEEE was established in Norway in 1999. This system is based on the Extended Producer Responsibility, which requires that all importers and producers of relevant products must be member of a Producer Responsibility Organization, which is responsible for establishing and operating of a system for collection and treatment of WEEE. Household appliances such as fridges, freezers and domestic air conditioners or heat pumps (domestic AC/HP), as well as smaller gas insulated switchgears (GIS) containing SF_6 can be handed in free of charge at collection facilities for subsequent environmentally sound treatment. The regulation specifies that CFCs, HCFCs, HFCs and other gases that are ozone-depleting or have a GWP of more than 15 shall be recovered at an early stage in the treatment process.

For collection of vehicles by end-of-life, a similar producer responsibility scheme has been established. The regulation requires that vehicles shall be delivered free of charge. As an extra incentive a compensation is being paid to those delivering the car, financed by governmental subsidies. In 2022 this amounted to 3000 NOK (appr. 24 000 INR) for a passenger car.

Enterprises that collect, treat, or destroy waste gases or other waste need an emission permit to operate. These permits, which come in addition to the specific legislation on F-gases and ODSes and the general regulations on waste, set specific requirements for operation and management of the plant. All undertakings with emission permits are audited regularly, evaluating all aspects of the permits as well as compliance to relevant regulations.

In addition to the environmental regulation, other legislation and policy, on safety and working environment in particular, is also important and will indirectly affect environmental performance as well.

In Norway there are primarily three companies involved in recovery and collection of gas on a large scale, commercial basis and each of them have a somewhat different approach:

- **Norwegian Foundation for Refrigerant Recovery (SRG)** collects ODSes and HFCs in bulk. This company was established in 1991 as part of the Norwegian implementation of the Montreal Protocol and has a nationwide network for collection and consolidation of waste- or surplus refrigerants, which is sent to France for final destruction. They are the sole commercial provider of refund for HFCs in bulk and are to a large degree financed by the governmental refund scheme. SRG was established before the refund scheme entered into force and they also have other activities which provide finance for their operation. SRG has a subsidiary, Isovator, that analyze the gas eligible for refunds or for other purposes. Isovator also issues mandatory F-gas certificates for personnel and companies and training attestations on behalf of the government.

- **Stena Recycling** is a company that treats all kinds of WEEE. Home appliances and small commercial appliances containing f-gases, such as refrigerators, freezers and domestic AC/HP, are sent to their facility in Sweden, where refrigerants and foam-blowing agents are recovered and destroyed on-site. On their Norwegian site, they have a vacuum chamber for complete recovery of SF_6 from medium voltage GIS. They also serve as a collection point for surplus SF_6 in cylinders.

- **Revac** is another company specializing in treatment of WEEE. They have a newly installed "Fridegeline" for the collection of refrigerants from freezers, fridges, domestic AC/HP and other home appliances (step 1) and foam blowing agents from insulation used in some of these appliances (an optional step 2). The recovered refrigerant is handled by SRG. Foam blowing agents are sent to a destruction facility in Germany.

In addition to the three companies mentioned above, vehicle- and metal recycling companies also perform related activities.

Much of the first line collection of products containing ODSes and F-gases is done by municipal waste companies, local retailers in the case of WEEE, car collection sites or businesses in the refrigeration and air conditioning (RAC) sector. Businesses in the RAC sector also collect gas recovered on-site in cylinders for delivery into the SRG system.

Norway has the technical capacity to destroy refrigerants by co-processing in cement kilns. However, for logistical reasons today all ODSes and F-gases collected in Norway are sent to other European countries for destruction or, possibly, reclamation.

Destruction is done thermally by incineration or by high temperature plasma arc technology. In these processes, the chemical compounds are destroyed by breaking them down to simpler molecules. The process must be carefully controlled to avoid new toxic compounds being formed during the process. CFCs and HCFCs contain chlorine that might contribute to the formation of extremely toxic dioxins and furans, and emissions of particulate matter and chlorine, fluorine and other compounds, are to be monitored regularly. Only ODS destruction technologies approved by the Montreal Protocol are used and the facilities are covered by the EU directive on the incineration of waste.

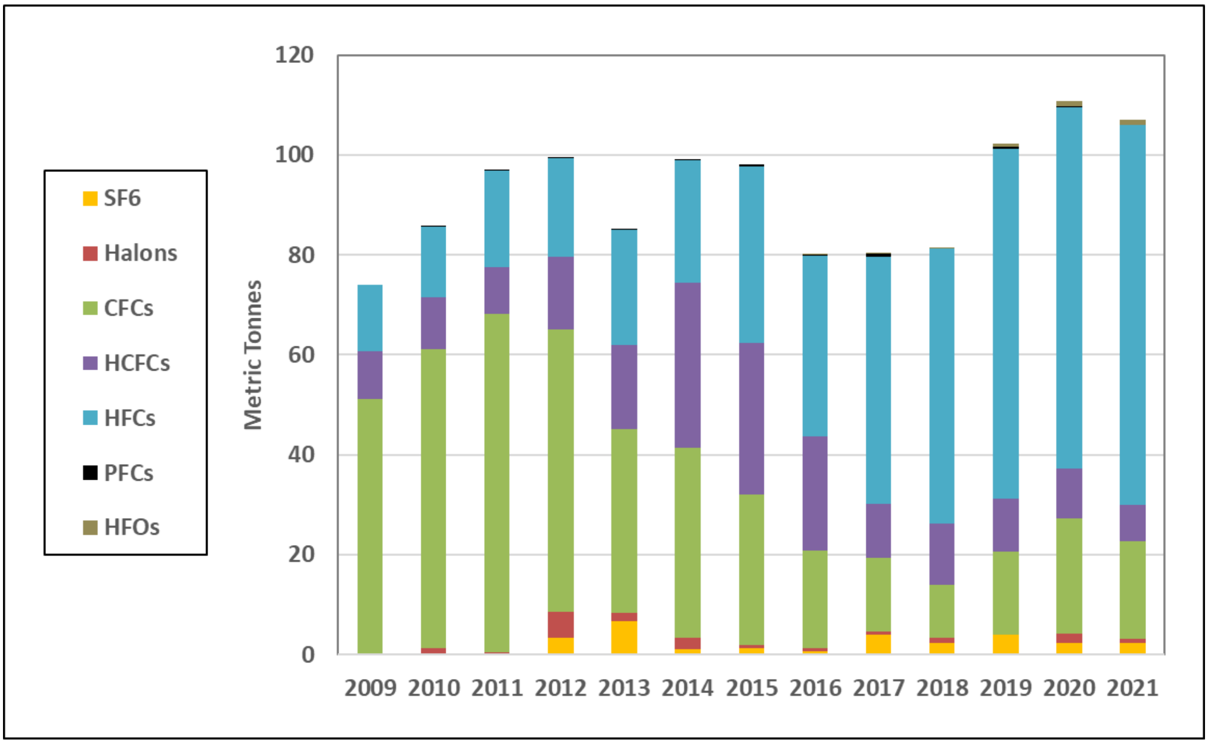
The gas collected by SRG (including the refrigerants from Revac) is sent to a hazardous waste treatment plant in France, while co-processing in cement kiln in Norway has been used previously. Refrigerants and foam blowing agents from Stena Recycling is destroyed on-site in Sweden.

Recovered SF_6 is sent to Sweden or Germany. Reclaimed halon fire extinguishing gas is exported for subsequent critical reuse according to the Montreal protocol and the EU regulation on ozone depleting substances. In addition to the established main lines for collection and destruction of gas described here, some surplus or waste gas might be handled independently by importers or other companies.

Legislation by itself is not enough to assure high recovery. The real-life recovery rates will depend upon factors such as:

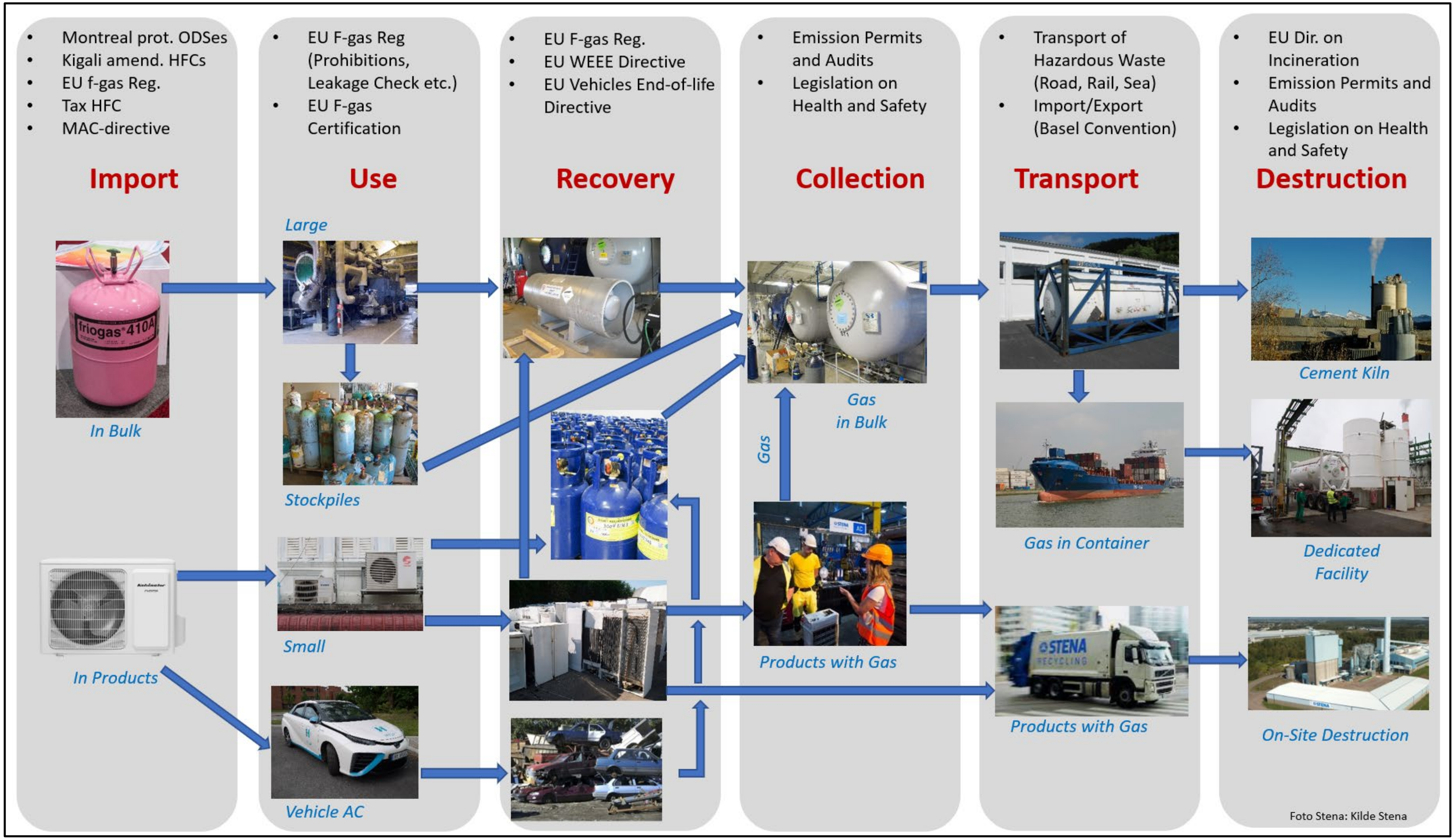
- Enforcement (incl. information campaigns, audits and sanctions)
- Available equipment and personnel skills
- Economic incentives (refund, reimbursement, value of waste gas for energy or reuse)
- The GWP or ODP of the gas if incentives are coupled to environmental characteristics
- Logistics and volumes (size of charges or batches, on-site vs. centralized recovery)
- Required safety measures (flammability, toxicity of gas)
- Destruction costs (or income)
- Existing systems for general waste recycling (for example for vehicles and WEEE)
- Technical recovery efficiency (completeness of recovery, leakages during handling)

Summary Figure 1: Recovered volumes of gas in Norway 2009-2021 measured in metric tonnes.



Source: Torgrim Asphjell, NEA

Summary Figure 2: Logistics chain for ODSes and F-gases in a cradle-to-grave perspective



Source: Torgrim Asphjell, NEA

Note: The Text at the top describes the legislation associated with each phase in the lifecycle. This example is based on Norwegian practices and experience, but for the purpose of illustration and simplification some minor modifications have been made. SF_6 is not included in the figure

1 Legislation and Policies on Refrigerants and Gases in Norway

In this chapter we will give an overview of national development, legislation, and policies on ozone depleting substances (ODSes) and fluorinated greenhouse gases (F-gases) in Norway. The main focus will be on refrigerants, but other uses and gases, such as SF_6 in gas insulated switchgears (GIS) will also be covered.

Legislation and policy cover all phases of the lifecycle. We will touch upon aspects related to production, import, placing on the market and emissions during use. However, since the project is on end-of-life (EOL) management, the main focus will be on recovery of gases from equipment taken out of service and the subsequent handling of this gas or stockpiles in terms of collection and destruction or reuse.

Although Norway is not an EU member, the European Economic Area (EEA) Agreement implies that most EU regulation is also implemented in Norway. Consequently, this description will to a large degree be illustrative for the situation in EU, although some measures, such as the tax on HFCs, are grounded nationally only.

As regards legislation we will focus on national implementation and supplementation of international obligations and EU regulations on ODSes and F-gases. We will also give an overview of the general waste regulation focusing on relevant sectors and waste fractions.

Information on the regulation and following up of undertakings performing recovery, collection, transport or destruction of gases will also be included. This will focus on pollution and the natural environment, but information on safety and working environment will also be included.

Because the use of ODSes is largely phased out in Norway, the description will also cover the situation in an historical context.

1.1 Refrigerants and Gases – Evolution of Use and Current Status

The Refrigeration and Air Conditioning (RAC) sector is the most important sector using ODSes and F-gases, while other significant sectors historically include fire suppression (halons) and aerosols (spray cans). For SF_6 Gas Insulated Switchgears (GIS) used in electricity supply dominates in Norway.

Industrial emissions of F-gases can be significant, but these sectors are of limited relevance as regards EOL management and will consequently not be dealt with in detail here.

In the RAC sector natural refrigerants such as ammonia (NH_3) and hydrocarbons (HC) were dominating up till the 1950s. When CFC were introduced, they were promoted to be "safer" alternatives and quickly gained ground.

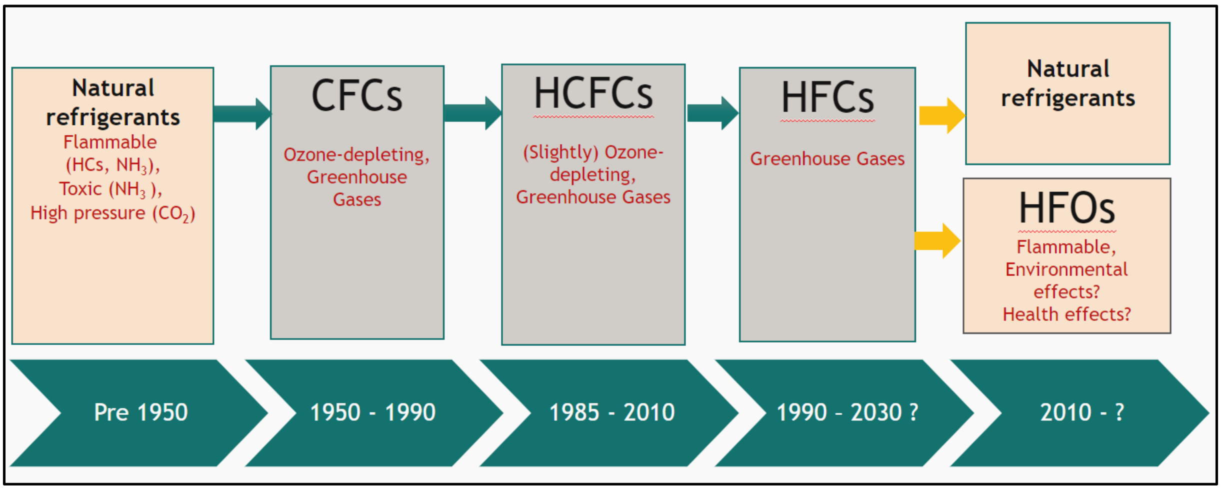
The detection of the ozone hole and the resulting adoption of the Montreal Protocol in 1987 then resulted in a phaseout of production and consumption of CFCs and other ozone-depleting substances. Later the transitional substances in the HCFC group were also phased out.

Thereafter, production and consumption of the substitutes in the HFC-group was regulated due to their contribution to climate change. For Norway this first took effect due to national tax and implementation of the EU regulation, before the global Kigali amendment to the Montreal Protocol was signed in 2016.

The future choice is now between the next generation HFCs with low contribution to climate change, the so called HFOs, or modern designs utilizing the same natural refrigerants that were predominant before synthetic alternatives were introduced.

As regards the development described above and in the figure 1 below, it is important to keep in mind that this focuses on the introduction phase, or by placing on the market. However, as regards recovery and collection of waste gases the focus is on servicing and End-of-life (EOL). This usually implies a time lag of decades, so HFCs, and to a considerable extent also ODSes, will dominate recovery for many years to come.

Figure 1: Development in the use of refrigerants in Norway



Source: Torgrim Asphjell, NEA

Parallel to the evolvement in types of refrigerants, economic and technological development has led to the increased use of RAC equipment in general and in new product categories. For Norway this is most pronounced in the large increase in the use of domestic heat pumps for heating (Domestic AC/HP) and vehicle air-conditioning, but also larger heat pump installations have become more common.

In Norway the use of **ozone depleting substances** is now limited to some minor exempted uses, such as the critical use of halons in aviation, and for some laboratory and analytical uses. The remaining stockpiles of ozone depleting substances are reckoned to be relatively small and the equipment still in use is probably limited to household fridges and other smaller installations. In addition to refrigerants considerable amounts of ODSes resides as foam blowing agents in old fridges, buildings and other structures.

CFCs ozone-depleting substances were used mainly as refrigerants, foam blowing agents and as solvents for cleaning in Norway until 1991-2000 when restrictions were phased in. Import and manufacturing of aerosol cans with CFCs was banned already in 1979. Halons were used mainly as fire suppressants, until the import and use (with some exemptions for aviation) were banned in 1994.

The use of **HCFCs** as a less ozone-depleting substitute increased temporary after CFCs were phased out, but from 2010 import of HCFCs was also banned in Norway and from 2015 refilling of existing equipment has also been prohibited. Only a limited number of equipment containing HCFCs is still in use and the amount of HCFCs collected by EOL and from stockpiles is decreasing.

HFCs were introduced as a non-ozone depleting substitute for HCFCs in the 1990s and the use increased rapidly. The first EU F-gas regulation of 2006 aimed at limiting the use of these gases due to their strong effects on climate change (measured in Global Warming Potential or GWP) and was implemented in Norway through the EEA Agreement. This curbed the expected exponential growth, but emissions increased before they stabilized around 2013. Afterwards there has been a slow downward trend in emissions measured in CO_2-equivalents (CO_2-eq). This is partly due to lower leakage rates, but in recent years substitutions based on lower GWP HFCs, HFOs or natural refrigerants have also gained ground.

PFCs, which are also strong climate gases have many possible applications similar to HFCs, but have never played an important role in applications or products in Norway. These gases are however regulated in the EU F-gas regulation in the same way as HFCs and covered by the Norwegian tax and refund scheme, so references here to HFCs apply to these gases as well (PFCs are, however, not controlled by the Kigali amendment to the Montreal-Protocol). PFCs are formed during the production of aluminum, and emissions from the seven Norwegian plants were large before emission reduction measures were implemented during the early 2000s.

The F-gas **SF_6** is not used as a refrigerant, but we have decided to include it here due to similarities in climate effects and treatment at EOL. Today the main source of SF_6 emissions is leakage from Gas Insulated Electrical Switchgears (GIS). Measures have reduced leakage rates, but increased use of this type of equipment might hamper further reductions. Norway also has emission of SF_6 from the production of medium voltage GIS and until the turn of the century emissions from the magnesium industry were large. SF_6 is covered by the EU F-gas Regulation.

Norway has no known use or emissions of **NF_3**, which is a "new" greenhouse gas with very high GWP.

Norway has never had any production of ODSes or F-gases, so all placing on the market has been regulated by restrictions on import.

See Annex II for a more detailed description of the most common refrigerants and gases.

1.2 Applications of Gases According to Product categories

ODSes and F-gases are used in a variety of equipment and products, ranging from large industrial installations to small disposable consumer products.

Since this report focuses on recovery and the subsequent handling of ozone-depleting- or greenhouse gases, the way gases are processed throughout the waste stream is a deciding factor. Taking this into consideration, we have decided to organize the description according to the following main categories:

Larger Refrigeration and Air Conditioning Equipment (Larger RAC). This includes all types of larger stationary refrigeration and air conditioning equipment. This equipment is normally built on-site and refrigerant is filled, refilled and recovered on-site. The refrigerant charge can be from a few kilos in supermarket fridges up to several metric tonnes in large industrial installations. Various types of refrigerants are used depending on regulation and application. Larger heat pumps are included in this category.

Domestic Air Conditioners or -Heat Pumps (Domestic AC/HP). This includes heat pumps and air conditioners intended for use in private homes, offices etc. The most common type is air-to-air units consisting of an indoor and an outdoor unit connected by piping. Installation is required and the refrigerant is often preloaded. These units are often referred to as semi-hermetically sealed, since they are not refilled under normal circumstances. Refrigerant is recovered on-site or in centralized recycling facilities. In Norway this equipment is generally referred to as heat pumps for space heating but is technically almost identical to equipment referred to as room air conditioners in India and other warmer countries. In Norway the refrigerant in these units is mostly the HFC mixture R-410A, while some newer units contain HFC-32.

Home Appliances. This includes plug-in household fridges and freezers and similar products used for cooling in shops, restaurants etc. These products can contain ODSes or F-gases in both the refrigeration circuit and in the insulation foam.

The cooling circuit is hermetically sealed, and recovery is normally done in centralized recycling facilities. Old products typically contain CFC-12 as refrigerants and CFC-11 a foam blowing agent. In a transition period some HFC-134a was used, while today hydrocarbons dominate both as refrigerants and foam blowing agents.

Vehicle Air-Conditioning (Vehicle AC) and Vehicle Refrigeration. Vehicle AC covers car compartment air conditioning systems in on-road and off-road vehicles.

Some old vehicles might contain CFCs or HCFCs, but in Norway HFC-134a dominate in air-conditioning systems in scrapped vehicles. HFO-1234yf is now predominant in newly registered vehicles.

Vehicle refrigeration refers to cooling and freezing equipment in refrigerated trucks, trailers and containers. Technically and as regards the gases being used in this equipment resembles similar stationary equipment.

Recovery from this equipment is usually done at car collection sites by end-of-life or by car workshops.

Larger Gas Insulated Switchgears (Larger GIS). This includes all types of larger GIS that use SF_6 or other gases as electric isolators. This equipment is normally built on-site and SF_6 is filled, refilled and recovered on-site. We have decided to also include other related high voltage equipment in this category.

Medium Voltage gas Insolated Switchgears (MV GIS). These are smaller GIS that are hermetically sealed and prefilled with SF_6 or another gas. Recovery of gas is normally done at a recycling facility.

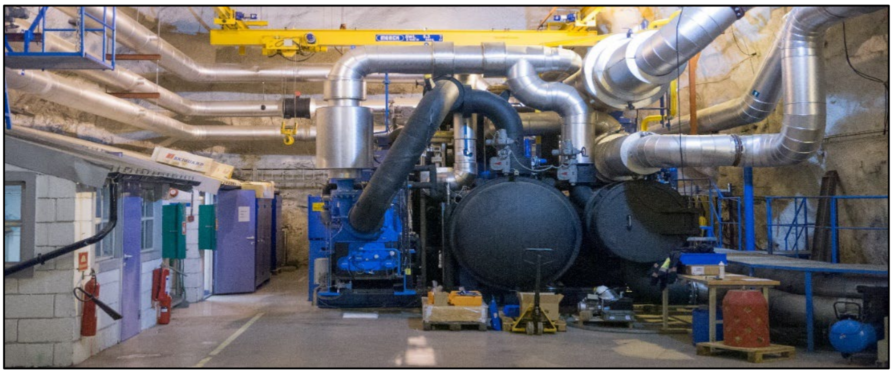
Foam in Buildings and other Constructions. This refers to blowing agents in foam used as insulation in buildings, roads and other larger constructions. Both CFCs, HCFC and HFCs have been used and due to the long lifetime all types of gases are still present in this type of waste. Recovery of gas from this waste fraction is challenging (see chpt. 1.7.3).

Fire Suppression. This is systems for fire protection of technical installations, aircraft and other critical infrastructure. The most well-known gases are ODSes in the halon-group, but also PFCs and HFCs have been or are being used for this. The gas is often found in gas cylinders connected to the equipment, which can be collected and transported relatively easily.

Stockpiles of Gas. This refers to cylinders or tanks of gas ready for collection and destruction that are outside of an established waste stream. Typically, this is old cylinders of used gas handed over by companies or discovered during audits. It can also be virgin surplus gas or gas recovered from industrial processes or production.

As regards industrial consumption of ODSes or F-gases, this is in Norway now limited to use of SF_6 in the production of MV GIS. Previously SF_6 was also used in magnesium production and HFC was used as a foam blowing agent for building foam. In addition PFCs are formed as a pollutant in the production of aluminium. The EU regulation prohibits the use of specific gases in some industrial processes and all emissions from industrial plants are regulated and audited by the general regulation on pollution. Consequently, since the scope of this work is waste and not emissions, industry will only be covered where relevant under the stockpiles category.

Figure 2: Larger RAC for district cooling



Source: Torgrim Asphjell, NEA

1.3 Lifecycle of Refrigerants and Gases

The path from recovery and collection of gas to final destruction or other treatment will vary depending on type of gas and application. The logistics will also vary over time as focus shifts to new groups of gases and products.

The life course of refrigerants (and also most ODSes and F-gases used for other purposes) from they are placed on the market till they are recovered for destruction, reclamation or recycling can be described as follows (also see Summary Figure 2 in the Executive Summary):

1. **Import:** The gas is imported and placed on the market in Norway. This can be as gas contained in new products or as gas imported in gas cylinders or tanks (bulk import) intended for filling into new equipment, refilling or other purposes. (Norway now has no domestic production or reclamation of gas, so all gas is imported. For countries that produce gas, the first step will also include production).

2. **Use:** The gases are typically used as a working fluids in installed equipment or products. During this period some gas will inevitably leak out to the atmosphere and for some equipment regular refilling of gas is needed. In this report the user phase will be associated with the total amount of gas in use or circulating in the market (the bank). This is the theoretical maximum potential for recovery and will also include all stocks of old and new gas found in cylinders, tanks, foam, and other products.

3. **Recovery:** Collection of gas typically starts at decommissioning by end-of life of equipment and products, but also includes collection of stockpiles of surplus virgin gas and waste gas recovered from equipment during servicing etc. For larger RAC recovery of gas is done on-site and is often performed by local RAC companies. For smaller products recovery is often done in a centralized recycling facility. Centralized recovery and recycling of smaller electrical or electronic waste (WEEE) such as freezers, fridges and domestic AC/HP is mainly done by large waste recycling companies (see chpt. 2.1.2 and 2.1.3). Gas from vehicle AC is recovered at scrapped car collection sites (see chpt. 1.7.2). SF_6 from larger GIS is recovered on-site, while gas from smaller switches is recovered in a vacuum chamber at a WEEE recycling facility (see chpt .2.1.2). Sometimes gas is temporarily evacuated from equipment during servicing etc. and reinjected after the work is has been performed. This will not be considered as recovery in this context.

4. **Collection:** After recovery the gas is stored in gas cylinders or larger tanks and will then be handled and transported further. For refrigerants this is usually done by the Norwegian Foundation for Refrigerant Recovery (SRG), which has established a system for consolidation of smaller batches of gas in bulk into a big tank destined for a destruction facility (see figure 26 in chpt. 2.1.1). This also includes administration of tax refund for HFCs (see chpt. 1.5.3.2). Most SF_6 recovered on-site is handed in to Stena Recycling. Foam blowing agents and some other fractions of waste gas are handled individually by recycling companies or other players.

5. **Transport:** Collected and consolidated gas is transported cross-border in suitable tanks to facilities in other European countries for destruction or, possibly, recycling or

reclamation. This must be done according to international agreement on transport and export of waste (see chpt. 1.8 and 2.1.1.7).

6. **Destruction:** The final stage in the lifecycle is when the gas is neutralized by destruction or made into a new product by recycling or reclamation. As regards the refrigerants collected by SRG (which constitutes most of the collected gas), destruction was previously done at the Norcem cement plant in Kjøpsvik (see chpt 2.2.1). For some years SRG used a Fortum facility in Kumla, Sweden, while they are now using the Trédi facility in France (see chpt. 2.2.2). Stena Recycling have their own on-site destruction facility for refrigerants in Sweden (see chpt. 2.2.3), while recovered SF_6 is sent to another facility for destruction. Minor fractions of waste gas end up in other European countries. Halons collected by SRG are sent to EU for reuse in applications still approved.

For the uses most relevant for this report the time from import to destruction typically can be measured in decades. However, for some small disposable consumer products, such as aerosol cans, this period will be much shorter. For this latter type of products there is no organized recovery in Norway.

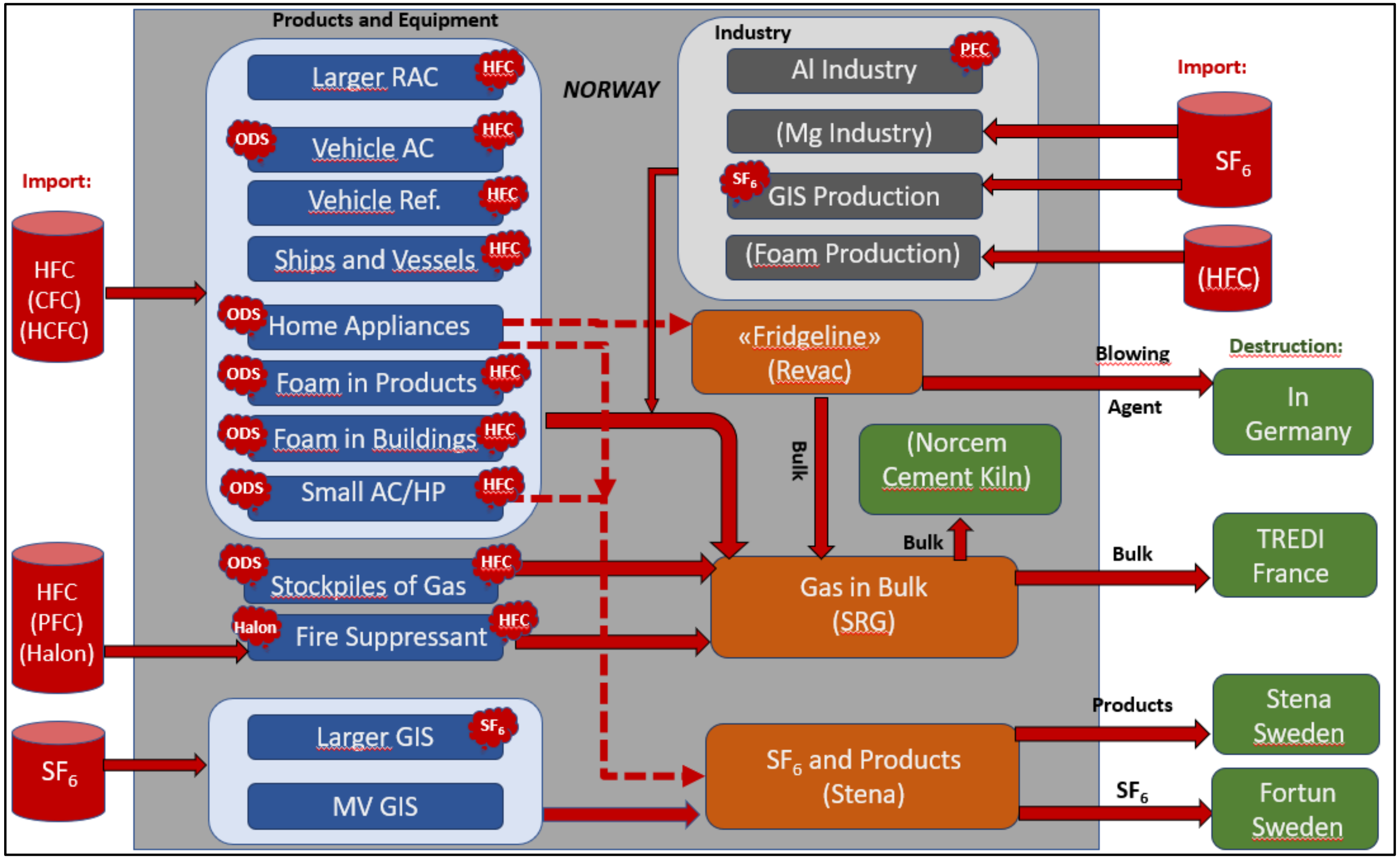
Figure 3: Domestic AC/HP in use. The system consists of an outdoor unit and an indoor unit connected by piping

Source: Torgrim Asphjell, NEA

Figure 4: Collected waste domestic AC/HP units. The gas is recovered prior to or after collection of waste product.

Source: Torgrim Asphjell, NEA

Figure 5: Flowchart illustrating the main flow of ozone depleting gases and F-gases in Norway in a cradle-to-grave perspective



Source: Torgrim Asphjell, NEA

Note: Red cylinders illustrate import of gas in bulk or in products. Bold arrows are movement of gas in cylinders, while dashed lines are movement in products. Blue boxes illustrate gas in products or equipment in use or stockpiles of used or surplus gas. Gray boxes illustrate use of gas in production or emissions formed as a pollutant during processes. Orange boxes are waste handling companies and green boxes are destruction facilities. Words in brackets illustrate activities that have ceased. Clouds illustrate the most important emission points at the time of writing. ODS is CFCs, HCFCs and other ozone depleting substances. Gray background illustrates activities within Norwegian territory.

Facts about Norway

Norway is a country in Northern Europe with the mainland situated between the 58th and 71st latitude. The climate ranges from tempered in the southern parts to subpolar in the north. There are four distinct seasons and in all parts of the country temperatures can be well below zero during the winter and above 20°C during the summer. In addition, the Arctic Archipelago of Svalbard is under Norwegian jurisdiction.

Mainland Norway has a total area of 323 781 square kilometers (about the size of Rajasthan state) and a population of 5,4 million. Most of the people live in the southern parts around the capital Oslo or along the coast.

The proximity to the sea has played a key role in Norwegian history. Fishing has always played an important role and today fish farming is also an important source of foreign income. The discovery of large oil- and gas reserves on the continental shelf in the 1960s has contributed greatly to today's high standards of living.

The interior is mainly mountainous, and the development of hydropower was key to the first phase of industrialization in the early 20th century. Production of raw materials such as aluminum, ferro alloys and fertilizer still dominate the mainland export industry.

Norway is a constitutional monarchy with a democratically elected government. It has both administrative and political subdivisions on county and municipality level. Although not a member of the European Union (EU), it is closely link to it through the European Economic Area (EEA) Agreement.

Figure 6: Map of Norway and neighboring countries in northern Europe.

Source: https://norwayeu.weebly.com/map.html

1.4 Regulation on Ozone Depleting Substances (ODS)

Norway complies with all regulations regarding ozone depleting substances controlled under the Montreal Protocol. Norway has not had any production of ozone depleting substances. Hence, all supply of the substances has been through import.

Norway started regulating the ozone depleting substances already in 1979 when a prohibition of import and manufacture of aerosol cans with CFC as propellant came into force. Subsequently, regulations for each of the groups of substances were introduced where the import and use of the substances were restricted. The focus was to limit the import and use of ODSes and products containing the substances.

A national regulation from 1991 regarding the production, import, export and use of CFCs and halons set out a number of prohibitions for import, export and use of these substances as aerosols, in foams, in refrigeration and air-conditioning appliances, fire-suppressing equipment, for dry cleaning of textiles etc. from 1991 to 2000. It also introduced a general ban on import of CFCs and halons.

The regulation required the owners of equipment containing the substances to recover the gas before decommissioning of the equipment. The recovered gas was to be handed in to the supplier of the gas and/or the equipment. The gas could also be handed in to a waste treatment facility approved by NEA. The de minima for this obligation were one metric kg of ODS.

A regulation from 1997 bans the production, import and export of HCFCs without a license from NEA. This regulation also introduced prohibition on the use of HCFCs in most products and equipment categories, the prohibitions mainly being introduced during the years 1997 until 2000. The use of HCFC for servicing and maintenance of existing refrigeration equipment was allowed until 2015. It further required the safe recovery of gas during maintenance and before decommissioning equipment containing HCFC.

Norway implemented the EU regulations on ODSes, including the Regulation No 2037/2000[5] in 2002 and the revised Regulation No 1005/2009[6] in 2013. This latter regulation introduced further restrictions on the use of all ODSes controlled under the Montreal Protocol to ensure full phase out of the substances according to the obligations under the Protocol. Restrictions applied both to the pure ODS substances and mixtures, as well as products and equipment containing ODS. It further regulated the uses of the substances that are exempted from some of the regulations under the Protocol, such as critical use of halons etc.

The environmental authorities required in the regulations described above, that during servicing and before decommissioning equipment, the ODSes were recovered for recycling, reclamation, or destruction. When the authorities issued licenses for import of the substances, it required that the importers had to make arrangements so that recovered gas could be handed in for collection and safe destruction free of charge for the operators of equipment containing the gas.

Because of these requirements, a collaboration between the importers and users of the gas was established, and the Norwegian Foundation for Refrigerant Recovery (SRG) was founded by

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32000R2037&from=EN
[6] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1005&from=EN

the refrigeration sector to ensure the safe collection and destruction of used gas as required by the national regulation (see chpt. 2.1.1).

The use of ODSes in Norway has gradually been banned from the 1980es. However, ODSes are still present in some old equipment and insulation foams. SRG continues to collect recovered ODSes from equipment and facilitates the safe destruction of the substances. However, a handling fee is charged (see chpt. 2.1.1.1). WEEE recycling firms Revac and Stena Recycling also still collect considerable amounts of CFCs from insolating foams in fridges and freezers (see chpt. 2.1.2 and 2.1.3).

Figure 7: Since Norway is situated at high latitude it is vulnerable to the ozone depletion around the poles. Warnings of high UV radiation are regularly issued during the easter holiday season when many Norwegians are skiing.

Source: Torgrim Asphjell, NEA

1.5 Regulation on other Fluorinated Greenhouse Gases (F-gases)

Norway is not a member of the European Union (EU) but have close relations to the Union due to the European Economic Area (EEA) Agreement. This implies that Norway implements most of the EU Directives and regulations. This is also the case for F-gases, where most of the framework- and implementing regulations from EU[7] have also been implemented in Norway. F-gases in this case refers to HFCs, PFCs, SF_6 and other fluorinated greenhouse gases that are not ozone-depleting.

Norway was an active part in the negotiation of the Kigali amendment to the Montreal Protocol, which aims to reduce the consumption and production of the HFCs group of F-gases.

Issues related to taxes are not part of the EEA Agreement, and Norway has implemented a unique domestic system of tax and refund on HFCs and PFCs.

In addition to the specific regulation, F-gases are also covered by the general waste regulation (see chpt. 1.7). Related activities and companies are also covered by general rules or regulations on pollution, safety and working environment.

Figure 8: Negotiating the Kigali amendment on HFCs to the Montreal Protocol, Rwanda 2016.

Source: Torgrim Asphjell, NEA

[7] For an overview of EU legislation to control F-gases, see: https://ec.europa.eu/clima/eu-action/fluorinated-greenhouse-gases/eu-legislation-control-f-gases_en

1.5.1 EU Regulation on F-gases Implemented in Norway

The first EU F-gas, Regulation, No 842/2006[8], was adopted by the EU in 2006 and implemented in national Norwegian legislation in 2010. In 2015 this was replaced in EU by a more ambitious regulation No 517/2014[9], which was implemented in Norway in 2018. National implementation is done by reference to the EU regulation in the Product Control Regulation administered by NEA. The Commission is in the process of another review and a Commission proposal for a revised regulation[10] was published on 5th April 2022. The intention behind the regulation is to limit the emissions of HFCs, PFCs and SF_6 through containment, recovery, and restrictions of use in products, equipment, and applications. The regulation is supplemented by implementing regulations on topics such as leakage checking, labelling, reporting and certification (see chpt. 2.3). The regulation No 517/2014 also prescribes limits on the total amount of HFCs that can be produced and consumed in the EU, which for the case of Norway is substituted by a domestic system (see chpt. 1.5.2).

Other relevant EU legislation is the Mobile Air Conditioning (MAC) Directive, which places a GWP-limit of 150 on refrigerants used in new cars. This legislation is administered by the Norwegian Public Roads Administration (see chpt.1.7.2).

For the purpose of this report, the part of the EU regulation dealing with recovery is of most direct interest. The Regulations require that gas from stationary RAC equipment, GIS and other equipment shall be properly recovered by certified personnel. Recovery of residual gases in gas cylinders or tanks by EOL is also required. In the new regulation the provisions for RAC are extended to include refrigerated trucks and trailers.

For mobile equipment the requirement is "to arrange for the recovery of the gases, to the extent that it is technically feasible and does not entail disproportionate costs", by appropriately qualified persons. Such mobile equipment is typically AC in large vans and trucks, refrigeration and freezing equipment in ships and fishing vessels.

Foams are explicitly exempted from requirements on mandatory recovery. For a detailed description on how this is done in practice in Norway see chpt 1.7.3 (building foams) and chpt. 2.1.3.2 (foam from fridges).

According to the regulation, products, equipment, and cylinders containing F-gases shall be clearly labelled with type and quantity of gas. This will facilitate recovery both in terms of quantity (easier to locate relevant equipment) and efficiency (less need for analysis). Furthermore, requirement as regards certification will ensure that recovery is carried out by qualified personnel (see chpt. 2.3).

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8 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R0842&from=EN

9 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&from=EN

10 https://ec.europa.eu/clima/eu-action/fluorinated-greenhouse-gases/eu-legislation-control-f-gases_en#review-of-the-eu-f-gas-regulation-and-the-new-commission-proposal

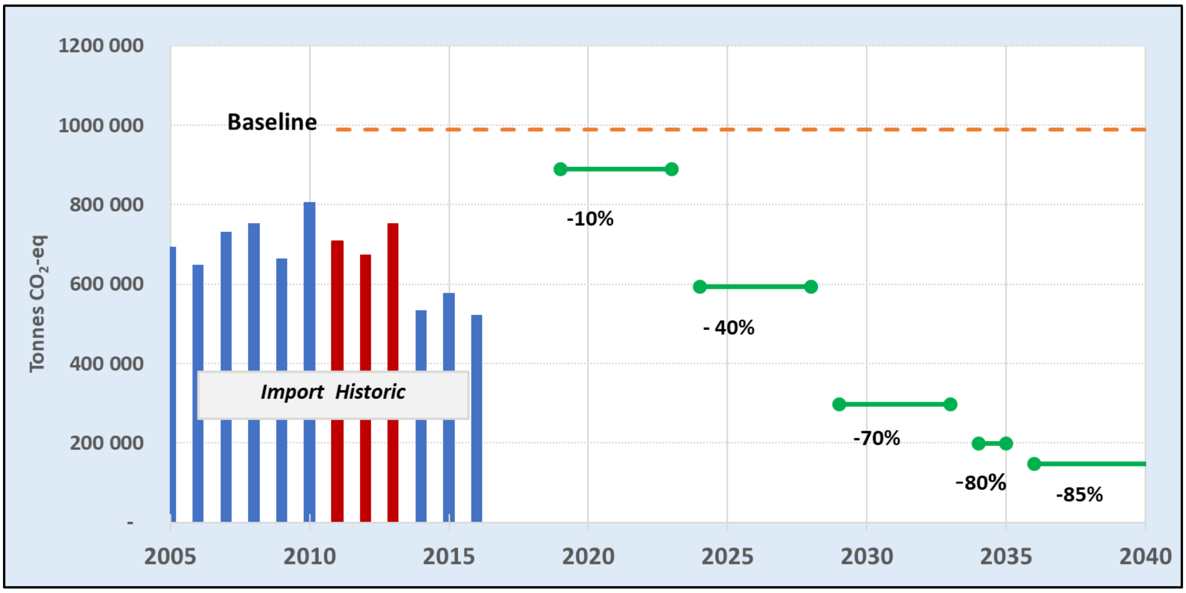
1.5.2 The Kigali Amendment to the Montreal Protocol

The Montreal Protocol was originally created to preserve and restore the ozone layer by phasing out CFCs and other ozone depleting substances. HFCs were introduced as alternatives friendly to the ozone layer, but they are powerful greenhouse gases. Since HFCs have many uses and characteristics similar to the CFCs, and later the HCFCs, it was decided to include phase-down of HFCs under the Montreal Protocol.

The Kigali amendment to the Protocol was agreed in Rwanda in October 2016, ratified by Norway in September 2017 and entered into force on 1st January 2019. The amendment operates with three different groups of countries subject to different phase-down regimes. Norway belongs to the group of "old, industrialized countries" committed to ultimately reduce use of HFCs by 85% measured in CO_2-equivalents by 2036 compared to a 2011-13 baseline (see figure 9 for details). To comply with this requirement Norway introduced a licensing system and import quotas on bulk HFCs from 2019. (Since Norway has no domestic production of HFCs, this was all that was needed to regulate supply.) Norway is well on the way of meeting its phase down requirements as a result of already implemented measures, including the EU F-gas regulation and the tax and refund scheme (see next chapter).

The Kigali Amendment focuses on phasedown by restricting the supply of new gas by domestic production and consumption. There are no obligations under the Montreal Protocol regarding prevention of venting, leakage or other emissions of gases, nor obligations of recovery of gases at EOL. However, the Parties are encouraged to develop or consider further improvements in the implementation of national and/or regional legislative strategies and other measures that prevent the venting, leakage or emission of ODSes by ensuring inter alia proper recovery of those substances during servicing, use and at end of life.

Figure 9: Norway's phase-down commitment according to the Kigali Amendment, with intermediate steps and ultimate goal of 85% reduction by 2036. (Import is bulk only at time of negotiations. From 2018 import stabilized at around 200 – 300 000 tonnes CO2-eq/year)



Source: Torgrim Asphjell, NEA

1.5.3 Domestic Tax and refund scheme on HFCs and PFCs

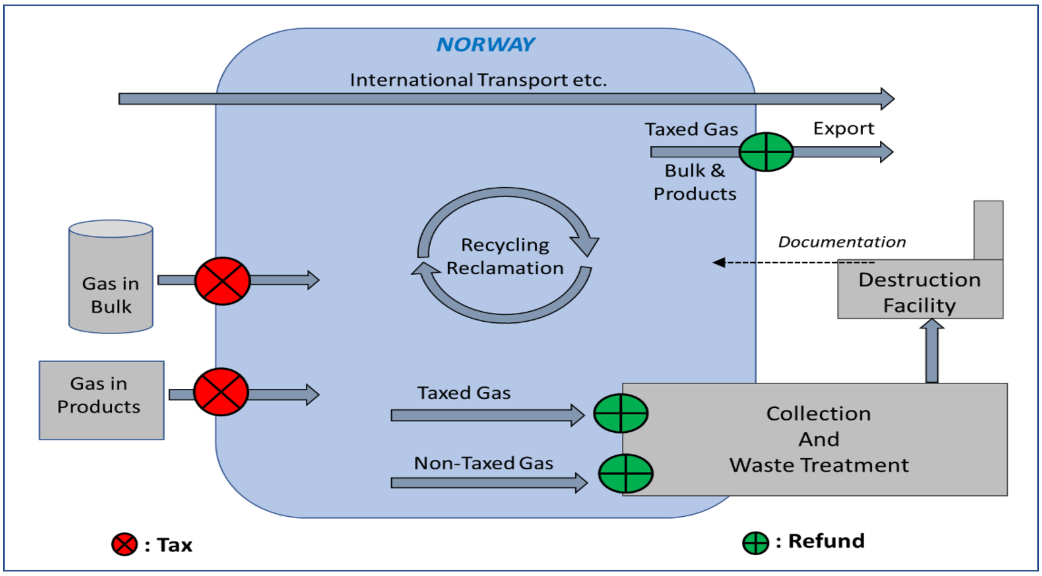
In 2003 Norway introduced a tax on the import and production of HFCs and PFCs and in 2004 the tax was supplemented with a refund scheme for the destruction of gas. The rates are based on the GWPs of the gases and the refund rate is the same as the tax rate.

Norway has no domestic production of these gases, so in practice the tax equals an import tax. The tax covers pure gases and mixtures (as compounds or mixed with other substances). Both bulk import in cylinders or tanks and import of products in which the gases are used as a constituent is covered by the tax. International cross-border transport and domestic recycling or reclamation of recovered gas are exempted from the tax and refund. Export of HFC/PFC gas and products containing the gases might qualify for a refund of the tax paid, provided that paid import tax can be documented. The tax is administered and collected by The Norwegian Tax Administration[11].

Refund will be paid, provided that it can be documented that collected HFC/PFC gas had been destructed by an approved facility. All HFCs and PFCs that are listed in the tax regulations are eligible for refund after destruction, regardless of whether it was taxed or not during import, and no proof of the origin of the gas or time of import is required. In principle any company or person can apply for refund, but since the logistics and requirements for documentation are quite extensive this is in practice only done by the gas collection company SRG (see chpt. 2.1.1) and Stena Recycling (see chpt. 2.1.2). The refund is administered and paid by NEA.

The scheme covers HFCs and PFCs that are specifically listed in the regulations. In practice, a handful HFCs and mixtures of HFCs are dominating and almost no PFCs are occurring.

Figure 10: Schematic description of the Norwegian tax and refund scheme.



Source: Torgrim Asphjell, NEA

[11] Taxation rates and description can be found at web-page of The Norwegian Tax Administration: https://www.skatteetaten.no/en/business-and-organisation/vat-and-duties/excise-duties/about-the-excise-duties/hfc-and-pfc/

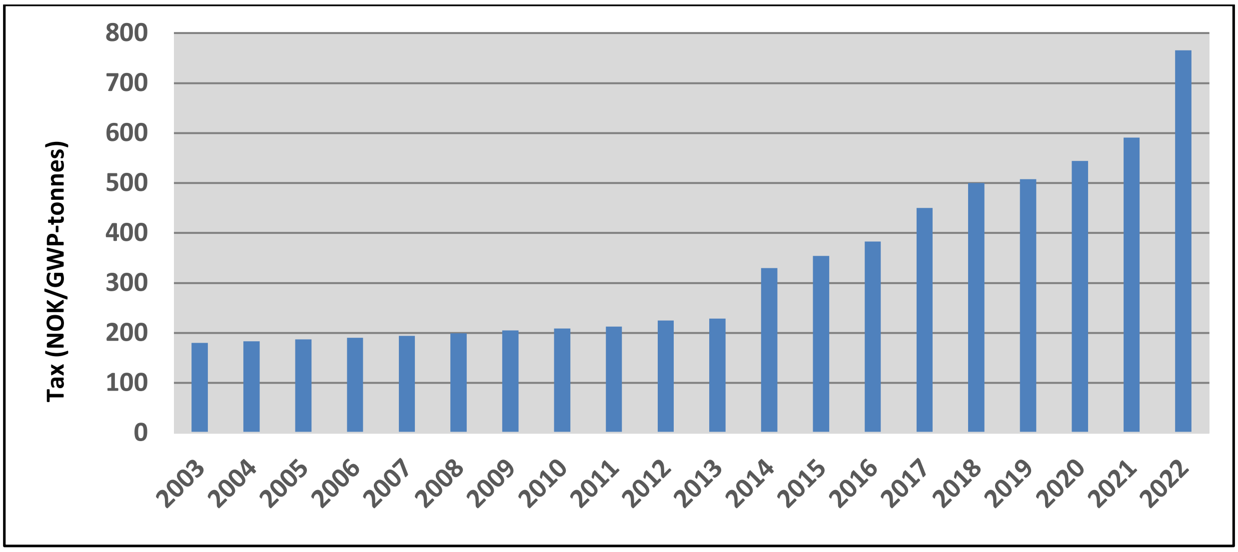
1.5.3.1 The Import Tax and Taxation Level

The taxation level for HFCs and PFCs is tied to the CO_2-tax for mineral oils. By the time of the introduction in 2003, the CO_2-equivalent taxation rate was 180 NOK/GWP-tonnes. For the first 10 years the rate was adjusted for inflation only, but since then, there have been several jumps in taxation level due to environmentally motivated increases in the general CO_2-tax. In 2022 the tax rate was 766 NOK (approximately 6000 INR) per GWP-tonnes, and the government has announced an intention to increase the tax further up to 2000 NOK/GWP-tonnes by 2030.

In 2022, 19 HFCs and 7 PFCs were covered by the scheme. These are the same gases that are covered by the EU F-gas regulation (No 517/2014, Annex I) and includes all gases in common use. The GWPs used in the calculations are from the IPCC 4th Assessment Report. There is no tax nor refund for HFO-1234yf that is now used in almost all air-conditioners in new cars. (Technically speaking this is an HFC with very low GWP, but is often referred to as an hydrofluoro-olefin or HFO).

The tax for a batch of pure gas is found by multiplying the weight of the gas with the CO_2-equivalent taxation rate and the GWP for that particular type of HFC. For blends the tax is calculated by taking into account the weight fractions and GWPs of the different types of HFCs contained in the blend. For the most common blends, such a R-numbered refrigerants (see Annex II), the tax, stated in NOK/kg, can be found in precalculated tables. For some products containing small but unspecified amounts of gas the regulation opens for the use of simplified calculation methods and standard values.

Figure 11: The tax (and refund) rate for HFCs and PFCs from the introduction in 2003 till 2022



Source: Torgrim Asphjell, NEA

Note: (1 NOK = 8 Indian Rupees or 0.095 Euros as of 17th November 2022).

Figure 12: 2022 Purchase price by import, tax (and refund) component, resulting retail prices and price increase in percent due to the tax for some commonly used pure HFC refrigerants and blends

Gas	GWP	Purchase Price	Tax	Retail Price	Surcharge
HFC-32	675	694	517	1 211	74 %
HFC-134a	1 430	750	1 095	1 845	146 %
R-404A	3 922	1 847	3 004	4 851	163 %
R-407C	1 774	750	1 359	2 109	181 %
R-410A	2 088	924	1 599	2 523	173 %
R-448A	1 387	1 131	1 062	2 193	94 %
R-507A	3 985	2 630	3 053	5 683	116 %

Source: Moderne Kjøling

Note: Surcharge is the increase in retail price due to the tax. All prices are excluding VAT and are in Norwegian krone (NOK) per metric kilo of gas (1 NOK = 8 Indian Rupees or 0.095 Euros as of 17th November 2022).

1.5.3.2 The Refund Scheme

The refund level per kilo gas by end-of-life mirrors the tax level by import. It is granted based on documentation specifying that the gas has been taken out of the market by approved destruction technology.

Since logistics, documentation, and destruction must be paid by the waste producer, applying for a refund only makes economic sense by coordination and larger batches of gas. This has resulted in a situation where the Norwegian Foundation for Refrigerant Recovery (SRG) provides logistical and administrative support to waste producers on a commercial basis.

SRG has established a nationwide system for the collection of used HFCs and PFCs (and also ODSes). The gas is transported to a central facility where the substances are analyzed, identified and weighed and later transferred to a large tank. This tank is then transported to the Trédi Saint-Vulbas hazardous waste destruction facility in France (see chpt. 2.2.2) for final destruction. SRG applies NEA for a refund and pays parts of this refund to the waste producers after deducting their costs related to handling, analyses, processing, and administration. Those costs are fixed at 300 NOK/metric kg gas in 2022. For small quantities of waste collected, less than 2 metric kilos, the cost for handling is often higher than the refund, depending on the composition of the waste. Frequently, the waste is mostly oil residues. So, to increase operation efficiency, all cylinders containing less than 2 kgs are sorted out and sent to a dedicated process line. Therefore, these cylinders will not accrue refund to be paid to the waste producers. However, SRG will let the waste producers hand in these small amounts for free. Proper waste treatment is a legal requirement anyway, and there is no de minima for small amounts. A detailed description of SRG is given in chapter 2.1.1.

The refund scheme is warranted in the national waste regulation. This regulation states that the scope and rate are the same as for the tax. This implies that changes in taxation level and scope that the Tax Administration does are automatically reflected in the refund scheme.

The waste regulation specifies some overall procedures and documentation requirements regarding application for refund, analyses of gas and audits. The more detailed regulation and practice are delegated to NEA. Shortly after the refund scheme entered into force, NEA publicized a guidance document specifying the application procedure and requirements as regards documentation. However, this document is outdated and is now no longer in active use. The practical implementation is now based on practical experience gained since the introduction in 2004 and NEA's assessment on a case-by-case basis of the characteristics of the different facilities that collect, recycle or destroy F-gases or F-gas-containing waste.

Before the refund can be paid, NEA needs verification on the composition of the gas, the amount of gas and proof that it actually has been completely destroyed according to requirements.

Cylinders or tanks of waste gas often contain gas from different sources, so an analysis is needed to determine the exact composition of the gas mixture. Even for cylinders with gas of presumably known origin an analysis is often required for verification or to determine purity.

According to the waste regulation the analysis shall be done according to standardized methods and performed by an independent third-party accredited laboratory. The only accredited laboratory in Norway is the laboratory at ISOVATOR (see chpt. 2.5), which is a subsidiary of SRG. With adequate documentation of results and the precondition that an independent third-party consultant regularly surveys the work, NEA has approved that this laboratory is used for analyzing the samples from SRG.

The initial intention was that the refund amount should be determined by the analyzed composition of the gas in the big collection tank that is sent to the destruction facility. However, it appeared to be difficult to get accurate samples from the complex, two-phased mixture in this tank. This challenge is enhanced because the tank is stored outside under varying ambient temperatures and might also contain ODSes and other substances or pollutants.

To determine the refund to be paid to the waste suppliers, SRG analyses every batch of gas that SRG receives and that is subsequently transferred to the collection tank. It was concluded that the sum of these fractions probably is a better estimate of the real content of the collection tank. After this the general approach has been to use the individual samples as the main input to the calculation, while the sample of the big tank is used for cross-checking.

The amount of gas destroyed is normally determined by comparing the weight of the gas tank before and after it has been emptied at the destruction facility. Documentation on weights and use of approved weighing equipment must be included in the application for refund.

Initially a prerequisite for refund was that the waste gas was stored on the premises of the hazardous waste destruction facility for two weeks after the application for refund is sent to NEA. This to allow for an additional audit of the composition and weight of the gas before destruction is initiated. This is no longer required.

As is the case for SRG the collection tank is sent to the Trédi facility in France for destruction of the gas. In this case samples are taken from the tank before it is sealed and transported. After receiving confirmation from the destruction facility that the seals were intact upon arrival, NEA gives approval for initiating the emptying of the tank and destructing its content.

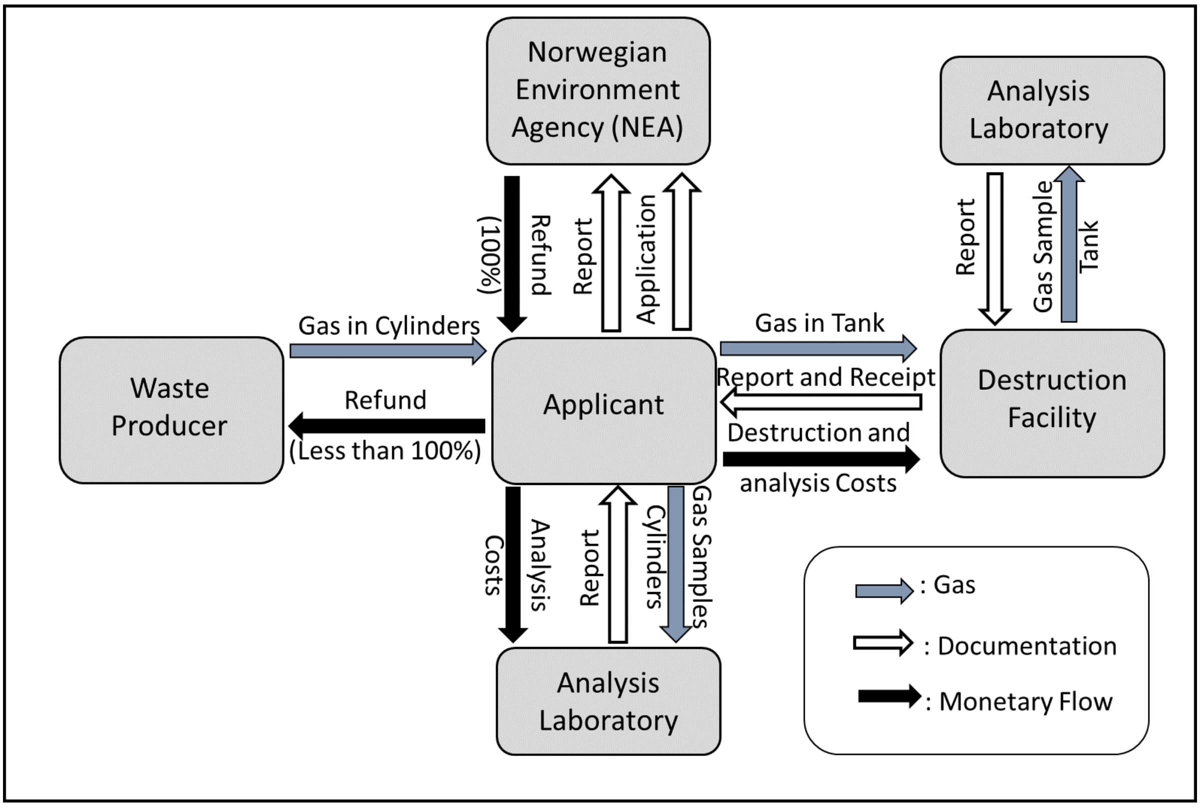
To determine the amount of gas destroyed, the tank is weighted upon arrival and after being emptied.

The refund is paid from NEA to SRG or any other applicant following these procedures. Waste suppliers that deliver gas through the SRG collection system relate to SRG as their business partner only and there are no administrative, legal or economic connection between these waste suppliers and NEA.

In addition to SRG, the only other applicant applying for refund directly to NEA is Stena Recycling Norge, which destructs gas from Norwegian household appliances at their on-site destruction facility in Sweden (see chpt. 2.2.3 and chpt. 2.1.2).

Refrigerants from the Revac "Fridgeline" are collected in a transport tank, sample collection for analysis takes place on-site, and subsequently the tank is sent directly to the Trédi destruction facility. This is done under the umbrella of SRG, who analyzes the samples and manages formalities related to transport, export, destruction, and refund.

Figure 13:Typical flow of gas, documentation and payments in the refund system. The figure is illustrative for how applications from the largest applicant, Norwegian Foundation for Refrigerant Recovery (SRG), are handled



Source: Torgrim Asphjell, NEA

Note: For other applications variations over this theme might occur. Documentation of quantity of gas (expressed by the difference in weight before and after destruction) is also required but is not included in this figure.

Figure 14: Sealed valves on tank before transport and weighing of tank containing recovered refrigerants

Source: Torgrim Asphjell, NEA

1.5.3.3 Long term trends

The lifecycle for the use of HFCs has many similarities to what has previously been seen for CFCs and HCFCs. First there is a build-up phase due to substitution, with increased import and use of the gas in refrigeration, air-conditioning and other applications. This import leads to an accumulation of gas in equipment in use and as this bank of gas increases, regular emissions from leakage also increase. This, again, increases the need for import of gas for refilling. Then when the equipment reaches End-of-life after maybe 10-20 years, the need for recovery, collection and destruction of waste gases starts to increase.

These different phases as regards Norway, from HFCs were phased-in from the early 1990s as substitutes for HCFCs, are illustrated in the figure 15. Notice that the denomination is in tonnes CO_2-equivalents.

The discontinuity around the introduction of the tax in 2003 is due to stockpiling of gas in bulk in 2002 before the tax was introduced. But a long-term shift from an exponential trend to a more linear trend in import and use can also be seen. This is mainly due the short-term effect of increased focus on leakage from larger RAC and the longer-term effect of switch to lower GWP refrigerants or natural refrigerants in the same type of equipment. This shift has been induced both by the economic incentives from the tax and the regulatory requirements in the EU regulations as well.

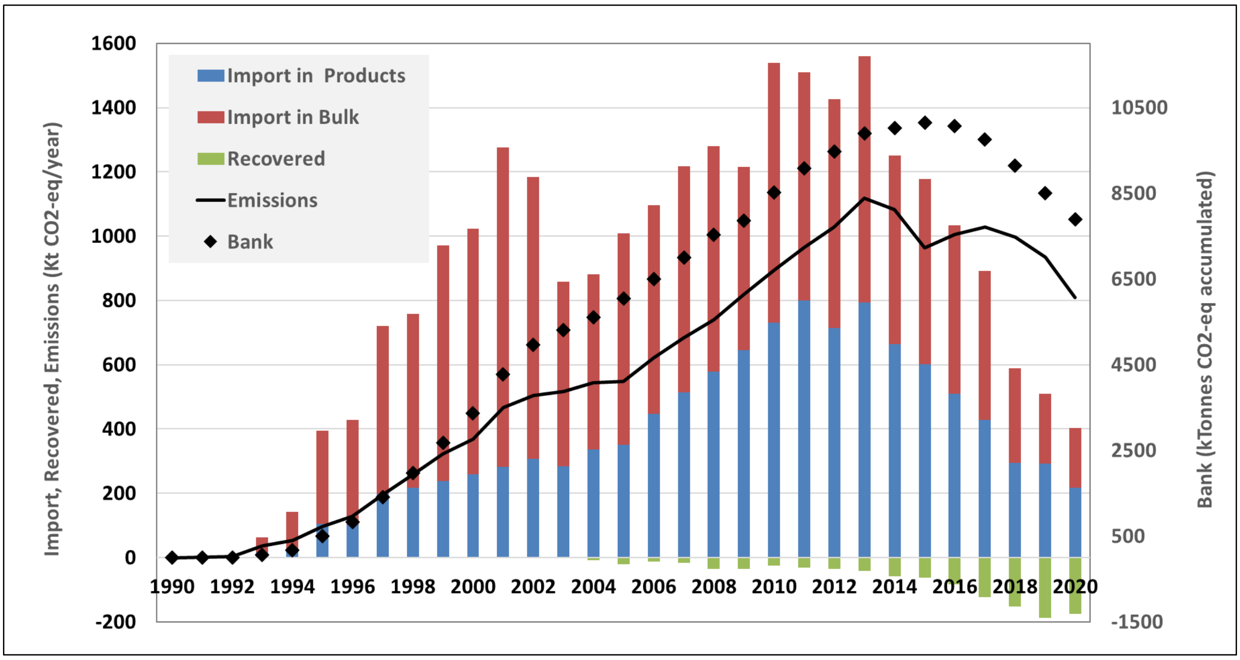
As regards smaller pre-filled products the effect of the tax has probably been less pronounced because of the relatively small HFC charges, and consequently the limited economic effects of the tax. The main products in this category, such as domestic AC/HP and vehicle AC are also all imported products, and the Norwegian market is too small to significantly induce technological change in these products. The downward trend for import in products, measured in CO_2-eq, since around 2010 is mainly caused by EU regulations on vehicle AC by the so-called "MAC-directive" (see chpt. 1.7.2).

The total CO_2-eq bank of HFCs installed in all kinds of equipment and products peaked around 2014 and has been declining slowly since then. This is due to both a move towards use of low-GWP alternatives in new equipment and products and an increase in decommissioning of equipment and products with high-GWP HFCs.

In early years, the amount of gas collected and destroyed was very limited, but this increased significantly from 2016. There has specially been an increase in the amount of collected gas with high GWP-value due to restrictions of use of gas with GWP above 2500 for servicing and maintenance. However, this is also due to increased refund rate that makes it more profitable to recover and collect the used gas. Improved infrastructure for the collection of recovered gas, information campaigns and audits have also led to an increased amount of gas being recovered and collected for destruction.

Due to reasons such as natural leakage only a fraction of the gas deployed can in practice actually be recovered. Our impression is that the economic incentive and seriousness of companies implies that most of the gas from larger equipment is collected by EOL. Potential shortcomings are most likely to be found in less organized areas, such as the decommissioning of domestic AC/HP, where the economic incentives are smaller, and the knowledge of refund and regulations might be incomplete.

Figure 15: HFCs in Norway measured in CO2-equivalents



Source: Torgrim Asphjell, NEA

Note: Bank is total amount of gas estimated to be present in equipment and products. Import is amount of gas added to existing bank by new products or refilling from bulk import. Recovered is amount of gas collected and thereby removed from the bank. Emissions are mainly ordinary leakages, accidental emissions and emissions during servicing or by end-of-life.

1.6 Regulation and Policy Specifically Aimed at SF6

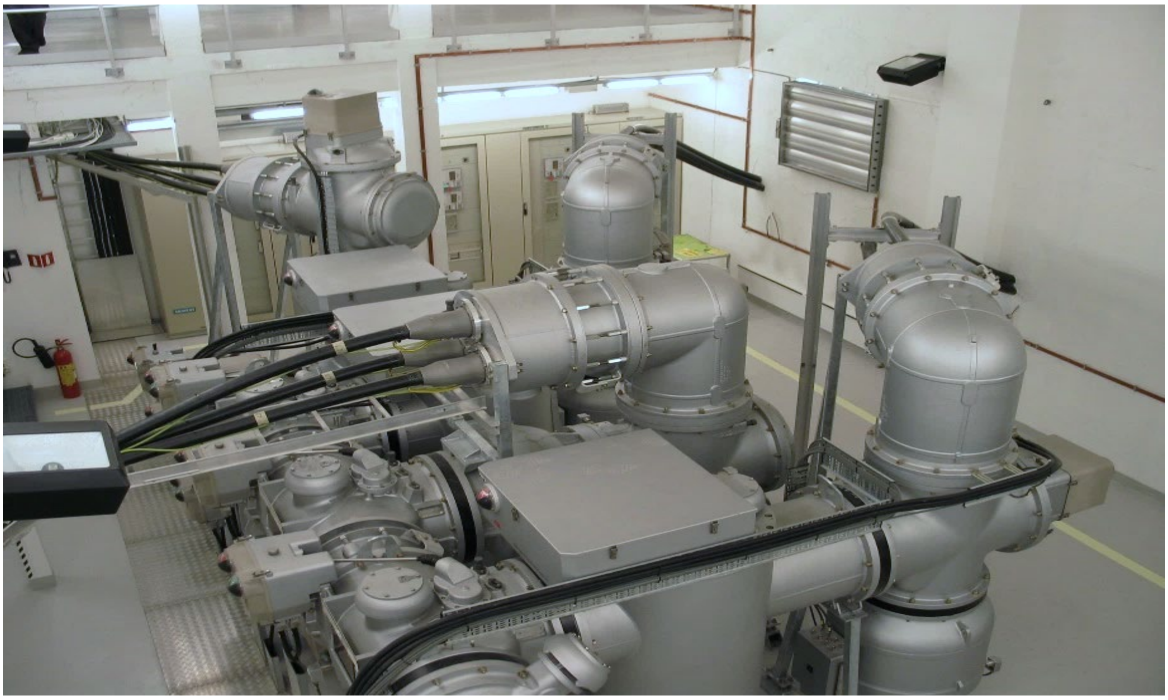
SF_6 is the strongest known greenhouse gas, with a GWP of 22 800 in a 100-year perspective. The gas has an atmospheric lifetime on approximately 3000 years, so consequently it is especially important to reduce emissions of this gas in a long-term perspective. In this perspective all use of the gas should be avoided, since possible future decline in maintenance or catastrophic events might lead to high emissions even from equipment initially regarded as more or less leakage tight.

Up till around the turn of the millennium the dominating source in Norway was the use of SF_6 as a cover gas in a, now defunct, magnesium foundry. SF_6 is now mainly used in gas insulated electrical switchgears (GIS) and other related components used in the electric utilities sector. Today most emissions are leakage from GIS in use or from a factory producing medium voltage GIS.

SF_6 is part of the "basket" of greenhouse gases under the UNFCCC and the Paris Agreement. Countries have committed to reduce their emissions of these gases according to their National Determined Contributions under the Agreement. The Paris Agreement does not have gas specific obligations, such as in the case of the phase-down of HFCs under the Kigali Amendment to the Montreal-protocol (see chpt. 1.5.2).

SF_6 is however included in the EU F-gas regulation (see chpt. 1.5.1). This includes, among others, a specific obligation to recover the gas from stationary GIS and compulsory certification for personnel handling SF_6 (see chpt. 2.3). Hermetically sealed medium voltage GIS and other smaller equipment is also covered by the Producer Responsibility Scheme for WEEE (see chpt. 1.7.1), which prescribes obligatory and free of charge receipt and proper recovery of climate gases during waste recycling.

Figure 16: A large GIS Installation



Source: Torgrim Asphjell, NEA

1.6.1 Voluntary Agreement on the Reduction of Emission of SF_6 from Electric Utilities

From 2002 till 2010 a voluntary agreement was in place between The Ministry of Environment and the users of GIS. According to this the users committed themselves to reduce the emissions by 13% in 2005 and 30% in 2010, compared to emissions in 2000. The agreement covered the complete life cycle of most GIS and included the one producer of medium voltage GIS.

Users (mainly producers of hydroelectricity, grid operators, some large industrial processing plants and the one producer of GIS) were legally represented in the Agreement by their business organizations, while the day-to-day coordination was the responsibility of Renas - a producer responsibility organization (PRO) on WEEE. From the Government side NEA was responsible for following up. The agreement resulted in better equipment, routines and training in both maintenance, decommissioning and production, and all reduction commitments were fulfilled successfully.

One crucial factor for the success of the agreement was probably the possibility introduced by the Government to include SF_6 in the tax regime on HFCs and PFCs that was in preparation at that time (see chpt. 1.5.3.1). The possibility of a very high tax served as an extra incentive to users who formed a "User Group", that among others developed an administrative tool for keeping track of all SF_6 in GIS during the complete lifecycle. This system proved very useful the following up of the agreement, and it also provided valuable input data for the calculation of national emissions. The system also provided accurate information on the amount and origin of recovered SF_6.

Although the agreement expired in 2010, much of the results are in effect till this day. The User Group and its tool is still up and running and the tight and good cooperation between users and the government has continued.

Due to an expected increased use of SF_6 in GIS, because of extension and modernization of the electricity grid, there are concerns that the positive emission trend might not continue and tightening of measures and policy are now being considered. Proposals include a tax modelled on the tax on HFCs (see chpt. 1.5.3.1). The basis for this would be full tax on import of gas in bulk (and due to the high GWP of SF_6 this tax would be very high). The rationale for this is that this gas is used as a replacement for gas that has leaked out and therefore constitutes a proxy emission tax. As regards hermetically sealed products a tax based on estimated total average emissions during lifetime is proposed (and this tax would be only a fraction, maybe around 20%, of the full tax). For producers of GIS and new installations of large GIS, tailormade solutions have been proposed. These proposals are based on the assumption that the tax shall approximate real emissions over time.

Figure 17: Fulfillment of the voluntary agreement on SF6. The target is based on reference year 2000 and reduction targets are 13% by 2005 and 30% by 2010

Source: Torgrim Asphjell, NEA

Note: The figure shows that emissions from 2003 to 2010 were well under the targets for all years. After 2010, when the agreement ended, the emissions showed a downward trend (not shown here).

Figure 18: Equipment from power supply awaiting recovery of SF6.

Source: Torgrim Asphjell, NEA

1.7 Regulation and Practices on Waste Handling

The requirements as regards treatment of the waste gases after recovery from products and equipment is found in the national waste regulation, which covers collection, recycling, destruction, export and other aspects as regards all types of waste. This is largely based on the EU Waste Framework directive (2008/98/EC)[12] and implementing acts.

The waste regulation includes a separate chapter on hazardous waste. Here waste CFCs, HCFCs and HFCs in bulk or in waste electric or electronic products (WEEE) are specifically listed and classified as hazardous waste (for some reasons PFCs and SF_6 are however not classified as such).

Classification as hazardous waste entails that specific requirements as regards storage, transport and treatment apply to this waste. Personnel handling the waste shall have documentable adequate skills and undertakings shall have a permit to handle hazardous waste.

Producers of hazardous waste shall deliver the waste to an approved undertaking at least once a year. A minimum quantity of one metric kilo applies and for cross-border transport specific rules have to be followed. The waste shall be labeled and declared with respect to origin and properties and the shipment shall be according to EU requirements on shipments of waste (No 1013/2006[13]. see also chpt. 2.1.1.7).

Figure 19: Cylinders of waste SF6 at Stena Recycling awaiting transport to Sweden for final destruction.

Source: Torgrim Asphjell, NEA

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN

[13] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1013&from=EN

1.7.1 Waste from Electrical and Electronic Equipment (WEEE)

A system for collection, recycling and other treatment of WEEE was established in Norway in 1999. The amount of waste collected increased steadily till it stabilized around 2010. 144 000 metric tonnes of crude waste, or 26 kilos per inhabitant, was collected in 2020.

The system is regulated in the chapter on discharged electrical and electronic products in the national waste regulation. In 2002 a similar system was established in the EU by the Waste Electric and Electronic Equipment (WEEE) Directive[14], which is also integrated in the Norwegian waste legislation.

The system is based on the Extended Producer Responsibility (EPR)[15], which requires that all importers and producers of relevant products must be member of a Producer Responsibility Organisation (PRO), which is responsible for establishing and operating a system for collection and treatment of WEEE. The PRO must be certified and approved by NEA and today five companies are in the market. The actual treatment of the waste is usually outsourced to other companies, mainly Stena Recycling (see chpt. 2.1.2) and Revac (see chpt. 2.1.3), that are regulated by emission permits from county level environmental authorities. First line collection of WEEE is done by retailers of electronic products. Households can also hand in WEEE at some municipal waste collection points.

Household appliances such as fridges, freezers and domestic AC/HP are covered by this system and smaller GIS are cover through the category "equipment for production of electricity". Large space-built installations, such as high voltage GIS and larger RAC, are not covered.

By reference to the specific regulation on ODSes (see chpt. 1.4) and F-gases (see chpt. 1.5), the regulation specifies that CFCs, HCFCs, HFCs and other gases that are ozone-depleting or have a GWP of more than 15 shall be recovered at an early stage in the treatment process.

The practical implication of this is that all ozone-depleting substances and greenhouse gases must be recovered from the waste covered by the WEEE directive, with a national extension of coverage to large industrial tools and equipment.

Products like fridges, freezers and domestic AC/HP, are collected at waste collection points and transported to a centralized facility for dismantling and recovery of gases, oils and other fluids. Refrigerants are recovered from the cooling circuit and insulation foam is processed with respect to blowing agents.

For larger equipment on-site recovery is usually the only practical solution (this in some cases also applies for smaller installed equipment, such as for some split domestic AC/HP units).

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[14] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02012L0019-20180704&from=EN

[15] OECD defines Extended Producer Responsibility (EPR) as an environmental policy approach in which a producer's responsibility for a product is extended to the postconsumer stage of a product's life cycle. An EPR policy is characterised by: (1) the shifting of responsibility (physically and/or economically; fully or partially) upstream toward the producer and away from municipalities; and (2) the provision of incentives to producers to take into account environmental considerations when designing their products. See: https://www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm

The waste gas will then usually be handled through the SRG system regardless of whether the equipment is covered by the WEEE Directive.

Earlier this scheme was important for collection of CFC and HCFC refrigerants from fridges and freezers. Today ozone-depleting refrigerants are relatively rare in these waste fractions, as hydrocarbons (HC) have long been the preferred choice (HC are, however, routinely also recovered from this equipment). As for foam blowing agents considerable amounts of CFC-11 are still collected, while cyclopentane has been used in newer models.

The use of domestic AC/HP, primarily used for heating, increased fast in Norway around the turn of the millennium, and with a lifetime of 12-15 years replacement is on the increase. Some old products may contain ODSes, but most decommissioned heat pumps contain the HFC blend R-410A, or sometimes HFC-32 in newer pumps.

Figure 20: Sorting and treatment of waste from electrical and electronic equipment (WEEE) at Stena Recycling.

Source: Torgrim Asphjell, NEA

1.7.2 Vehicle Air Conditioning (Mobile AC) and Refrigerated Trucks

Air conditioners (AC) are increasingly becoming standard equipment in new road vehicles, and heat pumps for both cooling and heating of car compartments are now introduced in electric vehicles. In addition, HFCs and other refrigerants are used in cooling or freezing equipment in trucks and trailers for transport of food or other refrigerated goods.

Technically the equipment mentioned above often resembles equivalent stationary equipment. However, the regulatory framework, working conditions and logistics related to refrigerants might be significantly different for mobile equipment. Hence, we have decided to deal with the use of ODSes and F-gases in the road transport sector in this separate chapter.

Mobile air-conditioners and refrigeration units in trucks and trailers falls within the scope of the EU F-gas regulation (Regulation (EU) no 517/2014), which is also implemented in Norway (see chpt. 1.5.1). This requires that personnel recovering F-gases from AC units in passenger cars and light vans shall have training attestation, Personnel recovering F-gases from refrigerated trucks and trailers shall, according to the EU F-gas regulation be certified (see chpt. 2.3). Personnel recovering F-gases from AC-equipment in road vehicles not mentioned above shall be carried out by "appropriately qualified natural persons".

As regards the requirement for recovery, the regulation states that for refrigerated trucks and trailers "operators shall ensure that recovery is carried out". For mobile AC the requirement is "Operators shall arrange for the recovery of the gases to the extent that it is technically feasible and does not entail disproportionate costs" (ref. Article 8).

The provisions for decommissioning of vehicles are detailed in the Norwegian waste regulation, in the chapter on scrapped vehicles, which is based on EU Directive 2000/53/EC[16] on end-of-life vehicles. Here a producer responsibility scheme for collection of vehicles is established. This requires that importers and producers of new cars must contribute to a system for collection of all kinds of vehicles by EOL. This contribution shall be proportional to their current market share.

To comply with the producer responsibility scheme, the company Autoretur AS was established in 2003. This is a Producer Responsibility Organization (PRO), owned by the vehicle importers which has the overall responsibility to ensure that vehicles taken out of service are scrapped and recycled in an environmentally sound and safe manner. This company is audited by NEA. Large vehicles, including refrigerated trucks and trailers, are not included in this and are scrapped at other licensed facilities, both in and outside Norway.

The collection and firsthand processing of vehicles, including recovery of refrigerants, is done by a network of around 140 car collection sites distributed all throughout Norway. These companies are licensed and audited by the county level environmental authorities. A system for general ISO certification of around 900 persons working in the sector is under

[16] https://eur-lex.europa.eu/resource.html?uri=cellar:02fa83cf-bf28-4afc-8f9f-eb201bd61813.0005.02/DOC_1&format=PDF

implementation and will become criterion to be a part of the network of the Autoretur AS PRO.

The regulation requires that vehicles shall be delivered free of charge. As an extra incentive a compensation has usually been paid to those delivering the car, financed by governmental subsidies. In 2022 this amounted to 3000 NOK (appr. 25 000 INR) for a passenger car.

The national waste regulation specifies technical minimum requirements to vehicle waste processing plants. This includes a requirement to recovery refrigerants and all other liquids and transfer it to suitable tanks for storage and further treatment. With the possible exemption of gases contained in foam, it can therefore be concluded that all ODSes, HFCs and other gases and liquids as well shall be recovered from vehicles during scrapping.

The use of refrigerants in mobile AC equipment in new cars is regulated by the so-called MAC-directive (Directive 2006/40/EC[17]) implemented by the Norwegian Public Roads Administration, which puts a GWP limits of 150 on refrigerants in new cars and light vans. This has led to a switch from HFC-134a refrigerant to R-1234yf, which is a low-GWP HFC, commonly referred to as an HFO. It will still take some years before this is reflected in the scrapping of cars. Before the implementation of Montreal-protocol regulation, CFC-12 was the preferred refrigerant in vehicle AC systems.

Around 130 000 vehicles are scrapped in Norway every year. In 2021, about 85 % of these vehicles had an AC unit. The AC units typically contained CFC and HCFC gases up to approximately 1995, but most of these vehicles have been scrapped already. Almost all units in vehicles scrapped today contain HFC-134a. With an estimated average charge of 0.4 kg per vehicles by the time of scrapping, this corresponds to a total of approximately 36 metric tons of HFC-134a per year. Some of this gas is recycled internally while the remaining is handled through the SRG gas collection infrastructure or other channels.

1.7.3 Foam in Buildings and other Constructions

Insulation foams blown with CFCs, HCFCs or HFCs have been commonly used in buildings, roads and other constructions. The foam has either been blown on-site or can be delivered pre-blown, or in prefabricated elements or products. The use of blowing agents has been successively regulated (see chpt. 1.4 and 1.5), and since 2008 hydrocarbons and several other substances, such as HFOs, have been introduced as blowing agents in new products in EU and Norway.

The demolition of buildings is regulated in the national building acts and regulations, Chpt. 9[18]. It prescribes that construction works shall be demolished in a manner that results in the least possible impact on natural resources and the external environment, and that construction waste shall be handled accordingly. For buildings (more than 100m^2 or 10 tonnes of waste) surveys of hazardous waste and specification on decontamination and proper treatment of

[17] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:161:0012:0018:en:PDF

[18] See: https://dibk.no/globalassets/byggeregler/regulation-on-technical-requirements-for-construction-works--technical-regulations.pdf

hazardous waste shall be prepared. This regulation has, however, no specific requirements for the recovery of any blowing agents. according to the F-gas regulation (see chpt. 1.5.1), HFCs in equipment shall be recovered by certified personnel, while "other products", such as foam, "shall be recovered to the extent that it is technically feasible and does not entail disproportionate costs".

According to the EU REACH regulation on chemicals, foam can be incinerated in waste treatment plants, provided that the blowing agents are completely decomposed. NEA or County Governors decide whether a facility fulfills this requirement. Today this is the only method used to destroy buildings and construction foam in Norway. Some years ago, a pilot plant for recovery of gas from this kind of foam was established, however due to logistical and other challenges the plant was closed soon thereafter.

The lifespan from construction till demolition is often very long, so significant quantities of foam containing CFCs or HCFCs is still awaiting demolition. However, due to diffusion over time the content of blowing agent in this ageing building materials might have been reduced by more than 50 percent.

Figure 21: Demolition of building containing insulation foam.

Source: Torgrim Asphjell, NEA

1.8 Transport and Export/Import of Waste Gases

Import and export of waste is subject to many international agreements under the umbrella of the Basel convention, which is implemented in Norwegian and EU through Regulation 1013/2006[19]. This regulation covers transboundary transport of all kinds of waste.

The Basel convention focuses on the protection of humans and the environment from the negative effects of hazardous waste. One of the main purposes of the convention is that export and import of hazardous waste shall be minimized and the waste shall be treated appropriately.

A permission is required for import and export of waste and in Norway this permission is issued by NEA. As is the case for the export of ODSes and HFCs from SRG to Trédis destruction facility in France, this permission is based on prior written notification and consent and proper labelling according to the requirements as regards hazardous waste. Proper treatment is ensured since destruction facilities in France comply with the EU Directive on the incineration of waste (see chpt. 2.2).

Figure 22: Tank at Revac containing a mixture of CFCs and hydrocarbons. The gases are collected from insolation foam in old household fridges and the tank has been readied for transport.

Source: Torgrim Asphjell, NEA

[19] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1013&from=EN

1.9 Emission Permits and Auditing of Enterprises

Enterprises that collect, treat, or destroy waste gases or other waste need an emission permit to operate. For the biggest and potentially most polluting undertaking this permit is issued by NEA, while for smaller facilities this work is delegated to the county level environmental authorities at the County Governor.

Compliance with the emission permit, the specific regulations on ODSes and F-gases, and the general waste regulation is audited by authorities at the same administrative level.

In addition to the environmental regulation by NEA and County Governors, the companies are also regulated by other agencies as regards safety and working conditions.

1.9.1 Emission Permits

The sites that process or handle waste need general emission permits as specified in the Pollution Control Act. These permits, which come in addition to the specific legislation on F-gases and ODSes and the general regulations on waste, focus on the general operation and management of the plant. They are issued by NEA or by the County Governor.

For the undertakings mentioned in this report, the following applies:

- Waste gas collection company SRG has a permit from the County Governor with general requirements for operation and specifying the amount of gas that can be collected pr year.
- WEEE treatment plants Stena Recycling, Revac and Metallco have permits from County governors. The permit will specify the amount of waste they can store and treat. Recovery of all types of gas is required for fridges, freezers, domestic AC/HP and other products.
- Norcem AS has a permit from NEA for co-processing of waste CFCs, HCFCs and HFCs in cement kiln in Kjøpsvik. This option was previously used by SRG (see chpt. 2.2.1).
- Vehicle EOL collection and recycling sites need permits from County Governors.
- Building entrepreneurs. When demolishing buildings or other installations it is required to have a plan how to handle waste, according to the planning and building regulation. The Municipalities ensures enforcement of this.

1.9.2 Audits of Compliance with Emission Permits

Compliance of emission permits is regularly audited by NEA or by County Governors.

All undertakings with emission permits are audited regularly, evaluating all aspects of the permits as well as compliance to relevant regulations in general. This will include the treatment of the waste itself, emissions from the treatment and the fate of the treated waste. The audits are often part of a concentrated action where NEA and County Governors will use the same checklist and follow up as many sites as possible during this period.

In general, all aspects of the activity related to the environmental legislation is followed up at the undertakings. This includes F-gas regulation and the general waste regulation. The County Governors do not have authority to follow up the F-gas regulation and can only follow up compliance with the Waste Control Act and the Pollution Control Act. The municipalities have the authority to ensure enforcement according to the Planning and Building regulation, for example the waste handling plans.

If non-compliance is found the sanctions can vary from a written advice to withdrawal of the permit to operate depending on the severity of the non-compliance and willingness and ability to improve. In severe cases the undertaking will be reported to the police.

All levels of sanctions have been used although no permit has been withdrawn because of non-compliance related to the F-gas regulation.

NEA also performs audits on the RAC service sector and imported products and gases. This is important for enforcement and communication as regards recovery of gas from equipment and detection of old stocks of gas (see chpt. 2.4).

Figure 23: NEA audit at the Norcem cement kiln in Kjøpsvik, which was previously used to destroy refrigerants.

Source: Torgrim Asphjell, NEA

1.10 Other Relevant Legislation

In this report, focus is on environmental regulation. However other legislation and policy, on safety and working environment in particular, is also important and will indirectly affect environmental performance as well.

The Norwegian Directorate for Civil Protection (DSB)[20] covers preparedness, emergency planning and safety. This includes national crisis preparedness and more specific issues such as fire- and explosion safety and transport of hazardous substances. The safety hazards associated with many of the gases covered in this report are moderate, however the equipment might be co-located with other installation containing toxic or flammable refrigerants such as NH_3 or hydrocarbons. The use of SF_6 in electricity supply also raises broad issues related the exposure of infrastructure with potentially high emissions in times of crisis.

Working environment is regulated by the Norwegian Labour Inspection Authority through the Working Environment Act[21], which regulates physical and psychosocial working environment, working hours, employment protection, etc. This includes requirements on routines and equipment to prevent or counteract injuries to health due to chemicals substances.

Figure 24: Emergency equipment for fire safety and exposure to chemicals.

Source: Torgrim Asphjell, NEA

[20] https://www.dsb.no/menyartikler/om-dsb/about-dsb/

[21] https://www.arbeidstilsynet.no/en/laws-and-regulations/laws/the-working-environment-act/

2 Infrastructure, quality assurance and lessons learned

In this chapter we will describe how recovery and collection of ODSes and F-gases is done in practice in Norway. We will focus on the major players for collection of gas and recycling of products. However, it is important to keep in mind that much of the first line collection is done by municipal waste companies or local resellers in the case of WEEE, or businesses in the RAC sector.

As regards final treatment, the general requirement on waste destruction facilities will be explained. Destruction will be exemplified with co-processing in cement kiln, a regular hazardous waste treatments plant and on-site destruction and an example of previous recycling in Norway will be given.

Finally, quality assurance will be exemplified by work on certification, audits and analysis of gas, before the report is finalized with some reflections on how to achieve high recovery rates.

2.1 Infrastructure for Recovery and Collection of Gas

In Norway there are primarily three companies involved in recovery and collection of gas on a large scale, commercial basis and each of them have a somewhat different approach:

- **Norwegian Foundation for Refrigerant Recovery (SRG)** collects ODSes and HFCs in bulk. This company was established by the refrigeration sector in 1990 and has a nationwide network for collection and consolidation of waste or surplus refrigerants (see chpt. 2.1.1).
- **Stena Recycling** is a company that treats all kinds of Waste from Electrical or Electronic Equipment (WEEE). They have on-site equipment for recovery of refrigerant from domestic AC/HP and a vacuum chamber for complete recovery of SF_6 from medium voltage GIS. They also serve as a collection point for waste or surplus SF_6 in cylinders (see chpt. 2.1.2). Fridges and freezers are transported to a recycling and destruction facility in Sweden for recovery and on-site destruction of refrigerants and foam blowing agents (see chpt. 2.2.3).
- **Revac** is another company specializing in treatment of WEEE. They have a newly installed "Fridegeline" (see chpt. 2.1.3) for collection of refrigerants (step 1) and foam blowing agents (an optional step 2) from freezers, fridges, domestic AC/HP and other home appliances. The recovered refrigerant is handled by SRG, while foam blowing agents are sent to a destruction facility in Germany

In addition to the three companies mentioned above, vehicle- and metal recycling companies also perform related activities. Much of the first line collection prior to this is done by municipal waste companies or local retailers in the case of WEEE, or businesses in the RAC sector.

2.1.1 Collection of Recovered ODSes, HFCs and PFCs in Bulk by SRG

Norwegian Foundation for Refrigerant Recovery (SRG) started out as a project for receiving waste ODS refrigerants. In 1991, the project was registered as a foundation for refrigerant recovery, and this was the beginning of SRG. Today SRG is the only Norwegian undertaking managing collection of synthetic refrigerants (ODSes, HFCs and PFCs) and halons in bulk. The company also collects used CO_2, glycols, and oils.

SRG managed the refund system for the reimbursable environmental fee on CFCs and HCFCs from 1991 to 2020 (see chapter 2.1.1.1). From 2004 SRG has been the sole commercial provider of refund for used HFCs and PFCs in bulk based on the governmental refund scheme (see chpt. 2.1.1.2).

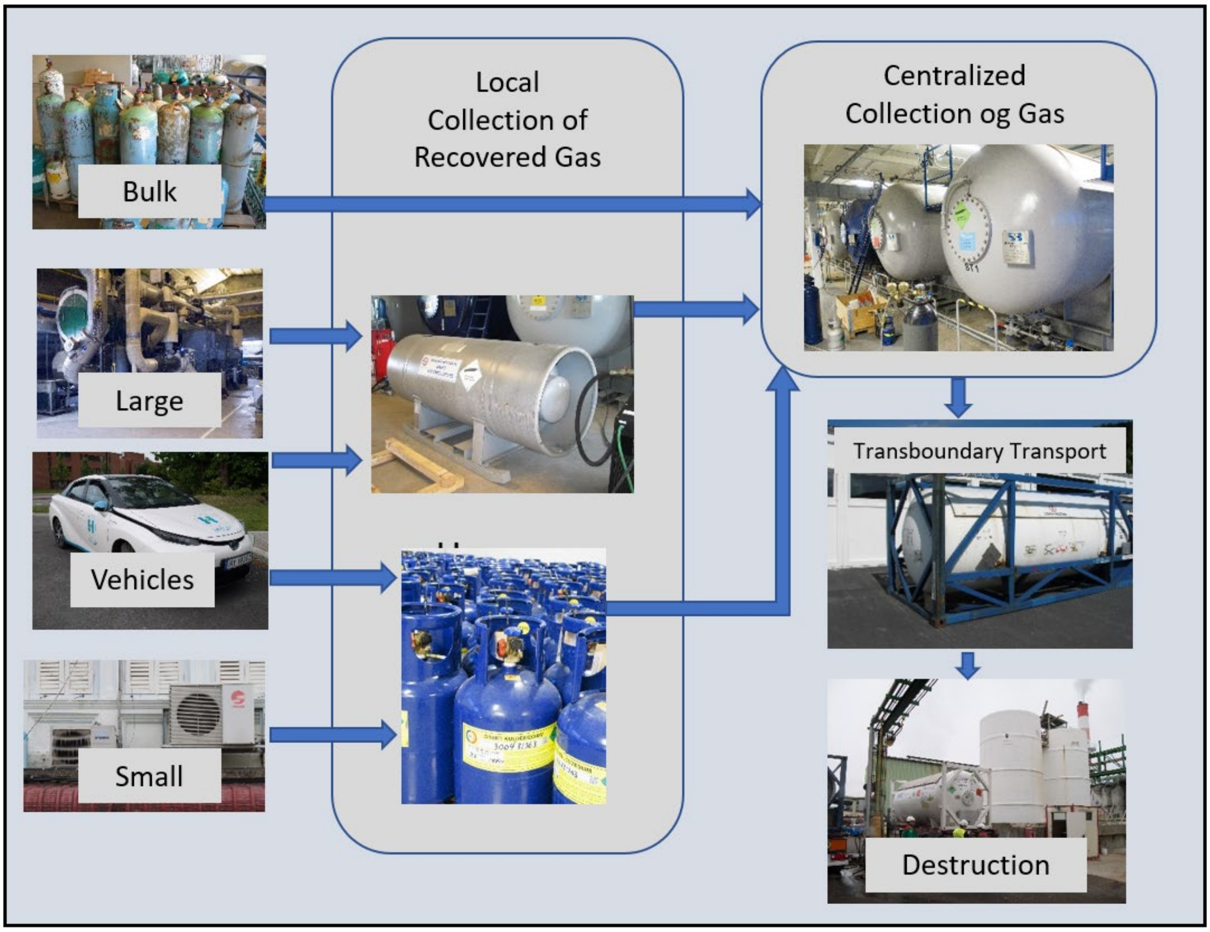
SRG's vision is to become a leading international company within collection of environmentally hazardous gases and waste. SRG's goal is to contribute to the reduction of net use and emissions of regulated substances in order to fulfill the obligations in the Montreal and Kyoto Protocols and national regulations. In addition, SRG aims to ensure that all relevant parties in the market utilize the SRG system for environmentally sound handling of waste refrigerants and other gases.

SRG is situated in Hokksund near Oslo, has 9 employees and has collected 1000 metric tonnes of waste including synthetic refrigerants, halons, oil, and glycol from 2009 to 2021. SRG is committed to a NetZero emissions target through preventive maintenance, use of leak tight hoses and connections and leak testing of all pressure vessels received and sent. So far there has been no accidental leakages of refrigerants or deviations from the emission permit.

Figure 25: Cylinders of collected waste refrigerants ready for analysis and further treatment.

Source: Torgrim Asphjell, NEA

Figure 26: Flowchart describing the logistics for collection of CFCs, HCFCs, HFCs and PFCs in bulk by SRG



Source: Torgrim Asphjell, NEA

Note: Stockpiles of gas or recovered gas from all types of installations and equipment can be delivered to local collection points. SRG provides gas cylinders or larger tanks according to the waste producer's needs. The cylinders and tanks are then sent to SRGs central facility near Oslo for analysis and consolidation where the smaller batches of gas are transferred to a large tank. The gas is then transferred to a transport tank for destruction at the Trédi facility in France. In addition to this SRG also collects Halons for recycling.

2.1.1.1 Reimbursable environmental fee on ODSes

SRG was initiated with the collection of CFCs and other ODSes such as halons. The project was a voluntary agreement between the Norwegian Government represented by NEA and the refrigeration sector including importers of gas and other users. The project was a consequence of Norway's adherence to the Montreal Protocol and the requirements imposed on CFC users. The project's aim was the organized recovery and destruction of ODSes, to avoid emissions from ODSes at end-of-life.

The project was led by a board consisting of associated deputies chosen by the importers and distributors of refrigerants, refrigeration contractors and NEA. The board members were elected for a one-year period.

The Ministry of Finance granted an exemption from the Norwegian competition Authority, in order to establish an environmental fee per kg of CFCs that was sold on the Norwegian market. This environmental fee was to be reimbursed when CFCs were returned for destruction. The CFCs had to originate from refrigeration systems installed in Norway, but the reimbursement was not limited to gas that had been taxed in the first instance. The Ministry of Finance allowed the project to build up a fund of NOK 25 million, which was to be used for the following activities:

- Reimbursement of the environmental fee
- Covering of environmental fee administration/handling expenses for importers and distributors
- CFC destruction costs
- CFC recycling costs (only HCFC-22 was recycled)
- Storage costs
- Project's administration costs
- Costs for information and outreach activities

Revenue from CFCs import through this environmental fee ceased in 1994 when import was banned. SRG discontinued the reimbursement of this fee for CFCs in 2015 but continued to receive gas free of charge until mid-2016.

Halons have been collected and reclaimed for critical use according to the Montreal Protocol. Today CFCs and halons can still be delivered to SRG; however, there is a handling fee charged per kg delivered.

In 1998, HCFC-22 was included in this voluntary scheme as the only HCFC-gas. When the environmental fee for HCFC-22 was phased out in 2020 the reimbursement also ceased, but HCFCs can still be delivered free of charge.

2.1.1.2 Refund for waste HFCs and PFCs in bulk

As a national measure, the Norwegian authorities introduced a tax on HFCs and PFCs in 2003 and from mid-2004 a refund equal to this tax was introduced (see chpt 1.5.3.2). This implies that the tax will be refunded if the HFCs or PFCs are recovered and destructed.

As the sole actor SRG established a system for collection of waste HFCs and PFCs in bulk based on the incentive given by the refund scheme. Ever since SRG has received refrigerant waste, performed an analysis, and reimbursed the tax minus SRG's expenses to the waste producers.

The reimbursement process has changed over the years. In the beginning, the waste producer was reimbursed only after the destruction was documented and SRG had received the reimbursement from NEA. This process was tedious and long, and most waste producers complained, while some did not bother to deliver the refrigerant gas at all. Therefore, SRG decided to pay the waste producers in advance after the analysis was available and registered in SRGs internal systems.

Prior to 2015, the environmental fee for CFCs and HCFCs was also reimbursed together with the governmental refund on HFCs/PFCs.

2.1.1.3 Collection

A key element for the recovery and collection of refrigerant gases is having refillable cylinders available. Hence, Isovator (SRG's subsidiary) rents out refillable cylinders approved for the collection of refrigerants.

Currently, Isovator offers two types of refillable gas cylinders, for non-flammable refrigerants and flammable refrigerants. Isovator also offers ton tanks (1000 kgs), see figure 28 chpt. 2.1.1.8. All pressure vessels are washed, dried and vacuumed before delivery to customers.

SRG, through bilateral agreements with refrigerant distributors, has approximately 60 collection points in Norway where gas can be delivered and transported to SRG free of charge. This system is financed through the sale of the Isovator refrigerant collection cylinders at a lower cost to the collection points. Isovator also credits the collection points with an incentive based on kilos of refrigerant delivered to SRG.

Figure 27: Isovator refillable cylinders for non-flammable and flammable refrigerants.

Source: Isovator

2.1.1.4 Recycling

As of today, all refrigerants SRG receive are dispatched for destruction. None of the waste received is recycled because the condition of the waste does not permit it, or it is not economically feasible.

However, in the past, there was a small percentage of the waste gas received which was recycled. HCFC-22 received was recycled by SRG in order to fit the criteria of the Norwegian Refrigeration Standard by removing impurities such as water content and acids. (see also chpt. 2.2.4).

SRG is still receiving halon-1301, -1211 and -2402. These halons are weighed and stored. The used halon is then sold to approved halon reclamation facilities in the EU for critical use according to the Montreal Protocol. The halon recycler either arrives at SRG's premises for decanting or the cylinders are exported.

2.1.1.5 Destruction

In the past, the waste refrigerant gas was destroyed at Norcem's cement kiln in Kjøpsvik, Norway (see chpt 2.2.1). As of today, SRG sends the waste to the Trédi Saint-Vulbas dedicated hazardous waste destruction facility in France (see chpt. 2.2.2).

The waste is sent in 25 m^3 transport tanks approved for transport by road, rail and sea. Upon arrival at Trédi the tank is connected to the internal piping at the destruction plant and the gas is gradually fed into the kiln over a period of approximately 1-2 weeks. When the transport tank is fully emptied it is sent back to Norway where it is weighed once more to make sure the tank is completely empty. The transport tank is then vacuumed and checked for leaks before being utilized again.

2.1.1.6 Refund for HFCs and System and Logistics for collection

The process for refunding waste HFCs and PFCs begins when the waste producer registers the waste gas in NEA's waste declaration system, and then sends the waste gas in cylinders to SRG's premises. The process can be summarized as follows:

1. The waste producer registers the refrigerant gas waste through the National waste declaration system administered by NEA.
2. Upon arrival at SRG, the waste cylinders are first leak checked and then registered in the waste management system (WMS) utilizing the number provided by the national waste declaration system. Afterwards, the gas cylinders are weighed in.
3. The gas in the cylinders is analyzed (see chpt. 2.5) and the results are registered in the WMS.

4. The contents of the analyzed cylinders are emptied over to a stationary tank for storage.
5. SRG is initially credited with the refund and after a deduction to cover internal costs, the remaining portion is paid out from SRG to the waste producer.
6. When the stationary tank reaches a certain weight, its contents are transferred to a transport tank.
7. SRG contacts a representative from NEA for audit of the tank's contents (expressed as weight fractions of the different components determined by analysis) and total weight. The valves are sealed.
8. The transport tank is sent to the Trédi destruction facility in France. (see chpt. 2.2.2). Trédi documents that the seals are not broken upon arrival. The gas is destroyed.
9. SRG sends reimbursement application to NEA for refund for the HFCs and PFCs destroyed. The application contains documentation, which specifies all the analyses for each cylinder of gas that was transferred to the transport tank and destroyed.

2.1.1.7 Employee Training

SRG, and its subsidiary Isovator, employs mostly internal training, but also some external training, to all its employees. The following topics are covered:

- Health, environment and safety related to refrigerants, halons and oils (used compressor oil)
- Operator training according to the Regulation for handling of flammable, reactive and pressurized substances
- Use of the national waste declaration system
- Transport of hazardous waste
  - by Road (European Agreement concerning the International Carriage of Dangerous Goods by Road, ADR[22])
  - by Rail (Convention concerning International Carriage by Rail (COTIF). Appendix C – Regulations concerning the International Carriage of Dangerous Goods by Rail, RID[23])
  - by Sea (the International Maritime Dangerous Goods, IMDG[24])
- Handling of hazardous waste

[22] https://unece.org/transportdangerous-goods/adr-2021-files

[23] https://otif.org/fileadmin/new/3-Reference-Text/3B-RID/RID_2021_e_01_July_2021.pdf

[24] https://www.imo.org/en/OurWork/Safety/Pages/DangerousGoods-default.aspx

- Handling of gas cylinders and tanks
- Personnel certification according to the F-gas regulation (see chpt. 2.3)
- First-aid course
- Fire and gas emergency evacuation course

All employees have access to personal protection equipment (including gloves, protection glasses, work clothing and protective footwear). SRG's premises are equipped with necessary first-aid equipment, and fire- and gas detection systems.

Section leaders are responsible for personnel training in their respective areas. SRG has its own safety advisor for the transport of hazardous waste, who will train personnel and advice customers.

2.1.1.8 Infrastructure/Equipment

For the management of approximately 100 metric tonnes of waste per year (CFCs, HCFCs, Halons, HFCs, PFCs, oil and glycol), SRG counts with the following equipment:

- *6 stationary tanks:* These have a capacity of 25m^3 per tank, currently 2-3 tanks are utilized. In the past, when HCFC-22 was recycled or cylinder-filling services were offered, all stationary tanks were used.
- *2 transport tanks:* These have a volume capacity of 25m^3 and are approved for the transport of waste refrigerant on road, by rail and by sea.
- *10 pcs 1 tonne tank* approved for transport according to ADR/RID
- *10 transportable medium-sized tanks:* these have a capacity of 1480 liters.
- *Cylinder park* (10.000-12.000 units) with 2 types of cylinders:
    - 27,2 liter refillable cylinders approved for transport (42 bar)
    - 12,3 liter refillable cylinders approved for transport specific for the collection of flammable refrigerants (48 bar)
- *Additional cylinder and tank valves*
- O-rings and seals for all valve and tank types
- IBC containers: for collection of waste oil and waste glycol received

- Equipment for washing, drying and vacuuming cylinders.
- Equipment for refrigerant gas transfer (2 recovery stations) between all types of pressure vessels.
- Gas manifold (system of pipes with valves to control the flow of gas or liquid) from recovery station to stationary tanks, and from stationary tanks to transport tanks.
- Waste management system (software) tailored to the needs of the waste industry and SRGs analytical requirements.
- Electronic quality system (software) for the internal control of procedures, deviations and adherence to laws, regulations and standards.
- Electronic maintenance program for equipment and building requirements

SRG/Isovator also has agreements with transport providers and other waste management providers for the final handling additional wastes such as glycol, oil, and discarded gas cylinders (metal recyclers).

Figure 28: Tanks for transportation of recovered refrigerants

Source: Isovator

Note: Upper left: Stationary tanks and 1480 litre tank; Upper right: 1 tonne tanks; lower left: Transport tank; and lower right: Medium-sized tank

Figure 29: 27,2 L refillable cylinders for non-flammable refrigerants. IBC container.

Source: Isovator

Figure 30: Equipment for cylinder washing and drying

Source: Isovator

2.1.2 Recovery of ODSes, HFCs and SF6 from Products by Stena Recycling

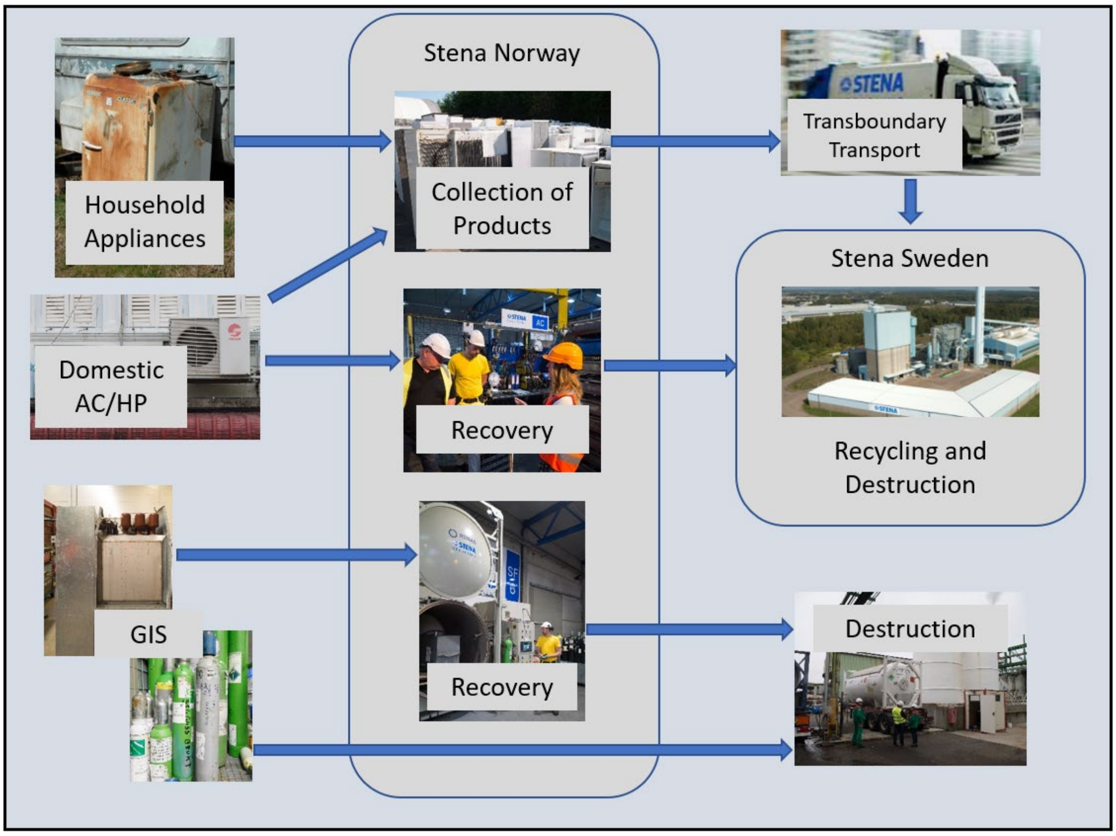
Stena Recycling AS is the Norwegian branch of the privately owned Swedish conglomerate Stena Group's Stena Metall AB. Their focus areas in Norway are metals recycling, waste from electric and electronic equipment (WEEE), hazardous waste and paper recycling.

Stena was established as a scrap dealer in Gothenburg in 1939, and has had an enormous growth since, splitting into two groups in 1972, Stena Metall and Stena Line shipping company.

Stena Metall has direct operations in 9 countries, at 200 sites, with an annual turnover around 2.5 billion USD, or alternatively, recycling material equivalent to one Eifel Tower per day. In Norway, WEEE is delivered to local pick-up points or collected by industrial waste companies and delivered to waste management companies, among which Stena Recycling at Frogner outside of Oslo is one of the three main undertakings.

At the Frogner facility Stena performs a first line recycling by dismantling the waste and taking out hazardous material like mercury capacitors and batteries. Some plastic and general waste is removed, and the remaining material is transported by truck to Stena Nordic Recycling Center in Halmstad, Sweden. Here the material is dismantled further and sorted into the various metals and plastics.

Figure 31: Flowchart describing the collection of ODSes and HFCs from household appliances and Domestic AC/HP and SF6 from GIS at Stena Recycling



Source: Torgrim Asphjell, NEA

As regards waste containing ODSes, HFCs or SF_6, there are three distinct processes or logistic lines:

1. **ODSes and HFCs from household appliances**
As required by the Producer Responsibility Scheme for Electric and Electronic Waste (see chpt. 1.7.1), products are collected and stored at the Frogner facility outside of Oslo before transport to the Nordic Recycling Centre in Sweden where the compressor is taken off and the refrigerants are collected and destructed on site by catalytic oxidation (see chpt 5.2.4).

The refrigerants recovered today are mostly HFC-134A and Isobutane (R-600A).

HFC-134A has also been used as blowing agent for polyurethane (PU) foam used as insulation foam for refrigerators. In newer products cyclopentane and HFOs have now replaced HFC-134A.

In older refrigerators (before 1990), both the compressor gas and the blowing gas (insulation) consisted mostly of CFC gasses, whereof CFC-12 was the most used refrigerant and CFC-11 as foam blowing agent.

2. **ODSes and HFCs from Domestic AC/HP**
Stena used to recover gas from small domestic heat pumps/air-conditioning units in Norway, but this is now done in Sweden. Most of the 15.000 units received from the Norwegian market annually have the gas charge intact, but sometimes the gas has leaked out or been recovered prior to delivery. The normal gas charge is 1 kg/unit.

After recovery the gas is oxidized in the same process as the HFCs from household appliances (see chpt. 2.2.3). The gas in domestic AC/HP is mostly the HFC mixture R-410A, with an increasing share of the lower GWP R-32 refrigerant from newer units.

The lifetime of domestic AC/HP is estimated to around 10 to 15 years, so items built before the ban of CFCs by the Montreal Protocol are seldom collected.

Some refrigerant charge might be lost during dismantling, transport and handling if care is not taken.

3. **SF_6 from medium voltage GIS and bulk deliveries**
Stena collects and receives, compact hermetically sealed, medium voltage GIS for recovery of the SF_6 insulation gas. These units, typically contain between 1 and 6 kg of gas, are placed in a vacuum chamber and the complete charge of SF_6 is recovered and transferred to a storage tank. Recovered gas is then sent to the Fortum facility in Kumla, Sweden for final destruction. Stena also use its facility in Norway as a logistics hub for collection of waste SF_6 in gas cylinders.

Stena has considered developing a cleaning and recycling unit for SF_6 gas but considers the volume for such a costly process development and operation is not viable.

Annually Stena Norway recovers approximately the following quantities in metric kilos:

- SF_6 recovered from medium voltage GIS: 600 kg
- SF_6 in collected waste gas cylinders: 1.000 kg
- HFC-134a refrigerant collected: 1.450 kg
- R-600a (Isobutane) refrigerant collected: 5.500 kg
- CFC-12 refrigerant collected: 2.000 kg
- HFC mixture gas R-410A collected: 12.000 kg

The Stena operations ensure an extremely high recovery rate of the gases it is collecting. Especially the SF_6 vacuum chamber recovery is close to free of leakage. Generally, the recovery rate at the plant is significantly higher than recovery done on-site with simpler equipment and procedures.

However, some of the refrigeration circuits received might have lost the charge prior to arrival. This can be due to accidental leakage or on-site recovery. Due to regular leakage during use, the received products are normally not fully charged, and some additional gas might also have leak out during transport and handling.

There are also a small percentage of received refrigerators where the compressor has been removed before recycling.

Figure 32: 100% recovery of SF6 in GIS by use of a vacuum chamber.

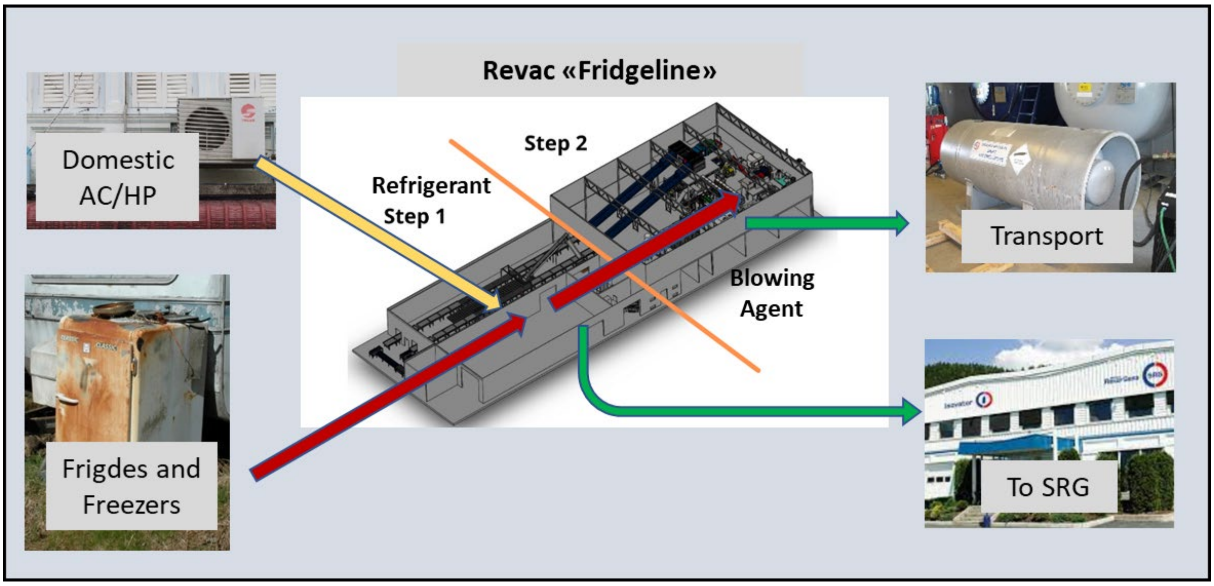
Source: Torgrim Asphjell, NEA

2.1.3 Recovery of Refrigerants and Foam Blowing Agents by Revac "Fridgeline"

Revac is one of Scandinavias biggest undertakings involved in collection and treatment of WEEE and has plants in Norway and Sweden. The Norwegian plant is by far the biggest in Norway and handles 70 % of the total post-consumer waste electronics placed on the Norwegian market. The plant is one Europe's most modern and meets all BAT[25] and BREF[26] regulations for now and the near future.

Revac was established in 1996 as a joint stock company, with main office in Norway and a daughter company in Sweden. It has around 180 employees and a yearly turnover of around 60 million Euros. The company operates under emission permits from County Governors and adherts to the ISO 9001 and ISO 14001 standards.

Figure 33: The Revac Fridgeline



Source: Torgrim Asphjell, NEA

Note: The Revac «Fridgeline. Refrigerants from freezers, fridges and domestic AC/HP are recovered in step 1 and the collected gas is sent to SRG. Freezers and fridges are then sent to a second step, where blowing agents from the insulation foam are recovered and sent to Germany for destruction.

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25 Best Available Techniques according to EU legislation.

26 EU Best Available Techniques reference documents. For waste treatment, see: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018D1147&from=EN

2.1.3.1 Collection of WEEE in Norway

According to the producer Responsibility Scheme for Electric and Electronic Waste (see chpt. 1.7.1) all importers and producers placing electrical or electronic products on the Norwegian market are obligated to a membership in a Producer Responsibility Organization (PRO). This includes commitments on volumes of electronic waste to collect yearly.

Revac has agreements with close to 2000 collection points all over Norway and handles the logistics from these point to the treatment facility outside of Oslo. Revac recycles 60-65.000 metric tonnes of WEEE a year.

The waste fraction of relevance for this report sorts under the WEEE waste category 1, "Temperature exchange equipment". This includes Refrigerators, Freezers, Equipment which automatically delivers cold products, Air conditioning equipment, Dehumidifying equipment, Heat pumps, Radiators containing oil and other temperature exchange equipment using fluids other than water for the temperature exchange.

2.1.3.2 The Revac "Fridgeline"

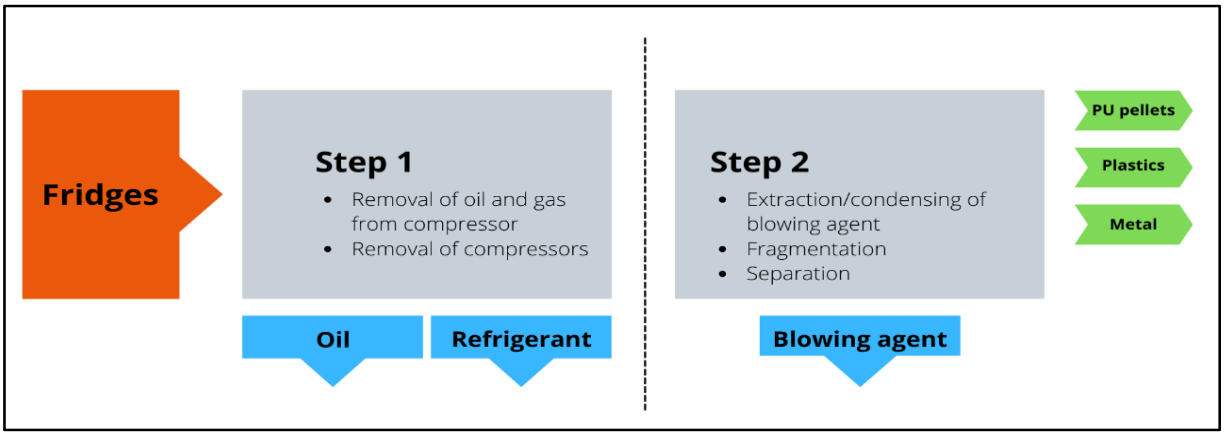
Revac's waste treatment line in Norway processes about 200.000 unit of fridges, freezers, Domestic AC/HP and similar equipment every year. Revac has also a similar line in Sweden with the double amount, approximately 400 000 units/year.

The handling is a two-step process:

1. Recovery of **refrigerants** and compressor oils. These are drained from the units as a mixture. The refrigerant and the oil are then separated by heating and pumped into separate storage tanks. The refrigerants in freezers and fridges are usually CFC-12 in old units, HFC-134a, or natural refrigerant isobutane (R-600a) in newer units. Domestic AC/HP usually contain the HFC mixture R-410A, but some old equipment contains CFC-12 and newer items might contain HFC-32.
2. Recovery of **foam blowing agents** in the insulation polyurethane (PU) foam in freezers and fridges. This is usually CFC-11 in old units and natural agent cyclopentane in newer units. After dismantling the foam is made into pellets. This is done in an inert atmosphere and blowing agents are taken out as a gas and separated out in active carbon reactors. After gradually colling the blowing agents will be stored in a tank as a mixture of CFC-11 and Cyclopentane. This stage requires a significant infrastructure and costly to run. The content of blowing agent in the residual PU is below 0,1 %.

The objective of both stages is to extract refrigerants and foam blowing agents with the potential to damage the environment, leaving commonly fractions like plastics, metals and PU without blowing agents. The remaining fractions are sorted and split in pure materials and forwarded for recycling.

Figure 34: Schematic description of the process flow in the "Fridgeline" for fridges, freezers and other home appliances and smaller units containing foam



Source: Torgrim Asphjell, NEA

Note: In the first step refrigerants are recovered together with compressor oils. In the second step blowing agents are recovered and solid materials are sorted out and prepared for recycling or further treatment. Step 1 is also used for domestic AC/HP and other home appliances containing refrigerant only. For this kind of equipment separation and fragmentation is done in another part of the facility.

Figure 35: The Fridgeline

Source: Torgrim Asphjell, NEA

2.1.3.3 Destruction or further treatment

From step 1 the refrigerants and the compressor oil are pumped by compressor pumps to two separate big unit tanks. The collected refrigerants total about 12.5 metric tonnes a year and are delivered to SRG as a mixture, which handles the waste further and pays out refund (see chpt. 2.1.1.2). The oil is delivered to external undertakings for energy recovery or re-refining.

The gas collected from step 2 totals around 50 metric tonnes a year and is a mixture of around 30% CFC-11 and 70% Cyclopentane. It is pumped into big unit portable tanks and transported to a destruction facility in Germany.

Revac ensures a high rate of the capture of ozone-depleting substances and greenhouses gases in the newly built fridge lines and ensure no leakage due to closed loop processes. There are though a small percentage of received equipment in which compressors already have been removed or the cooling circle is broken. In these cases, the gas is lost. This is outside of the responsibility of the waste handling companies.

Figure 36: Study tour at Revac

Source: Torgrim Asphjell, NEA

2.2 Destruction, Recycling or Reclamation of Recovered Gas

Destruction of the gases is usually performed thermally by incineration or by high temperature plasma arc technology. In these processes the chemical compounds are destroyed by breaking them down to simpler molecules. Many of the break down products are harmless or naturally occurring compounds, such as CO_2, water, and some salts, that can be released more or less directly to air or water. Others are acids or other pollutants that need further treatment. None of the chemical elements in these gases are heavy metals, radioactive or particularly toxic in elementary form.

The destruction must be carefully controlled to avoid new toxic compound being formed during the process. CFCs and HCFCs contain chlorine that might contribute to the formation of extremely toxic dioxins and furans, and emissions of particulate matter and chlorine-, fluorine- and other compounds, are to be monitored regularly. Careful control of process parameters such as temperature is often used in combination with scrubbers, filters, and other cleaning equipment to keep emissions under required thresholds.

Task force on Destruction Technologies (TFDT) under the Montreal Protocol have prepared a list of approved ODS destruction technologies, taking destruction efficiency, emissions, and technical capability into account. Incineration and plasma destruction facilities on this list are also capable of accepting HFCs for destruction (Ref. ICF). All destruction facilities used by Norwegian undertakings fulfill these requirements.

In Norway destruction of waste is covered by chapter 10 in the waste regulation, which is based on EU directive No 2000//76/EF on the incineration of waste. This regulation covers both dedicated waste incinerators and co-processing. Operators of waste incinerators shall have an emission permit from NEA or County Governors, that specifies which types of waste that can be incinerated.

The regulation contains, among others, requirements as regards combustion conditions, emissions to air, emissions to water and the treatment of combustion residues. For co-processing in cement kilns there are specific emission limits on emissions to air of NO_X, SO_2, HF, HCl, TOC, dust, heavy metals, and dioxins.

As regards CFCs, and HCFCs and other hazardous waste containing chlorine the permit shall specify additional requirements as regards Cl-content, feeding speeds and combustion conditions (at least 1100˚C in at least 2 sec.). Operators shall report yearly to the permitting authority on emissions to air and water.

After required gas samples are taken, the destruction process normally starts with connecting the transport tank directly to the feeding pipelines of the destruction facility or by transferring the content to an on-site tank. The gas is then gradually fed into the high temperature incineration or plasma zone – a process that might take days or weeks. For home appliances from Norway handled at the Stena Recycling facility in Sweden destruction is integrated into the recycling process (see chapter 5.2.4).

No dedicated hazardous waste destruction facilities have ever been in operation in Norway, and all domestic destruction of hazardous waste is done by co-processing in the two cement kilns approved for this use.

Today all ODSes and F-gases collected in Norway are sent to other European countries for destruction or, possibly, reclamation.

The gas collected by SRG (including the refrigerants from Revac) is now sent to the Trédi hazardous waste treatment plant in France (see chpt. 2.2.2), while co-processing in cement kiln in Norway has been used previously (see chpt. 2.2.1). Refrigerants and foam blowing agents from Stena is destroyed on-site in Sweden (see chpt. 2.2.3).

Recovered SF_6 is sent to Sweden or Germany. Reclaimed halons are exported for subsequent critical use according to the Montreal protocol and the EU Regulation on ozone depleting substances.

In addition to the established main lines for collection and destruction of gas described here, some surplus or waste gas might be handled directly by importers or other companies.

2.2.1 Domestic Destruction of Refrigerants and other hazardous waste in Cement Kilns

Norcem Kjøpsvik is one of two cement plants in Norway and the northernmost in the world. The other is Norcem Brevik south of Oslo. The Kjøpsvik plant has 108 employees and an annual production capacity of 650 000 metric tonnes of cement. The plant typically operates the production process in 7000 hrs/year. The kiln at Norcem Kjøpsvik is a relatively small kiln with a designed production capacity of 1600 tons clinker/day.

Cement is produced by grinding intermediate clinker together with gypsum and some other additives. The kiln system consists of a preheater, with an in-line calciner and the rotary kiln with the primary burner where raw meal (consisting of 99.5% limestone) is converted to clinker, which is the key intermediate product used to produce cement. Cement is finally produced in the cement mill from the following materials: clinker, gypsum, iron sulphate and fly ash.

The rotary kiln is shaped as a long cylinder placed at an angle at about 4 degrees, rotating at 1-4 turns per minute. The temperature in primary burner is at 2000°C, and in at top of calsiner 900°C (at the top where preheated raw materials are input.)

Coal is the main fuel, and about 50% of thermal energy from coal are replaced with alternative fuels. In main burner waste oil and residual waste pellets (RDF) are burned together with coal.

In the preheater various waste fractions like shredded tires, residual waste (RDF) and bone meal and other slaughter waste are used as fuel together with coal.

Norcem Kjøpsvik seeks to increasingly replace remaining use of coal with alternative fuels, preferably with high share of biomass. The plan is to increase the use of alternative fuel from 30% to 90% by 2030.

Due to the high flame temperature in main burner, CFC, HCFC and HFC refrigerants are destructed in the main burner.

The flue gas is treated with NO_x-removal (SNCR) and SO_2-removal. The SO_2-removal is further improved by installation of seawater scrubbing in 2019. The flue gas will be cooled in the scrubbers and reheat is required to lift and disperse the gas from the emission point. Main source for sulfur input to process is from the limestone.

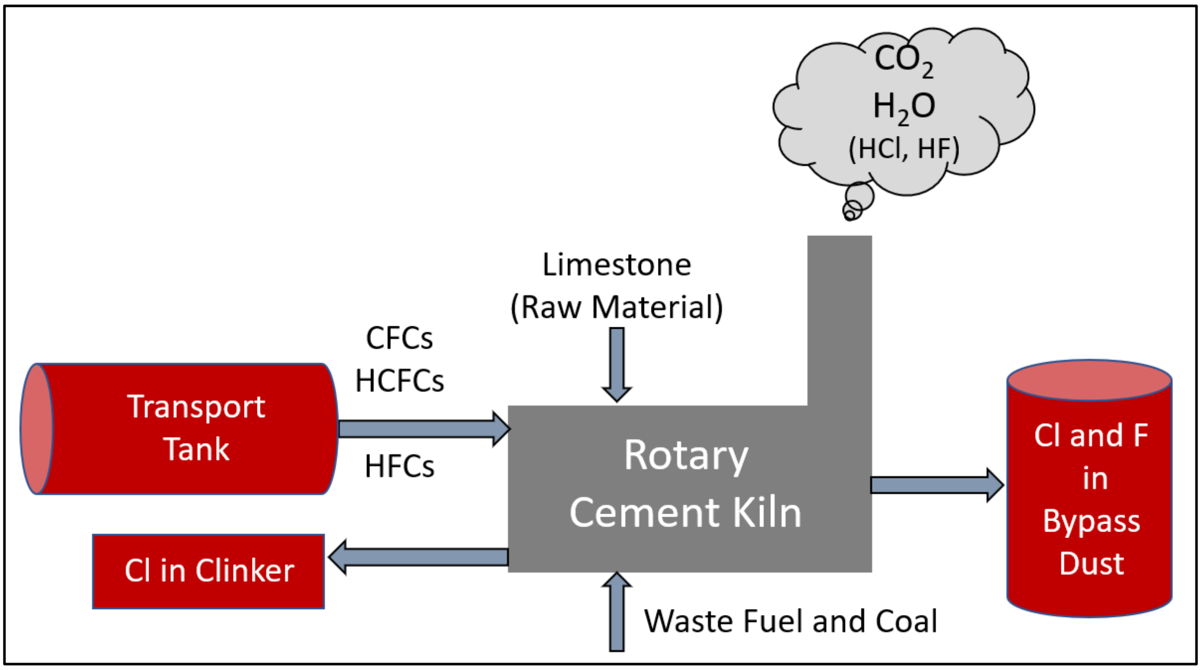
The carbon and hydrogen in the refrigerants are recombined into CO_2 , water and acidic gases (HCl and HF), that are emitted to air. Depending on the bypass level of kiln gas, some of the chlorine and fluorine will also be extracted out in the bypass dust, further sold as a legal product. Flue gas from bypass ends up in the same emission point as kiln flue gas, and all emissions are under permitted levels and monitored by online analyser.

The plant has been testing destruction of refrigerants in different feeding levels from 25 to 100 kg/h. Emission levels of HCl and HF was not measured to be in conflict with plants permit of respectively 10 and 1 mg/Nm^3.

The refrigerant gases are very volatile and can cause accumulation in the kiln if the feedrate is too high or bypass rate of kiln gas too low. To ensure no impact of process operation, the feedrate to kiln main burner was normally in a range of 30-50 kg/h.

The refrigerant gases have different boiling points, and gas with low boiling point were more challenging to achieve stable feeding flow, due to evaporation and freezing of condense in feeding pipeline, leading to blockage. To improve the situation, the gas tanks were set on pressure, by installing a compressor and air dryer.

Figure 37: Illustration of destruction gas in Norcem cement kiln. CFCs, HCFCs and HFCs, from the connected transport tank, are destructed in the primary burner flame at 2000 ºC in the rotary kiln



Source: Torgrim Asphjell, NEA

Figure 38: The Norcem co-processing cement kiln in Kjøpsvik.

Source: Torgrim Asphjell, NEA

2.2.2 Destruction of CFCs, HCFCs and HFCs at Trédi Saint-Vulbas Facility in France

Refrigerants collected by SRG are destructed at the Trédi Saint-Vulbas plant outside of Lyon in France. This plant, which belongs to the Séché Environment Group, is a specialist facility for management and processing of hazardous industrial waste. The plant was founded in 1976, has a staff og 150 employees and treats around 40 000 tonnes of waste per year. The facility has a rotary kiln and a static kiln for treatment of various kinds of solid, liquid and gaseous hazardous waste, including PCB contaminated waste and bromine brine.

The CFCs, HCFCs and HFCs are destroyed in the rotary kiln by co-incineration with other waste with high energy content, such as contaminated oils, under stationary conditions. Under startup, before 1100°C combustion temperature is reached, regular fossil fuel is used.

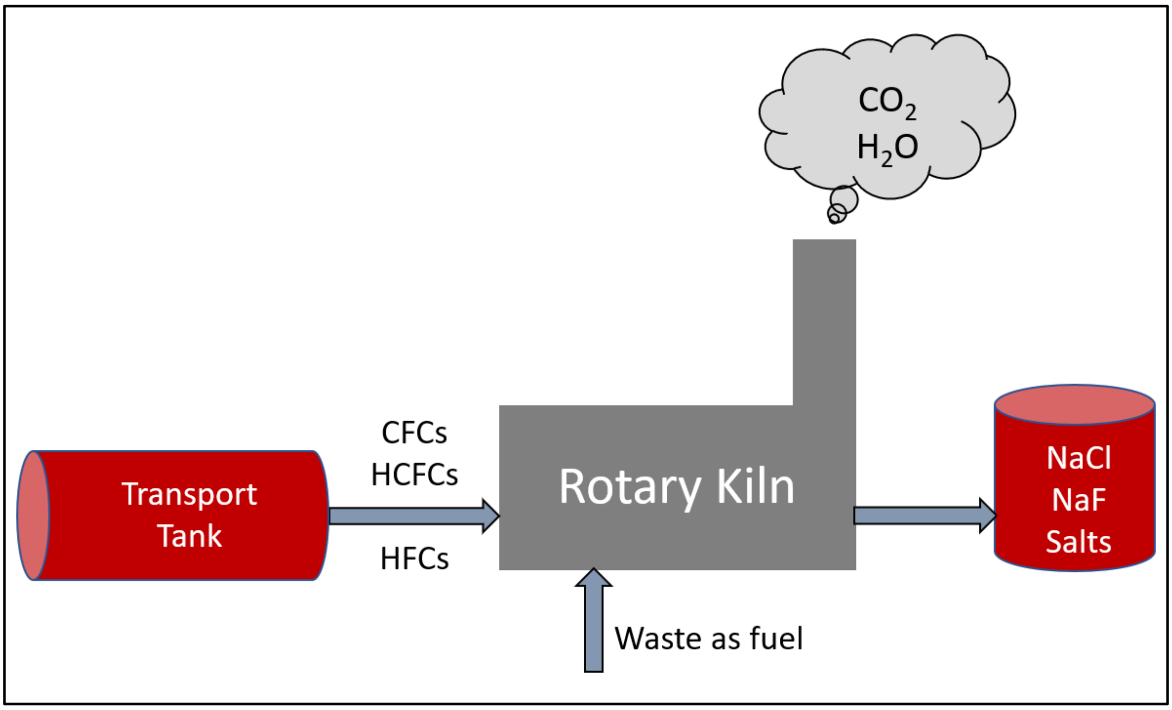
During the combustion the carbons and hydrogens in the waste gases are reduced to CO_2 and water and the halogens (chlorine and fluorine) end up in a HCl and HF acid mix. Air and wastewater are treated before emitted and solid byproducts are sent to a landfill for hazardous waste.

The plant is certified according to ISO 9001, ISO 14 001, OHSAS 18 001 and "Responsible Care". The emission permit is issued by the French environmental authorities and is based on EU directive No 2000//76/EF on the incineration of waste. The environmental performance is regularly audited by the government and subject to self-monitoring. The site is also certified for energy efficiency according to ISO 50001.

Atmospheric emissions of metals, dust, CO, TOC, HCl, HF, SO_2, NO, NO_2 are monitored continuously, while dioxins and furans are monitored through internal and external campaigns several times a year.

An industrial water and stormwater management system is in place and wastewater is continuously monitored for important pollutant including chlorinated organic compounds. Surrounding areas are regularly monitored for environmental impact on fauna, flora, soil and groundwater.

Figure 39: The Trédi facility for destruction of gas outside of Lyon, France



Source: Torgrim Asphjell, NEA

Note: CFCs, HCFCs and HFCs, from the connected transport tank are destructed in a rotary kiln. The carbon and hydrogen in the gases are recombined into CO_2 and water, that are emitted to air. The chlorine and fluorine end up as salts in wastewater that needs further treatment. The process is fueled by waste under stationary conditions and by regular fossil fuel during start up.

Figure 40: The Trédi facility for destruction of gas outside of Lyon, France

Source: Torgrim Asphjell, NEA

2.2.3 On-Site destruction of Gas by Stena Recycling in Sweden

The Stena Nordic Recycling and Destruction Center in Halmstad, Sweden has an on-site facility for destruction of CFCs, HCFCs and HFCs collected in products or gas cylinders from several Stena sites across Europe.

The destruction of the gases is done by a process called Regenerative Thermal Oxidizing (RTO). In this process the gas to be destroyed is sent through a so-called Vocsidizer unit, where it passes through a ceramic bed heated to 1000 ºC by flameless oxidation of high energy content gasses like isobutane, supported by natural gas.

The gas flow in the Vocsidizer unit changes direction every 3-5 minutes. By the changing direction, one assures that there is a static, high temperature field in the middle of the bed. This has the effect that the waste gases are broken down by "thermic regenerative incineration", without the use of open flames.

The Carbons and hydrogens in the waste gases are reduced to CO_2 and water and the halogens (chlorine and fluorine) end up in a HCl and HF acid mix.

The acid mix is again reduced by adding a water solution of NaOH base in a gas scrubber after the ceramic bed oven. This produces water, containing NaCl and NaF salts which are cycled several times through a scrubber, before being collected in a tank and sent to an external Stena hazardous wastewater treatment plant.

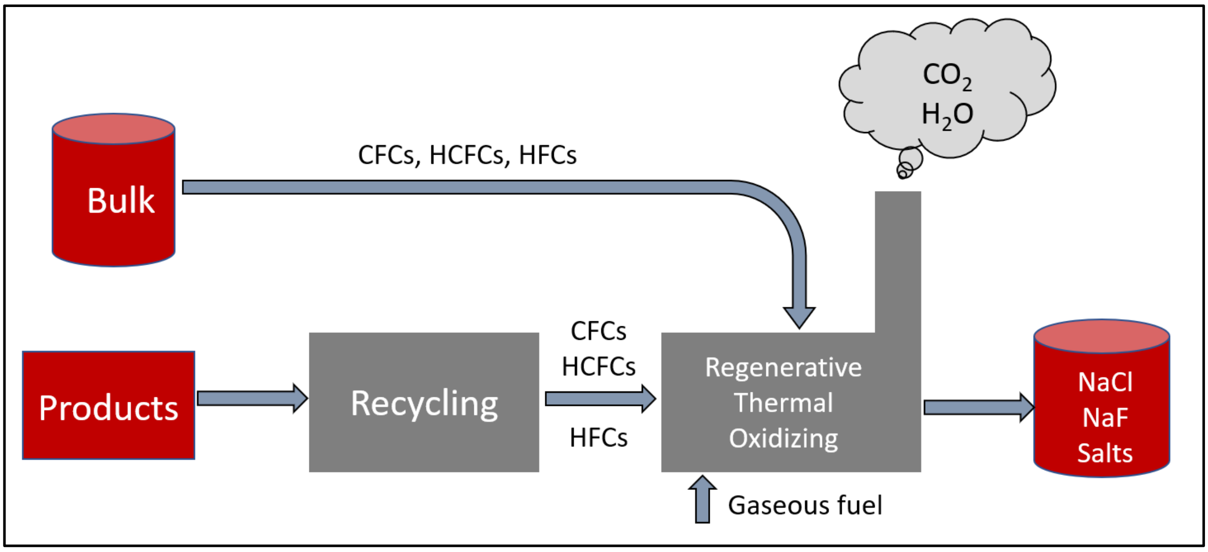
At the facility in Halmstad oil from compressors in refrigeration equipment is also thermally treated to extract dissolved refrigerants. The recovered gases are then fed into the process described above, while the oil undergoes further waste oil treatment.

Fridges, freezers, domestic AC/HP and other WEEE collected by Stena Recycling Norway are also recycled at this plant. Refund for the HFC refrigerants in these products are paid by NEA based on appropriate documentation of the amount HFC gas recovered from appliances exported from Norway and destroyed according to agreed procedures.

Figure 41: Fridges and freezers collected by Stena Recycling Norway awaiting transport to Sweden for final treatment.

Source: Torgrim Asphjell, NEA

Figure 42: Stena Nordic Recycling Center in Halmstad, Sweden



Source: Stena Recycling

Note: The Stena Recycling on-site facility for destruction of gas in Halmstad, Sweden. CFCs, HCFCs and HFCs, from the the on-site recycling facility or delivered in bulk, are reduced in a regenerative thermal process. The carbon and hydrogen in the gases are recombined into CO_2 and water, that are emitted to air. The chlorine and fluorine end up as salts in wastewater that needs further treatment. The process is driven by isobutane and natural gas fuel.

2.2.4 Recycling and Reclamation of Recovered Gas

An alternative to destruction of the recovered gas is to use the gas again. This can be done locally or in the market, and can be motivated by practical, economic, or legal reasons.

On-site Re-use is the simplest form often occurs during maintenance, when the recovered gas is transferred directly back into the equipment without any processing, or after undergoing a simple cleaning process to filter out some impurities such as water and oil. Since this is done within the company and outside of the market, it is not affected by any taxes or refund schemes. The company and personnel undertaking the maintenance might however be subject to certification (see chpt. 2.3) and other requirements.

Any commercial re-use of the gas implies centralized treatment and some kind of quality control. In this respect it is often distinguished between:

1. **Recycling:** The reuse of a recovered fluorinated greenhouse gas following a basic cleaning process. This process requires the gas to be free of cross-contamination. Cross-contamination occurs when the same cylinder is used to service different systems containing different gases or using the same hose to connect to different cylinders.
2. **Reclamation**: Reprocessing of a recovered fluorinated greenhouse gas in order to match the equivalent performance of a virgin substance, taking into account its intended use. For this purpose, mechanisms such as adsorption/desorption beds, cryogenic subcooling and distillation are employed. Some reclamation systems are sold commercially while others have designed their own systems; some commercial systems are unable to handle low-pressure refrigerants.

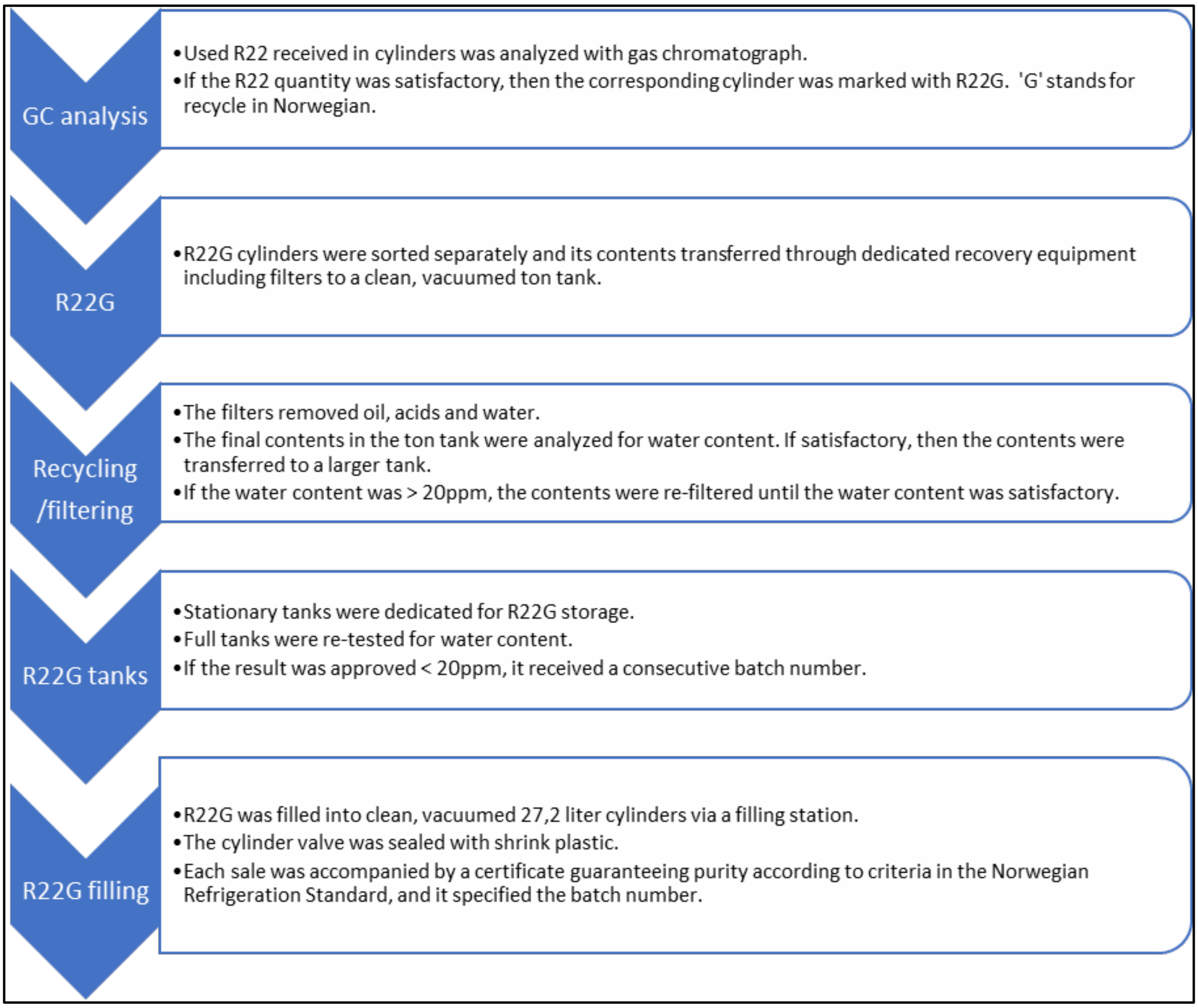
Norway introduced an import ban for HCFCs in 2010, together with a ban on the use of virgin HCFCs for maintenance or servicing of equipment. Only reclaimed or recycled HCFCs were allowed. Hence, from 2010 to 2015, SRG provided the market with recycled HCFC-22. The gas was treated to fit the criteria of the Norwegian Refrigeration Standard by removing impurities such as water, oil and acids. The Figure 43 illustrates and describes the recycling process for R-22 that SRG followed until 2015, when the use of recycled and reclaimed HCFCs were also prohibited.

The halons collected by SRG are sold to approved halon reclaimers in the EU for critical use according to the Montreal Protocol.

Both these recycling/reclaiming initiatives were a result of restrictions in the production and/or import of virgin products.

Economies of scale have limited recycling and reclamation in Norway. However, new EU restrictions on the use of virgin R-507A and R-404A HFC mixtures have again actualized commercial recycling or reclamation. Such activities performed domestically would not be subject to tax, but any export to and re-import from facilities outside of Norway would complicate this issue.

Figure 43: SRG system for recycling of HCFC-22 (ceased in 2015)



Source: Isovator

2.3 Certification of Personnel and Companies

According to the F-gas regulation personnel and companies that perform work on facilities with HFCs, PFCs and SF_6 shall be certified or possess attestation of training. This ensures that the work is done by qualified personnel and increases awareness on legal requirements as regards proper handling of the gases.

The certification covers minimization of leakage and other aspects related to environmentally good practices, but for the purpose of this report we will focus on recovery of gas.

The most common certification in Norway is described in Implementing Regulation (EC) No 2015/2067[27], which establishes requirements and the conditions for certification of companies and personnel working on stationary refrigeration, air conditioning and heat pump (RACHP)

[27] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2067&from=SV

equipment and personnel working on refrigeration units on refrigerated trucks and trailers. Personnel must pass theoretical and practical exams and there are four categories of certificates depending on the type of work that is done and the size of the equipment. For certificates that include recovery the curriculum includes practical skills on how to perform recovery with minimal emissions and knowledge of procedures for handling, storage, and transportation of recovered refrigerant.

Company certificates are required for undertakings carrying out installation, servicing, repairs and decommissioning for other parties. The certificates are issued based on evidence that they employ certified personnel and a review of the undertakings quality assurance system and other organizational issues.

Similar requirements for certification also exist for stationary fire protection equipment (personnel and companies, EU no 304/2008[28]) and the solvents sector (personnel only, EU no 306/2008[29]).

The validity of the certificates both for personnel and companies used to be "until further notice". But from 1 July 2022 the validity became limited to 5 years, upon which a new exam must be passed and a new certificate will be issued.

As regards SF_6 in stationary electronic switchgears (GIS) personnel shall be certified according to Implementing Regulation (EU) 2015/2066[30]. This includes practical training in recovery of SF_6 from the decommissioning of GIS, and theoretical knowledge on storage and transportation of SF_6.

For air-conditioning systems in passenger cars and light vans, Implementing Regulation No 307/2008[31] specifies minimum requirements on training programs for personnel. This includes theoretical knowledge and practical skills on recovery and an attestation of training will be issued upon request. These training attestations have no expiration date so far.

After an open tendering process, the undertaking Incert AB was selected as certification body for SF_6 in GIS. Isovator was selected as for all other certifications and for attestation of training.

[28] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0304&from=EN

[29] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0306&from=EN

[30] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2066&from=EN

[31] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0307&from=EN

Certification at Isovator

The practical implementation of the F-gas certification requirements for RAC, fire protection equipment and solvents, as well as the issuing of training attestations on vehicle AC, was awarded to Isovator in 2011 after an open tender process.

Isovator authorizes certificate examination centers and examiners, approves training centers and personnel including course material, manages exam questions and tasks, and issues certificates and training attestations. Currently, there are 13 authorized examination centers and 43 training centers for vehicle AC. Many of the Isovator-approved examination and training attestation centers are located in municipal upper secondary schools.

Undertakings that perform work on stationary refrigeration, air conditioning, heat pumps and refrigerated trucks for other parties need a **Company Certification**. This implies, among others, that they must have a quality control system for recovery equipment and other tools and internal procedures on how to use this equipment properly. As of 2022 these certificates cost NOK 4192 for first time certification and NOK 3105 for recertification.

Personnel involved in the activities mentioned above need a **Personnel certificat**e. These certificates are issued in four categories depending on the complexity of tasks to be performed. A theoretical and a practical exam must be completed and skills on recovery are included in the curriculum. These certificates cost NOK 6520 or NOK 5967 and NOK 3105 for recertification.

43 training centers approved by Isovator offer theoretical and practical courses on AC systems in vehicles passenger cars and light vans. **Training attestations on vehicle AC** cost NOK 362 and have no expiration date (The actual course falls outside the mandate of Isovator and is not included here).

Certificates and training attestations and are registered in Isovator's Customer Relationship Management (CRM) system, including contact information, examination date and results. The CRM system also facilitates the control of the 5-year validity of company and personnel certificates. Isovator's website has a search portal where the certificate numbers may be used to check expiration dates. It is also possible to search for companies that are F-gas approved.

Figure 44: Example of certificate issued by Isovator.

Source: Isovator

2.4 Audit of User Compliance with F-gas Regulation and Import of Gas

NEA is responsible for auditing undertakings to ensure compliance with the F-gas regulation. These audits are often done as campaigns where importers, resellers, users, or service technicians and -companies are targeted. The main purpose can, for example, be to check certification, compliance with leakage check requirement or to trace illegal import or use of gas.

These audits are often well covered in industry related publications and on-site visits emphasize the awareness rising aspects. Checks on certification of personnel and companies (see chpt. 2.3) are also of direct relevance to EOL refrigerant management, because it will contribute to increased and more complete recovery of gas from equipment.

During visits to undertakings handling refrigerants or other gases, NEA also tries to track down old stockpiles and illegal use of ODSes and illegal storage of larger quantities of waste HFCs. For verification of content, gas sample from cylinders or equipment are often collected and analyzed.

Together with the Norwegian Customs Service and the Police, NEA also tracks and follows up possible illegal import and sales of gas. Information on assumed smuggling is shared with the Police who then take the necessary action.

Figure 45: Sampling of gas from cylinders with unknown content. The samples are taken to Isovator's laboratory for analysis.

Source: Torgrim Asphjell, NEA

2.5 Analysis of Synthetic Refrigerant Gases and Ozone Depleting Substances

Isovator AS is a subsidiary of SRG established in 1995. Isovator has a qualified laboratory for analysis of synthetic refrigerants (CFCs, HCFCs, HFCs and PFCs) and ozone depleting substances including halon 1211 and halon 1301. The laboratory is ISO 17025 accredited and under constant improvement and development. The analyses performed in Isovator's laboratory are both quantitative, which determines the amount of a component in a substance, and qualitative, which identifies components present in a mixture of gases.

The principal purpose of the analysis is the identification and quantification of the refrigerant components in the waste gas received. This analysis provides the basis for the calculation of the refund for recovered and destroyed HFCs and PFCs (see chpt. 1.5.3.2). Previously, this analysis was also used as a basis for calculating the reimbursable environmental fee on CFCs and HCFC-22 (see chapter 2.1.1.1).

Isovator is able to identify the following 24 refrigerants and other components:

- CFC-13
- CFC-115
- CFC-12
- HCFC-22
- HCFC-124
- HC-290 (propane)
- HC-600a (isobutane)
- HC-600 (butane)
- Halon 1211
- HFC-23
- HFC-32
- HFC-41
- HFC-125
- HFC-143a
- HFO-1234yf
- HFC-134a
- HFO-1234ze
- HFC-152a
- HFC-227ea
- HFC-236fa
- PFC-c318
- PFC-31-10
- PFC-116
- PFC-218

Isovator's activities consists primarily of analyses of waste refrigerants delivered to SRG for destruction, with the purpose of calculating the HFC and PFC tax refund. On occasion analyses of seized refrigerants are also performed for customs authorities when there has been reason to believe that imported refrigerants were liable to confiscation. Additionally, Isovator offers commercial services on analyses of refrigerants from equipment in use. These analyses provide an indication of whether the quality of the refrigerant is satisfactory or if it should be recovered for recycling or destruction. For this objective, the samples are analysed for contamination by components such as, water and acid content, and volumetric non-volatile residue.

Thus, as of today, Isovator performs the following analyses on refrigerants:

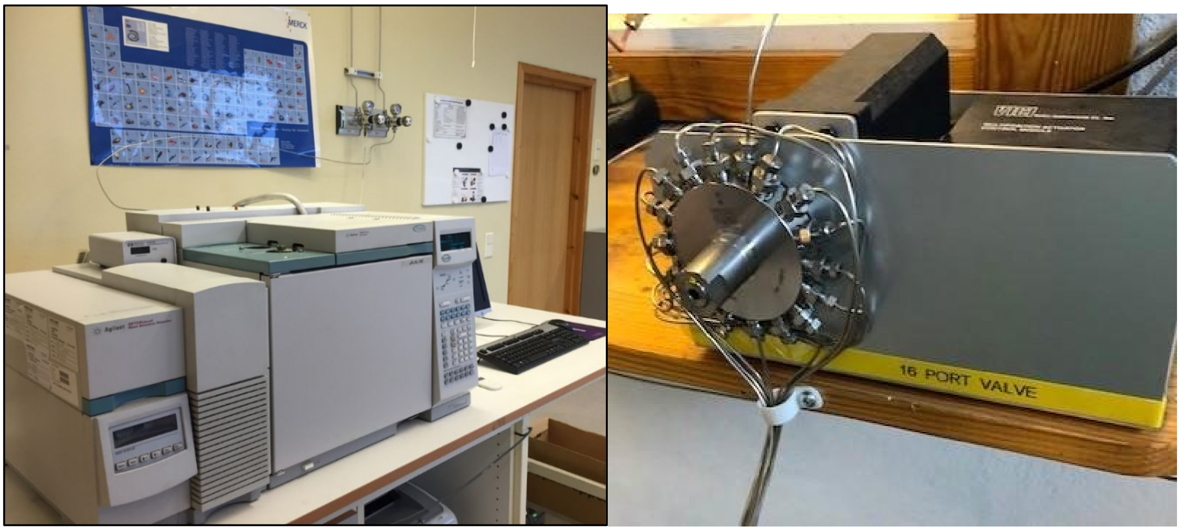
- Identification and quantification of refrigerant (weight %): ISO 17025 accredited method for the components HFC-32, HFC-125, HFC-143a, HFC-134a, and HFC-152a.
- Water content (ppm): Karl Fisher titration
- Volumetric non-volatile residue (vol %): Evaporation
- Acid content (ppm): Acid-base titration

For the identification and quantification of refrigerants, Isovator uses three gas chromatographs (GC) equipped with one or more of the following detectors: flame ionization (FID), thermal conductivity (TCD), and mass spectrometer (MS). All three GCs utilize bonded silica plot columns with the same or similar operating conditions. One of the instruments has an automatic gas sampler that feeds eight samples consecutively after the gas cylinders are manually connected. Isovator also counts with a system gas manifold, which distributes system gas to each instrument including helium, hydrogen, nitrogen and air. These gases are of high quality suitable for laboratory instrument applications.

All three GCs count with a data system for acquisition and electronic integration of the peak areas from the detector. The refrigerant component concentrations are quantified by the area normalization response factor method. The instruments are calibrated with pure refrigerant components with a specified purity of >98% (mass %). The concentrations of each refrigerant component are reported in volume % and then converted to mass % using the ideal gas law.

The maintenance of the laboratory instruments is outsourced to the suppliers of the instruments. After each annual preventive maintenance, the instruments are calibrated. Since the laboratory is accredited according to ISO 17025, Isovator participates in proficiency testing with an external laboratory every two years.

Figure 46: GC-FID with MS and Gas Sampler, 16 ports.



Source: Torgrim Asphjell, NEA

Analytical results and refund of tax on HFCs

Each cylinder received with refrigerant waste gas is analyzed and its result is registered. The sum of the individual results pertaining to all the cylinders transferred to the transport tank serves as the basis for the application to NEA for refund of the tax on HFCs and PFCs.

In addition, the contents in the tank that transports the gas to the destruction site are analyzed by taking a 300-500 gram sample from the liquid phase. A sample cylinder with a capacity of 500 cm^3 is utilized for this purpose. NEA uses the analytical result from the tank for control purposes only in order to double check and corroborate that the tank has not been filled with other substances other than CFCs, HCFCs, HFCs, and PFCs.

In practice, the difference between the weight % for components in the analysis from the transport tank and the sum of the weight % for components from all analyses from cylinders can be substantial. This can be due to the fact that the components with very low % in the cylinders received are not represented in the sample taken from the transport tank and that the blend of components in the transport tank is more complex and challenging to analyze than the simpler mixtures received in each cylinder.

2.6 Recovery Rate and Recovered Volumes of Gas

Due to concern for the ozone layer and climate change all gas that can be recovered should be recovered. Due to strict legislation, this should be the case, but obviously the reality might be very different. The amount of gas (measured in metric tonnes, ODP-tonnes or GWP-tonnes) actually recovered through this infrastructure to a large degree depends on other factors related to enforcement and commercial considerations.

Our experience is that the main factors that influence the recovery rate are:

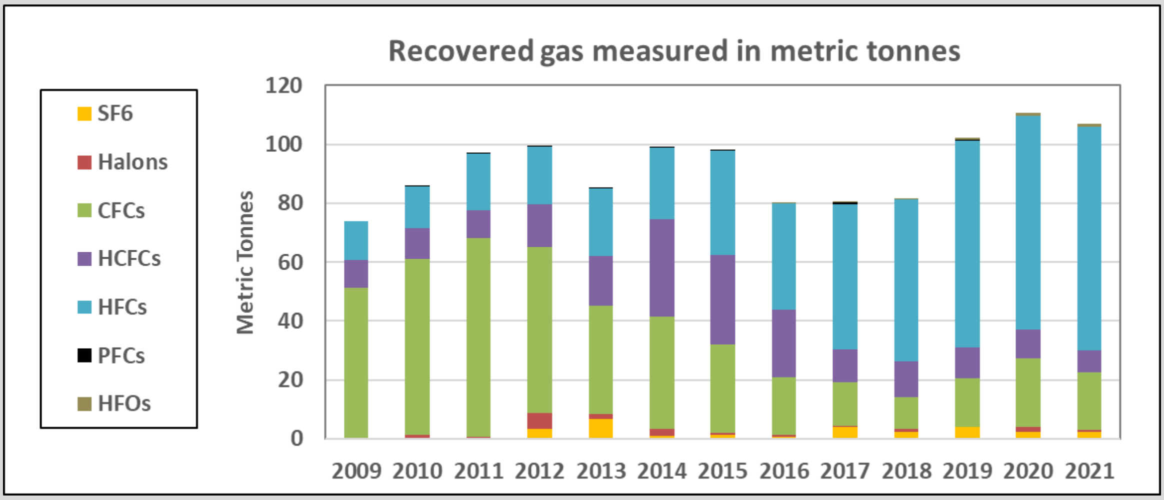
- **Legislation:** Avoidance of unnecessary emissions and recovery of stockpiles and by EOL is required for all ODSes and F-gases. The most noticeable exemption might be foam blowing agents, where recovery often is technically difficult and very costly. The Producer Responsibility system ensures that relevant products containing F-gases can be handed in free of charge and collected for recovery of the gas.
- **Enforcement:** The degree to which the legislation is followed in real life practice depends on, among others, the enforcement in terms making the legislation known, audits, and sanctions.
- **Equipment and skills:** Adequate equipment for recovery must be available and the personnel must know the requirements and how to operate the equipment to avoid leakage and achieve the highest possible recovery rate. In this respect certification plays a key role (see chpt. 2.3).
- **Economic incentives:** These waste gases may have little commercial value, so waste companies depend on income from refunds, payment by waste suppliers and relevant product suppliers. Waste gas might have a commercial value as a raw material for recycled or reclaimed gas, but currently no such activities are taking place in Norway. Flammable gases might have some commercial value as an energy source.
- **The GWP of the HFC:** For HFCs and HFC-blends the refund is proportional to the GWP. This makes it more profitable to collect the potent HFCs.
- **Reimbursement:** For CFCs and HCFC-22 the reimbursable environmental fee (see chpt. 2.1.1.1) was a general incentive, but it was not tuned according to the environmental effects of the specific gases in terms of ODP or GWP.

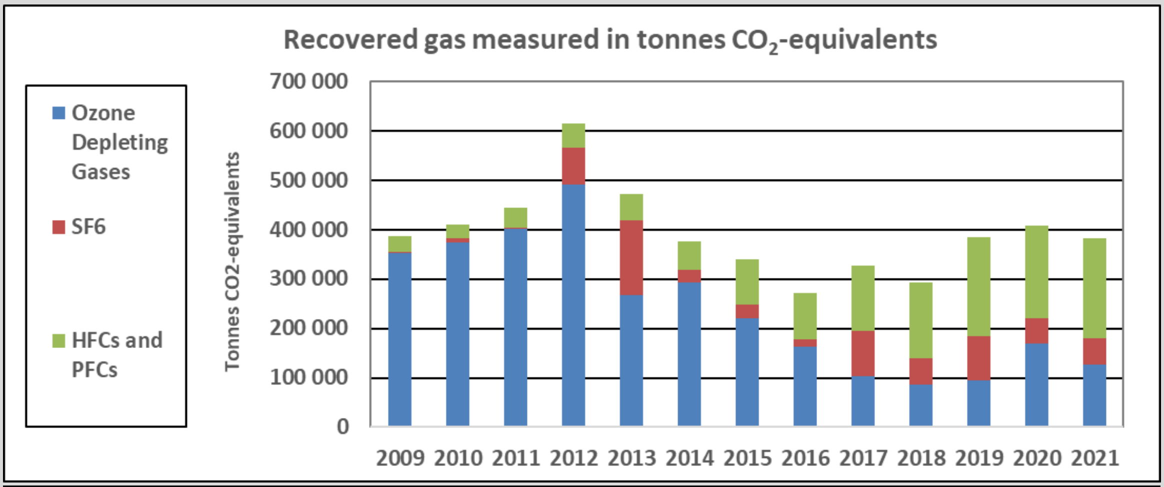
- **The size of the charge of gas:** Economics of scale makes it more profitable to handle gas from equipment with large fillings. For home appliances and other small charges, recovery may only be economically viable if it is an integrated part of a process for general product recycling or if the gas is particularly potent.
- **Logistics and volumes:** On-site recovery of gas may simplify transport of gas. In some instances, such as for WEEE and vehicles, requirements as regards general recycling makes it necessary to transport the entire waste product to a site where recovery can be done. On-site recovery is not possible for building foams and large transport volumes are a challenge for this waste fraction.
- **Completeness of recovery:** On-site recovery will eliminate possible leakage during transport but might also lead to incomplete recovery due to limitations as regards available equipment, procedures and skills.
- **Safety:** Flammable or toxic gases might require additional measures as regards safety and health during recovery and transport.
- **Destruction costs:** Costs (or possible income) from destruction will vary according to the chemical composition of the gas, energy content and challenges as regards emissions and degradation products.
- **Batch size of HFCs:** To determine the size of the refund, the composition of the gas in each cylinder or tank of gas delivered has to be analyzed. This implies that a fixed costs for laboratory work and administration is associated with each batch of gas.
- **Cooperation:** For SF_6, which has not been included in any tax and refund scheme, the high recovery rates can to some degree be ascribed to the voluntary agreement between the Government and the users and one producer of GIS (see chpt. 1.6.1).
- **Total efficiency:** Emissions during transport and transfer of gas and efficiency of recovery and destruction will directly affect total efficiency. Provided that regulations and procedures are followed these emissions are generally considered to be low. However, challenges prevail as regards incomplete recovery from some types of equipment and leakage from transport of waste products containing gas.

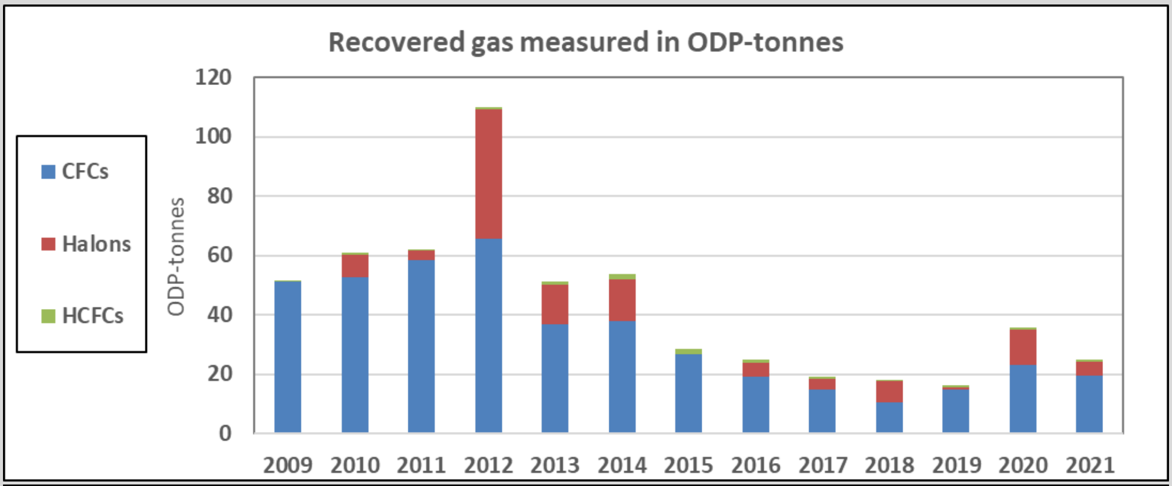
In Norway the reimbursable environmental fee (see chpt 1.4 and 2.1.1.1) was the main driving force behind a high collection rate for ODSes and for HFCs the tax and refund scheme (see chpt. 1.5.3) now serves a similar purpose, in addition to the Extended Producer Responsibility System.

Recovered Volumes of Gas

The figures below show the amounts of gas from Norway recovered, collected and destroyed (or recycled in some instances for Halons and HCFC-22) measured by different metrics.







The figures reflect gas collected in bulk by SRG and refrigerants and foam blowing agents recovered from the Revac Fridgeline. In addition, gas of Norwegian origin recovered at the Stena Recycling facility in Sweden is included. SF_6 from medium voltage GIS is recovered at the Stena Recycling facility. SF_6 from larger GIS is recovered on-site and collected by Stena Recycling or SRG.

Glossary and Acronyms[32]

Air Conditioning or **AC** means cooling of private homes, office space or other spaces by means of heat pump (HP) or similar technology.

Bank means the total amount of gas in use or circulating in the market. This includes all gas contained in equipment, products and stockpiles (gas cylinders).

Blend means a mixture of different gases. For cooling agents some of the common blends of different CFC, HCFCs or HFCs have "R-names" (for example "R-507A" for a 50/50 mixture of HFC-125 and HFC-143a).

Bulk or **Gas in bulk** means a gas or a mixture of gases contained in a gas cylinder or a large gas tank.

Chlorofluorocarbons or **CFCs** are group of potent ozone depleting substances. This is the first generation of ozone depleting substances banned by the Montreal Protocol. CFCs were commonly used as refrigerants, solvents, and foam blowing agents. CFC are also potent climate gases.

CO_2-equivalent or **CO_2-eq** is the quantity of a gas in metric tonnes multiplied by its associated global warming potential (GWP). This is used to compare the various greenhouse gases based upon their global warming potential.

Collection means the collection of bottles of recovered or surplus CFCs, HCFCs, HFCs, SF_6 or similar gases for the purpose of destruction, recycling og reclamation.

Decommissioning means the final shut-down and removal from operation or usage of a product or piece of equipment.

Destruction means the process of permanently transforming or decomposing all or most of a fluorinated greenhouse gas into one or more stable substances that are not fluorinated greenhouse gases.

Domestic Air Conditioner or -Heat Pump or **Domestic AC/HP** means small heat pumps used for air-conditioning or heating in private homes or small commercial spaces. These systems often consist of an outer and inner unit connected by pipes with refrigerant flowing. In Norway this equipment is mainly used for heating, but in hot countries technically similar equipment is mainly used for cooling.

End-of-life or **EOL** means when a product or chemical is taken out of use and thereafter classified as waste.

[32] Many of these descriptions are based on terminology used by the European Commission.

Fluorinated Greenhouse Gases or **F-gases** means hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), SF_6, NF_3 and other greenhouse gases that contain fluorine or mixtures containing any of those substances (Also see Annex II)

Gas Cylinder means a bottle for storage of virgin or recovered gas under pressure.

Gas Insulated Electrical Switchgear or **GIS** means switching device or related equipment used in high voltage electricity transmission using SF_6 or other gases as insulating medium. In this report we distinguish between large place-built **High Voltage GIS (HV GIS)** and compact, hermetically sealed, **Medium Voltage GIS (MV GIS)**.

Global warming potential or **GWP** means the climatic warming potential of a greenhouse gas relative to that of CO_2, calculated in terms of the 100-year warming potential of one kilogram of a greenhouse gas relative to one kilogram of CO_2.

Greenhouse Gas or **GHG** means a gas that has properties contributing to global warming through the so-called "greenhouse effect". Most ODSes and F-gases are strong to very strong greenhouse gases.

GWP-weighted tonnes or **GWP-tonnes** means metric tonnes of a substance multiplied by its global Warming Potential.

Halons are a group of ozone depleting substances that has been used as fire extinguishers. These gases have to a large degree been phased out du to their strong ozone depleting potential.

Household Appliances in this context means freezers, fridges and other smaller plug-in units containing ODSes or F-gases used in private homes, supermarkets or other commercial applications and covered by the WEEE regulation. If not described separately, domestic AC/HP is also included in this category.

Hydrochlorofluorocarbons or **HCFCs** are a group of second generation ozone-depleting substances, since they replace chlorofluorocarbons (CFCs) due to their lower ozone depleting potential. HCFCs are also potent climate gases.

Hydrofluorocarbons or **HFCs** are a group of F-gases. They are used as replacements for ozone- depleting substances because they do not deplete the ozone layer. Most HFCs are potent climate gases and HFCs with very low GWPs are sometimes referred to as **HFOs**.

INR means Indian rupee.

Natural refrigerant means the use of CO_2, NH_3, hydrocarbons or other naturally occurring gases as a refrigerant.

NOK means Norwegian krone (as of 15th February 2023, 1 NOK is approximately 0.09 Euro or 8 Indian rupees)

The Norwegian Environment Agency or **NEA** is the Norwegian government agency that implement and give advice on the development of climate and environmental policy (see: About the Environment Agency - Norwegian Environment Agency)

ODP-weighted tonnes or **ODP-tonnes** means metric tonnes of a substance multiplied by its ozone-depleting potential.

Ozone Depleting Potential or **ODP** refers to the amount of ozone depletion caused by a substance. The OPD values of the different ozone depleting substances range from close to 0 to around 16. CFC-11 used as a reference with a defined ODP value of 1. The higher the ODP value, the more the substance depletes the ozone layer.

Ozone Depleting Substance or **ODS** means substances that lead to a deterioration of the stratospheric ozone layer. CFCs, HCFCs and Halons are ozone depleting substances.

Perfluorocarbons or **PFCs** are a group of F-gases used in some equipment or formed as a pollutant in industrial processes such as aluminum production. PFC are very potent climate gases but are not ozone depleting.

Producer responsibility organization or **PRO** is an undertaking which is responsible for establishing and operating a return scheme for collection and treatment of waste. All importers and producers operating in a product category covered by a PRO must be member of a corresponding PRO. In the context of this report the term is used for EE-waste and vehicles.

Refrigeration and Air Conditioning or **RAC** means refrigeration (cooling or freezing) and room or space air conditioning (both cooling and heating). It can refer both to the sector (**RAC undertakings**) or to the appliances used to achieve the required temperatures.

Reclamation means the reprocessing of a recovered fluorinated greenhouse gas in order to match the equivalent performance of a virgin substance, taking into account its intended use.

Recovery means the collection and storage of gas from products or equipment prior to disposal or during maintenance or servicing. Recovered gas can be either destroyed or reused. In the case of maintenance or servicing recovered gas is sometimes put directly back into the equipment without further processing.

Recycling used in connection to gases means the reuse of a recovered refrigerant or other gas following a basic cleaning process. The word is also used in a more general term in this report, referring to collection and treatment of WEEE and other waste to prepare for reuse or destruction of metals, gases, fluids and other materials.

Refrigerant charge means the weight of refrigerant used in equipment or products. The weight can be expressed in metric tonnes, ODP-tonnes or tonnes of CO_2-equivalents.

Refrigerant means a pure charge or mixture of CFCs, HCFCs, HFCs or other gases use in a refrigeration circuit in refrigeration equipment, air conditioners or heat pumps.

Refrigeration means cooling or freezing of food, drinks or other products.

Reuse means reuse of recovered gas by refilling, recycling or reclamation.

SRG or **Norwegian Foundation for Refrigerant Recovery** is a Norwegian undertaking that collects waste ODSes and HFCs for destruction. **Isovator** is a subsidiary under SRG.

Stockpile means used or new gas stored in bottles awaiting collection or sale.

Sulphur hexafluoride or **SF_6** is a F-gas used in equipment such as high voltage switchgears and some industrial processes. SF_6 is an extremely potent and long lived climate gas, but is not ozone-depleting.

Tonnes of CO_2 equivalents or **TCO_2-eq** means a quantity of greenhouse gases expressed as the product of the weight of the greenhouse gases in metric tonnes and of their global warming potential.

Vehicle Refrigeration means a refrigeration unit in a motor vehicle or container used to cool or freeze transported gods.

Virgin substance means a substance (gas) which has not previously been used.

Waste from Electrical or Electronic Equipment or **WEEE** is a general term for all waste fractions from smaller product and equipment in this category. Household freezers and fridges, domestic heat pumps and air-conditioning units and medium voltage GIS, are particularly relevant in the context of this report.

ANNEX II

Common ODSes and F-gases

Here is a description of the most common Ozone Depleting Substances (ODSes) and Fluorinated Greenhouse Gases (F-gases). The description is from a Norwegian perspective and the situation might be very different in other countries. For ODSes we have taken an historic perspective, while for F-gases we have focused on the current situation.

The gases are referred to by the group name followed by a number. Sometimes the "R-numbers" is used instead. For example, HFC-134a can also be referred to as R-134a. In this text we have used group name for pure substances and R-numbers for blends (mixtures of different gases).

Another group of gases that are often used as substitutes for ODSes or F-gases are the so-called **natural refrigerants**. These gases are not ozone depleting and have zero or very low GWP. The most common of these gases also have R-numbers – for example **R-744** (CO_2), **R-717** (Ammonia), **R-600a** (Isobutane).

Ozone Depleting Substances (ODSes)

These substances contain either chlorine (Cl) or Bromine (Br), which contributes to their ozone depleting abilities. The ozone depleting potential (ODP) is, pr definition, measured relative to CFC-11.

These substances are controlled under the Montreal protocol. Although potent greenhouse gases, they are not covered under the UNFCCC.

First generation ODSes include CFC refrigerants and fire suppressing halons, while the less potent HCFCs are often referred to as second generation substances or transition substances.

The most common ODSes that have been used in Norway are:

CFC-11 has an Ozone Depleting Potential (ODP) of 1 (GWP-value of 4 750). CFC-11 was used mainly as a foam blowing agent in Norway. But CFC-11 was also to a smaller degree used as a refrigerant in cooling equipment and for textile cleaning.

CFC-12 (ODP = 1 and GWP = 10 900)) was used as a refrigerant in fridges and freezers, both in households and in larger equipment, including large industrialized and commercial equipment.

CFC-115 (ODP = 0,6 and GWP = 7 370)) was used as a refrigerant. CFC-115 also occurs in blends with HCFC-22 (R-502) and HFC-32 (R-504).

HCFC-22 (ODP = 0,055 and GWP = 1 810) Hydrofluorocarbons came as a substitute for CFCs. HCFC-22 was for several years the main refrigerant used in Norway. It was mainly used as a refrigerant in multiple types of refrigeration- and freezing equipment.

HCFC-124 (ODP = 0,022 and GWP = 609) was used as a refrigerant in Norway. The use was small, compared to the use og HCFC-22.

HCFC-141b (ODP = 0,110 and GWP = 725) was mainly used as a foam blowing agent in Norway, but was also used to a much smaller extent as solvent for cleaning textiles.

HCFC-142b (ODP = 0,065 and GWP = 2 310) was used as a foam blowing agent.

Halon 1301, Halon 1211, Halon 2402 (ODP 10, 3 and 6, respectively) – Halons were used in Norway as fire suppressant. The only allowed use of halons are now for critical use, including in aviation.

Fluorinated Greenhouse Gases (F-gases)

These are gases containing fluorine (F), but not chlorine (Cl) or Bromine (Br). They are not ozone-depleting, but most of them are strong greenhouse gases.

The most common F-gases are the HFCs, which are in widespread use as refrigerants (both as pure substances or as blends) and in foams and other products. Some of these gases are unsaturated and with very low GWP and are often referred to as HFOs.

PFCs are pollutants from aluminum production. They are also produced for commercial purposes but are very seldom used in equipment or products in Norway.

SF_6 and NF_3 are very potent greenhouse gases used in some specialist equipment and production processes.

HFCs, PFCs, SF_6 and NF_3 are covered by the UNFCCC and the Paris Agreement. Most of the HFCs that are at present commercially in use are also controlled by the Kigali Amendment to the Montreal protocol.

The most common F-gases in Norway are:

HFC-134a is a pure substance with a GWP-value of 1430 used in various types of cooling and freezing equipment. It was, until recent phase-out in new cars, the "standard" refrigerant for mobile air-conditioners.

HFC-152a with a GWP-value of 124 is used in refrigerant blends, as a foam blowing agent, as cleaning solvent and as an aerosol propellant. Flammability has limited the use of this gas in larger equipment.

R-507a (GWP-value of 3985) and **R-404a** (GWP-value of 3922) are HFC-blends used in larger cooling and freezing equipment and in transport refrigeration. Those blends are composed of a mixture of **HFC-143a** and **HFC-125 (**and also HFC-134a in the case of R-404a).

R-448a (GWP-value 1387) is used as a substitute for R-507a or R-404a. It is a blend, composed of **HFC-125**, **HFC-134a**, **HFC-32**, **HFO-1234ze** and **HFO-1234yf**.

R-407c (GWP-value of 1774) is commonly used in large air-conditioning units and heat pumps. It is a blend composed of **HFC-125**, **HFC-134a** and **HFC-32**.

R-410a (GWP-value of 2088) was until recently the dominating refrigerant for domestic AC/HP. It is a blend composed of a 50/50 mixture of **HFC-125** and **HFC-32**. This blend is now being replaced by **pure HFC-32** with a GWP value of 675.

HFO-1234yf is a "second generation HFC" with a GWP-value estimated to be around 4. It is becoming the standard refrigerant in AC systems in new cars. It is also used as a pure substance or in blends in many other types of equipment, products and applications.

HFO-1234ze with a GWP-value estimated to be around 7 is used as a single refrigerant or in mixtures and in foams.

SF_6 has a GWP-value of 22 800. Today it is in Norway mainly used in Gas Insulated Switchgears (GIS) and other equipment in electric power transmission. Previously it was used as a noise insulation in windows. Norway previously had high emissions of SF_6 from use as cover gas in magnesium industry.

As regards **NF_3,** Norway has no known use or emissions of this gas. It is a gas with a GWP-value of 17 200 which has relatively recently been added to "the basket of greenhouse gases" under the UNFCCC and is subject to reporting in the F-gas regulation (No 517/2014). It is used in the production of some electronic products such as semiconductors and solar panels.

Common name	Chemical name/ mixture and mixture ratio	Chemical formula	GWP
HFC-23	Trifluoromethane	CHF_3	14 800
HFC-32	Difluoromethane	CH_2F_2	675
HFC-41	Fluoromethane	CH_3F	92
HFC-125	Pentafluoroethane	CHF_2CF_3	3 500
HFC-134	1,1,2,2-tetrafluoroethane	CHF_2CHF_2	1 100
HFC-134a	1,1,1,2-tetrafluoroethane	CH_2FCF_3	1 430
HFC-143	1,1,2-trifluoroethane	CH_2FCHF_2	353
HFC-143a	1,1,1-trifluoroethane	CH_3CF_3	4 470
HFC-152	1,2-difluoroethane	CH_2FCH_2F	53
HFC-152a	1,1-difluoroethane	CH_3CHF_2	124
HFC-161	fluoroethane	CH_3CH_2F	12
HFC-227ea	1,1,1,2,3,3,3-heptafluoropropane	CF_3CHFCF_3	3 220
HFC-236cb	1,1,1,2,2,3-hexafluoropropane	$CH_2FCF_2CF_3$	1 340
HFC-236ea	1,1,1,2,3,3-hexafluoropropane	CHF_2CHFCF_3	1 370
HFC-236fa	1,1,1,3,3,3-hexafluoropropane	$CF_3CH_2CF_3$	9 810
HFC-245ca	1,1,2,2,3-pentafluoropropane	$CH_2FCF_2CHF_2$	693
HFC-245fa	1,1,1,3,3-pentafluoropropane	$CHF_2CH_2CF_3$	1 030
HFC-365 mfc	1,1,1,3,3-pentafluorobutane	$CF_3CH_2CF_2CH_3$	794
HFC-43-10 mee	1,1,1,2,2,3,4,5,5,5-decafluoropentane	$CF_3CHFCHFCF_2CF_3$	1 640
PFC-14	tetrafluoromethane	CF_4	7 390
PFC-116	hexafluoroethane	C_2F_6	12 200
PFC-218	octafluoropropane	C_3F_8	8 830
PFC-3-1-10	decafluorobutane	C_4F_{10}	8 860
PFC-4-1-12	dodecafluoropentane	C_5F_{12}	9 160
PFC-5-1-14	tetradecafluorohexane	C_6F_{14}	9 300
PFC-c-318	octafluorocyclobutane	$c\text{-}C_4F_8$	10 300
SF6	sulphur hexafluoride	SF_6	22 800
R-507A	HFC-125, HFC-143a (50/50)		3985
R-404A	HFC-125, HFC-143a, HFC-134a (44/52/4)		3922
R-448A	HFC-32, HFC-125, HFO-1234yf, HFC-134a, HFC-1234ze (26/26/20/21/7)		1387
R-407C	HFC-32, HFC-125, HFC-134a (23/25/52)		1774
R-410A	HFC-32, HFC-125 (50/50)		2088

Figure: Global warming potentials (GWPs) for F-gases based on the Fourth Assessment Report adopted by the Intergovernmental Panel on Climate Change (IPCC, AR4). This is the substances covered by the EU F-gas regulation (No 517/2014). The HFCs and PFCs are also covered by the Norwegian tax and refund scheme. Substances designated with an "R" are mixtures of HFCs, where the components and mixture ratio are listed in the second column.

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