



# E: Environmental Impacts

Length: 90 minutes

Theory

## Agenda E: Environmental impacts



Introduction

Environmental impact of refrigeration and related policies

Overview of natural refrigerants

Practical implications for technicians

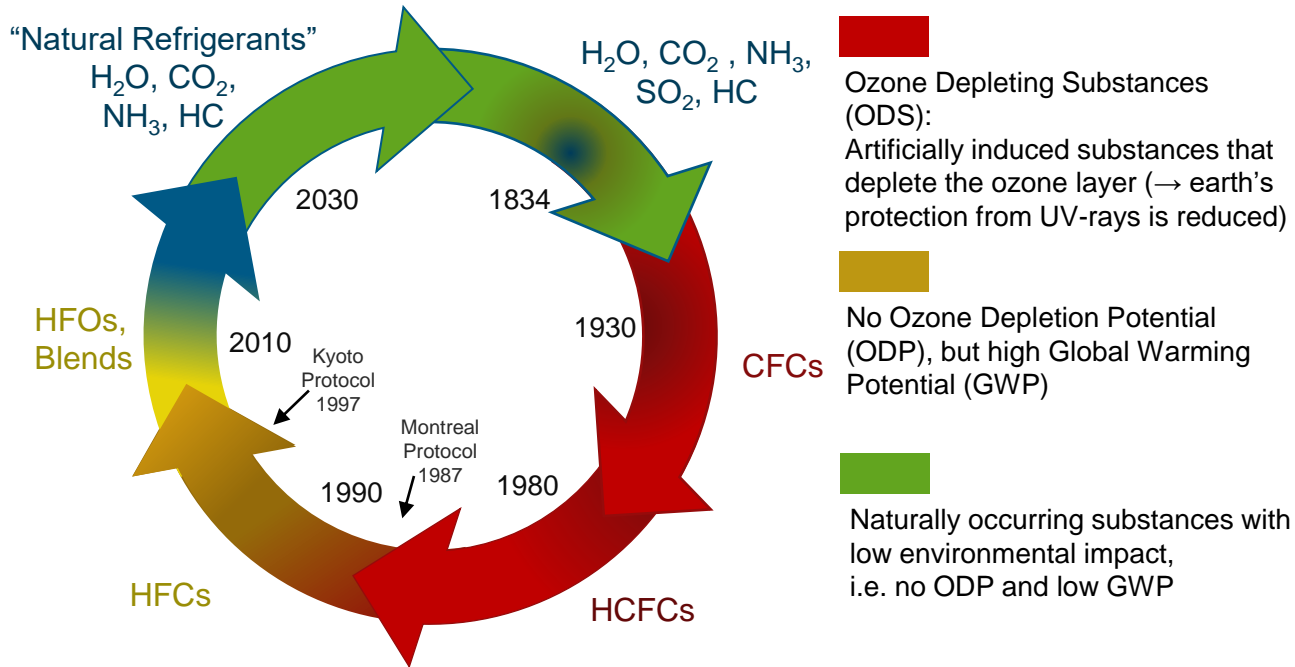
# Introduction

## Definitions

- **Refrigeration** is a process of removing heat from a location (surrounding air) or a substance to be cooled (e.g. rooms, refrigerators or water) to another place where the heat can be released (e.g. to the outdoor ambient).
- A **refrigerant** is a substance (heat transfer media) that is used in this process to absorb or release latent heat, typically using phase change.

# Introduction

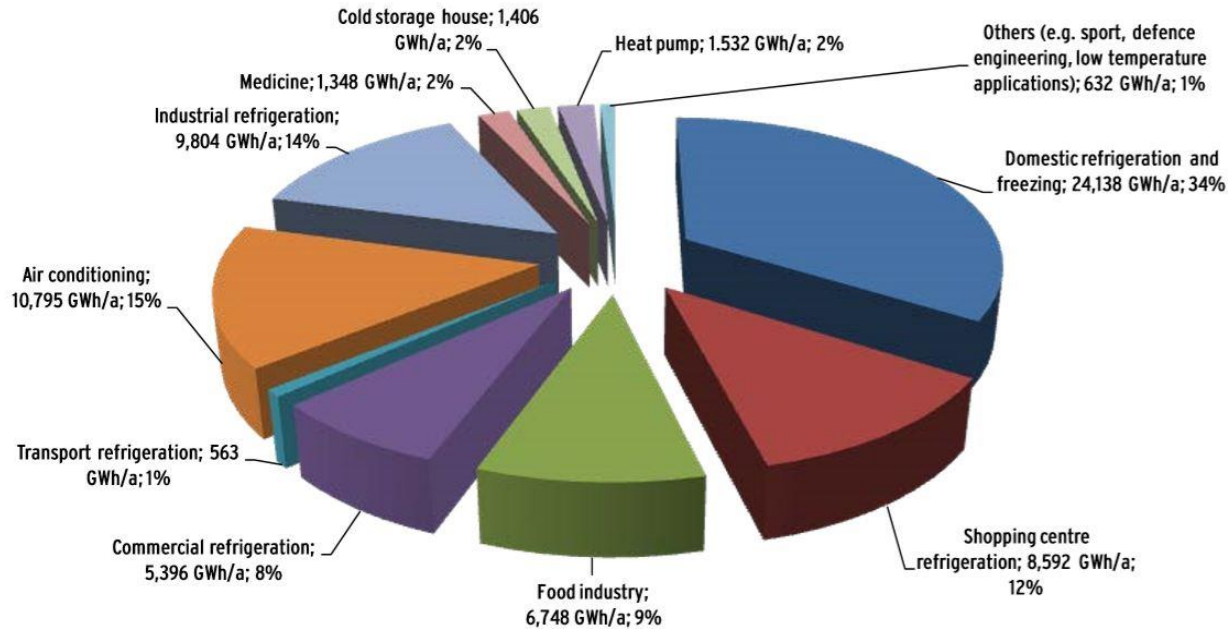
## Refrigerants – historical development



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# Introduction

## Energy consumption of refrigeration appliances



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## Introduction

# Choosing the refrigerant

The ideal refrigerant should combine the following characteristics:

- Performance (capacity and efficiency)
- Safety (including flammability and toxicity aspects)
- Availability of the refrigerant
- Zero Ozone Depletion Potential (ODP)
- Impact on climate change (reduced direct and indirect impact, reduced energy-related emissions)
- Impact on product and servicing costs
- Skills and technology required to use
- Recyclability
- Stability and materials compatibility

## Agenda E: Environmental impacts

Introduction



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## **Environmental impact of refrigeration and related policies**

### **Ozone Depletion Potential (ODP)**

Ozone-depleting substances (ODS) are substances that damage the earth's ozone layer in the upper atmosphere.

The ODP of a chemical compound is the relative amount of degradation to the ozone layer it can cause, with the CFC R11 being fixed at an ODP of 1.0.

ODS include:

- Chlorofluorocarbons (CFCs) such as R12 and R502
- Hydrochlorofluorocarbons (HCFCs) such as R22, R123, R142b
- Drop in blends such as R408A

**A single chlorine atom released by CFCs can last for up to 100 years in the atmosphere, and can destroy 100.000 ozone molecules!**

# Environmental impact of refrigeration and related policies

## Global Warming Potential (GWP)

- Relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming
- Many synthetic refrigerants have very high global warming potentials
- HFC refrigerants are reported under the United Nations Framework Convention on Climate Change (UNFCCC)
- No binding HFC reduction targets, but several countries include HFCs in their nationally determined contributions (NDCs)

## Environmental impact of refrigeration and related policies

# Total Equivalent Warming Impact (TEWI)

TEWI is a calculation method that helps to individually assess the effects on the greenhouse effect during the operation of refrigeration systems:

The TEWI has three parts, which are added to calculate the total value.

$$\text{TEWI} = \text{GWP} \times L \times n + \text{GWP} \times m \times [1 - a_{\text{rec}}] + n \times E_{\text{anno}} \times b$$

L	leakage rate per year (kg/a)
n	system operating life in years (a)
m	charge of refrigerant (kg)
$a_{\text{rec}}$	recovery/recycling factor from 0 to 1
$E_{\text{anno}}$	energy consumption per year (kW/a)
b	CO <sub>2</sub> emission factor of power generation (kg/kWh)

As several of the assumptions and factors in this calculation method are usually specific to an application in a particular location, the TEWI allows only a comparison at one specific place (e.g. France, Germany, or elsewhere) and comparisons between different applications or different locations are not suitable. The TEWI calculation is important at the design stage or to support a retrofit decision (EN 378-1, Annex B).

# Environmental impact of refrigeration and related policies

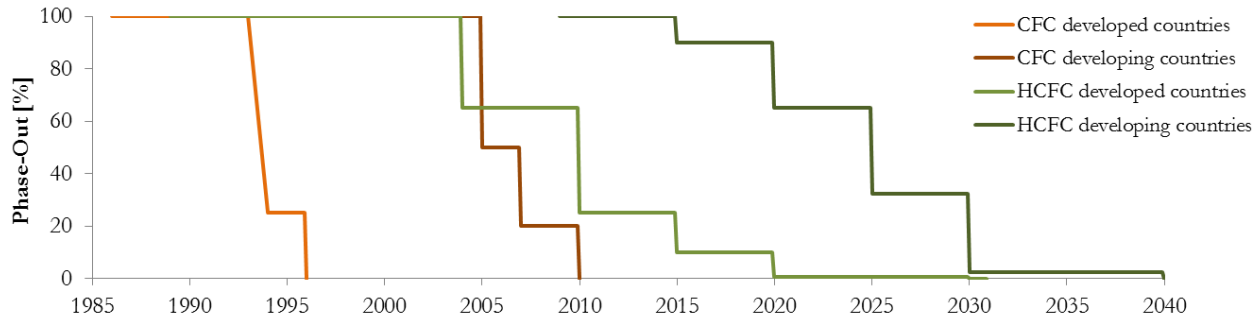
## Overview GWP and ODP of refrigerants

Refrigerants (common examples)		ODP	GWP (time horizons of 100 years)
CFCs	R11	1	7,100
HCFCs	R22	0.055	1,700
HFCs	R507A	0	3,985
	R404A (R125+134a+143a)	0	3,800
	R410A (R32+135)	0	2,000
	R134a	0	1,300
HFOs	R1234yf	0	6
	R1234ze	0	4
	R290 (Propane)	0	3
	R600a (Isobutane)	0	3
Natural refrigerants	RC270 (Cyclopropane)	0	n/a
	R744 (Carbon dioxide)	0	1
	R717 (Ammonia)	0	<1

# Environmental impact of refrigeration and related policies

## The Montreal Protocol

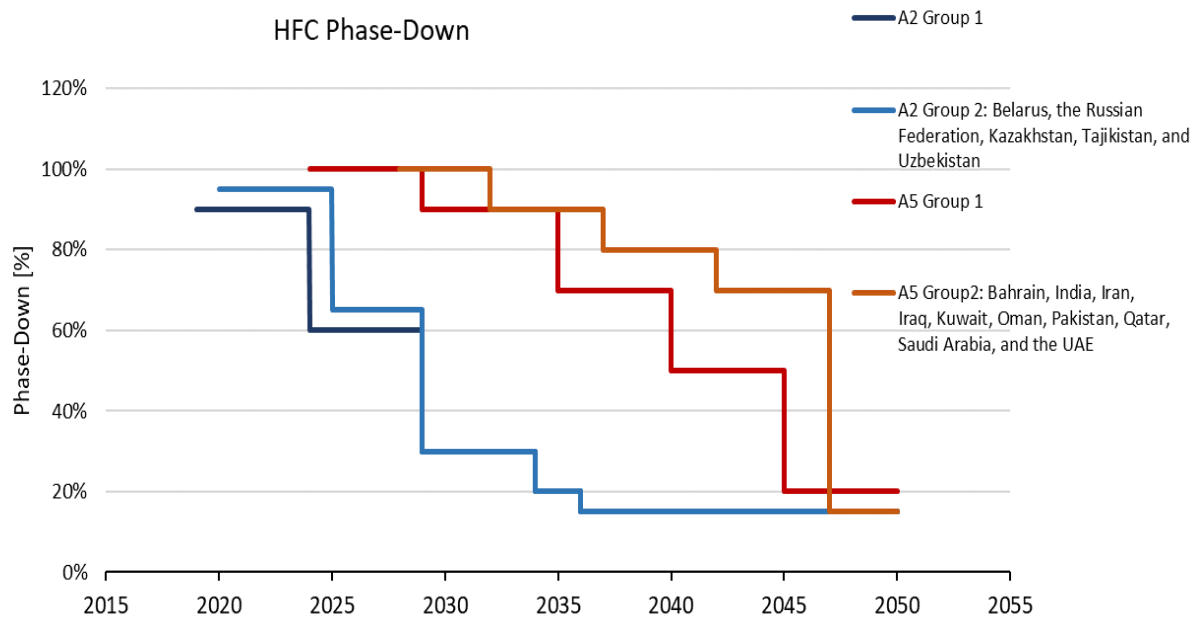
- Phase-down of production and consumption of ODS
- Higher requirements for industrial countries
- Most successful international environmental agreement



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# Environmental impact of refrigeration and related policies

## The Kigali Amendment to the MP: HFC phase-down



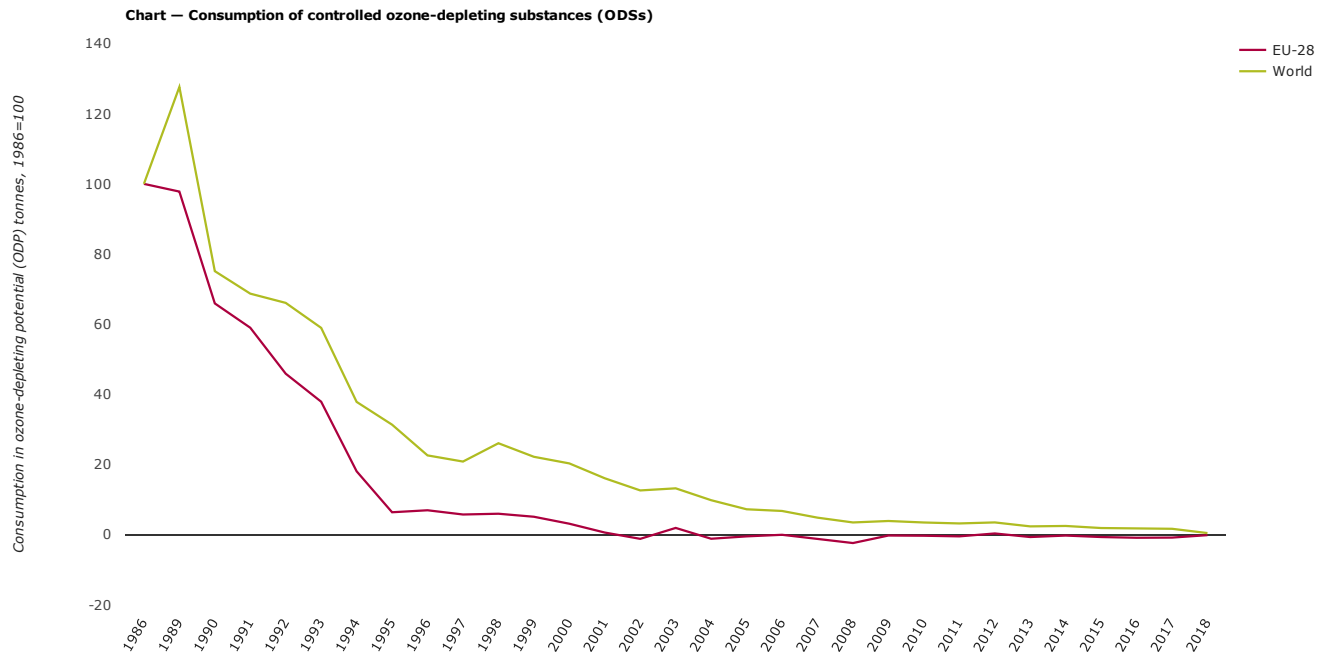
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The Kigali Amendment has set a milestone for climate change mitigation. Even though HFC emission reduction is part of the Kyoto Protocol to UNFCCC since 2005, binding obligations or phase-down schedules were never set.

The Kigali Amendment can prevent up to 0.5°C of global warming!

## Environmental impact of refrigeration and related policies

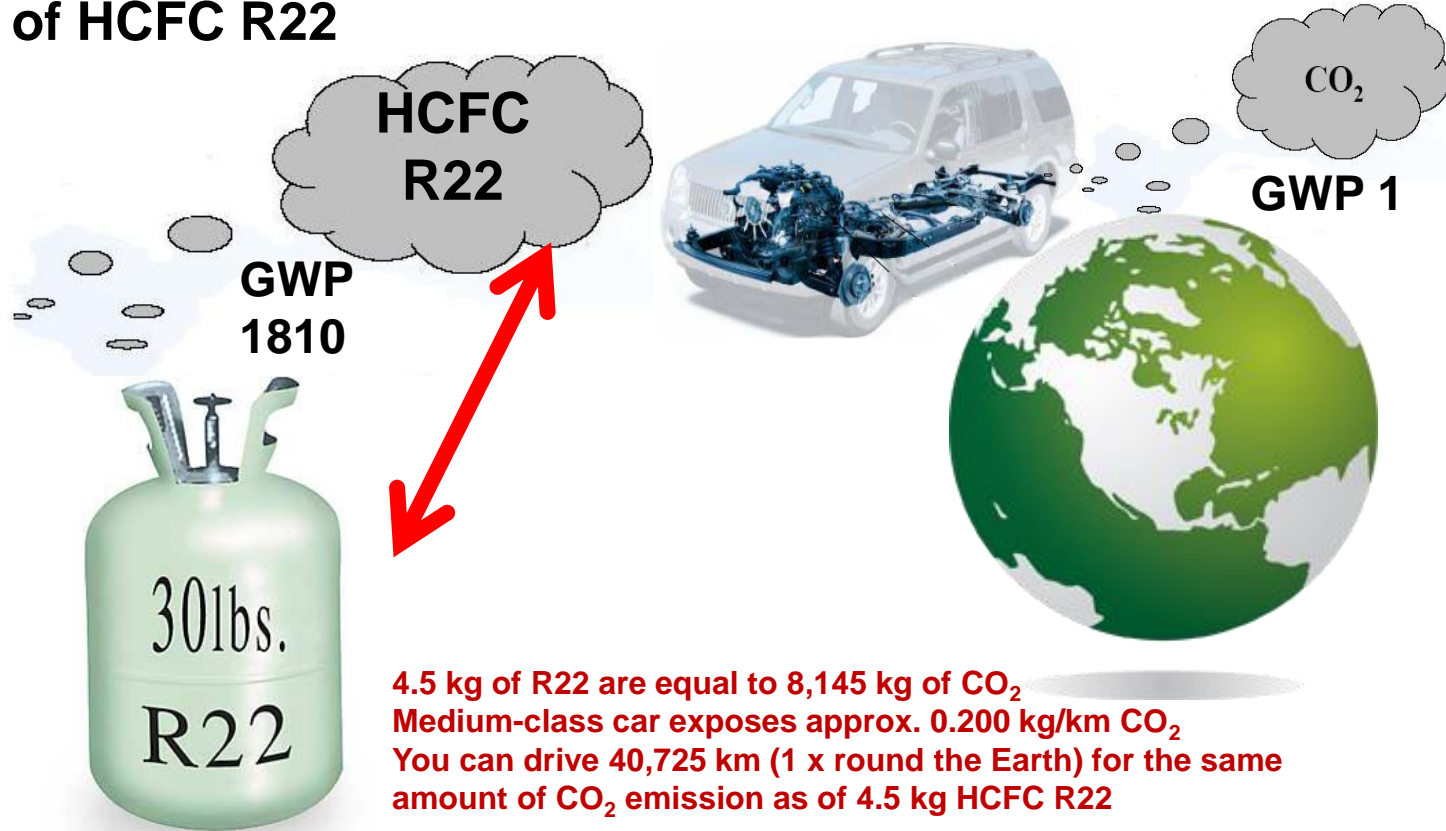
# Success of the Montreal Protocol - Global and European consumption of ODS since the year 1986



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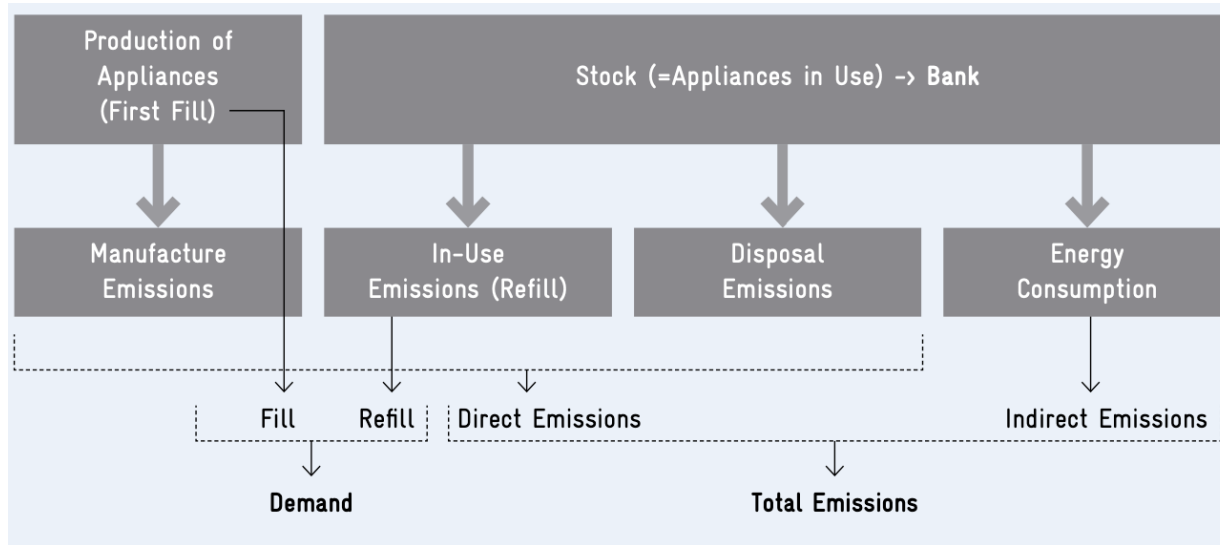
# Environmental impact of refrigeration and related policies

## GWP of HCFC R22



# Environmental impact of refrigeration and related policies

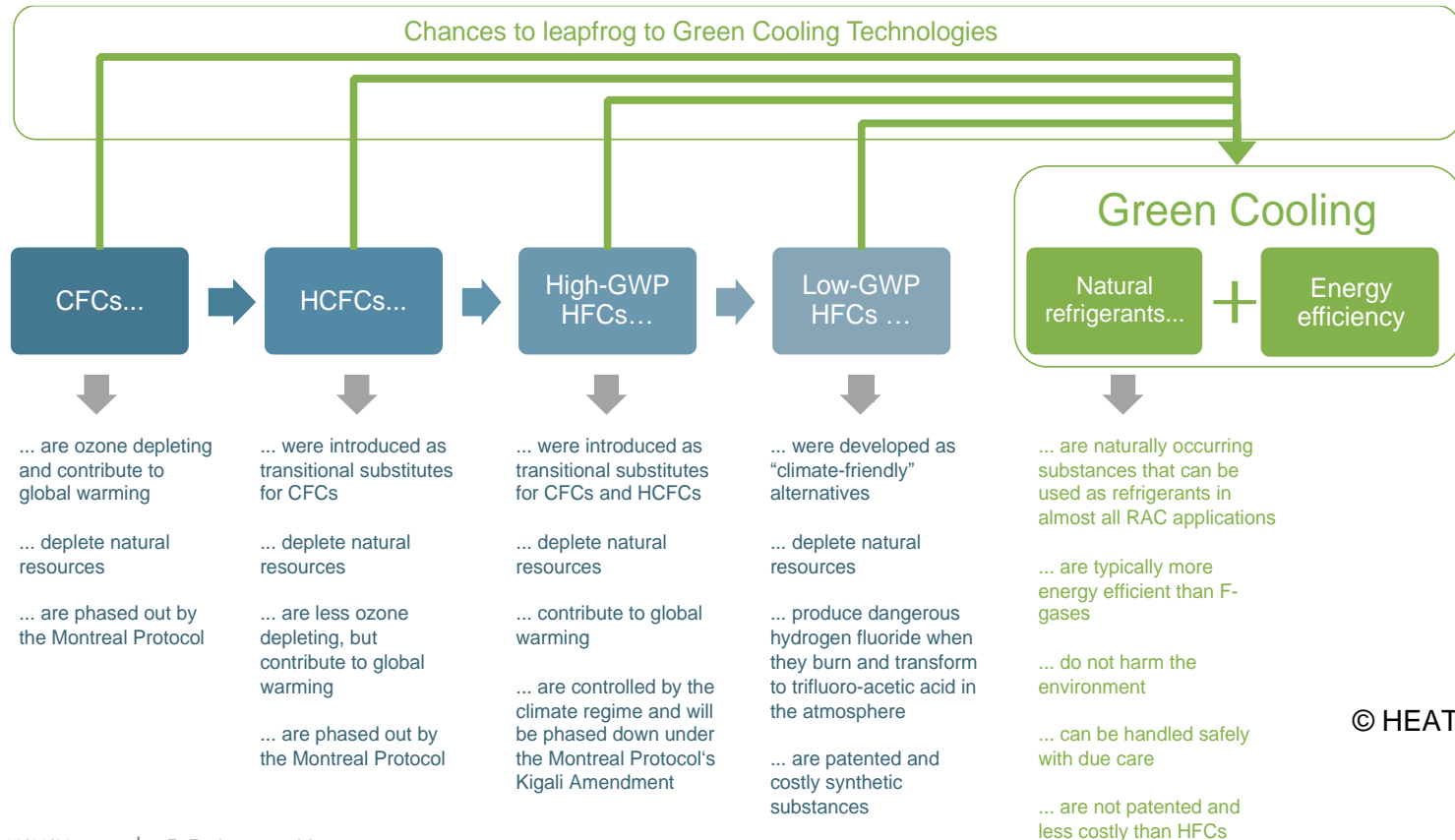
## Emissions of RACHP equipment



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# Environmental impact of refrigeration and related policies

## Looking ahead green cooling technologies



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## Agenda E: Environmental impacts

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Environmental impact of refrigeration and related policies

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## Overview of natural refrigerants

### Natural refrigerants: The natural five

Refrigerant		Chemical structure	Refrigerant nomenclature
Hydrocarbons	propane	$C_3H_8$	R290
	propene	$C_3H_6$	R1270
	isobutane	$C_4H_{10}$	R600a
Carbon dioxide		$CO_2$	R744
Ammonia		$NH_3$	R717
Water		$H_2O$	R718
Air		$N_2, O_2, Ar, CO_2, \text{others}$	R729

# Overview of natural refrigerants

## Natural refrigerants characteristics

Refrigerant	Refrigerant Number	Chemical Formula	GWP (100 years)	ODP	Normal boiling point (°C)	Critical temperature (°C)	Critical Pressure (bar)	Safety group	Molecular weight (g/mol)
Ammonia	R717	NH <sub>3</sub>	0	0	-33.34	132.4	114.20	B2L	17.03
Carbon dioxide	R744	CO <sub>2</sub>	1	0	-78	31.04	73.77	A1	44.00
Propane	R290	C <sub>3</sub> H <sub>8</sub>	3	0	-42.1	96.7	42.48	A3	44.10
Isobutane	R600a	C <sub>4</sub> H <sub>10</sub>	3	0	-11.7	134.7	36.40	A3	58.12
Propylene	R1270	C <sub>3</sub> H <sub>6</sub>	2	0	-47.6	92.42	46.68	A3	42.10
Water	R718	H <sub>2</sub> O	0	0	100	373.95	217.70	A1	18.02
Air	R729	N <sub>2</sub> /O <sub>2</sub> /Ar/CO <sub>2</sub>	0	0	-192.97	-140.53	37.85	A1	28.97

Lower flammability & toxicity
  Higher flammability
  Very high pressure
  Vacuum

## Overview of natural refrigerants

### Hydrocarbon (HC) characteristics

- Elementary compound of hydrogen and carbon
- Occurs naturally and is found in large concentrations in crude oil
- Cheap production cost as by-product
- Zero ODP and negligible GWP
- Non-toxic
- Application for heating/cooling and freezing
- Lower condensing point, positive thermodynamic attributes, and superior COP
  - Optimization of energy-efficient operation possible
- Use of propane known from cooking and heating

## Overview of natural refrigerants

# Greenfreeze – a success story

- 1993 launch of the Greenfreeze refrigerator, developed by Greenpeace in cooperation with East German manufacturer Foron (formerly VEB dkk Scharfenstein)
  - Proving that R600a & R290, although flammable, caused no problems in a household refrigerator.
- Traditional manufacturers (Bosch-Siemens, Liebherr, Miele, AEG, Electrolux, Bauknecht) decided to accelerate the introduction of R600a and to phase out the recently introduced R134a
- Danfoss Compressors (today Secop) introduced compressors for R600a in 1993.
- Today more than 700 million domestic refrigerators globally use R600a.
- By 2020, 75% of the global production will be based on R600a.

# Overview of natural refrigerants

## Greenfreeze – a success story



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On March 15, 1993, the first Greenfreeze left the factory of DKK Scharfenstein (later FORON) in Lohbeck, eastern Germany!



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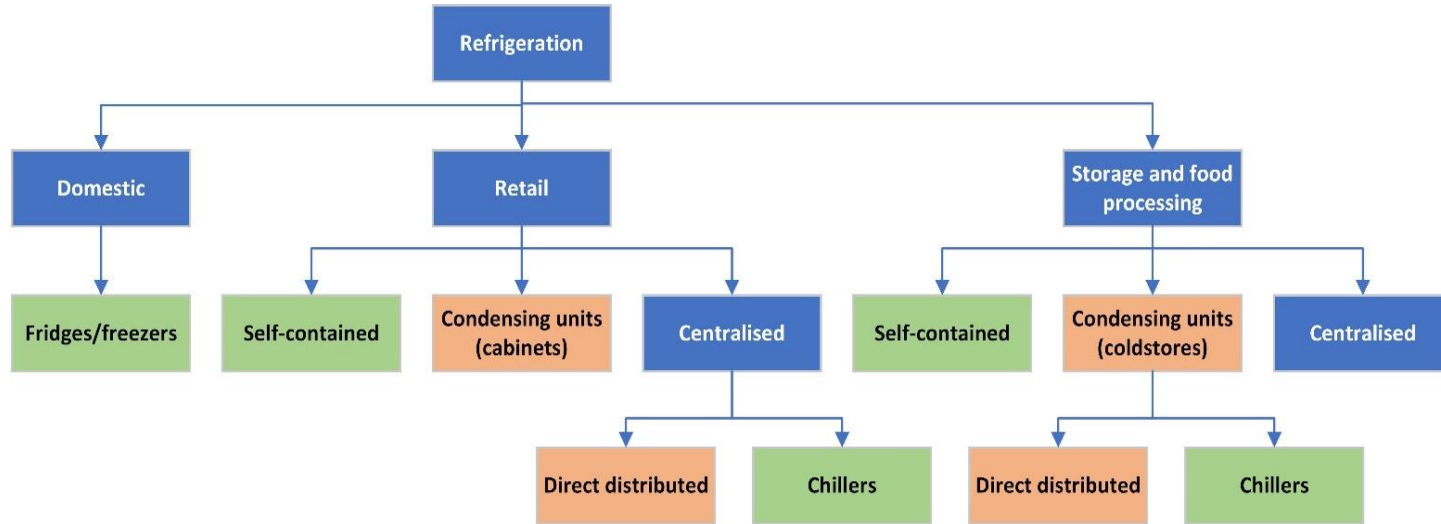
## Overview of natural refrigerants

### First Blue Angel eco-label for R290 split AC

- The number of residential air conditioners is increasing rapidly and a large share of electricity consumption is caused by ACs.
- If it is not possible to avoid the use of ACs by using appropriate construction measures, environmentally friendly ACs are necessary. This can be reached by energy efficient units with natural refrigerants.
- Midea's "All Easy Series" residential split system air conditioner using R290 refrigerant has been awarded the German environmental label "Blue Angel".
- The Blue Angel Certification is owned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The world's oldest ecolabel represents the highest standards for energy efficiency, health and environment-friendliness of home appliances. Criteria included are ultra-low GWP, high energy efficiency, low noise, and stringent material safety control.

## Overview of natural refrigerants

# Ease of application of hydrocarbons for the refrigeration sector

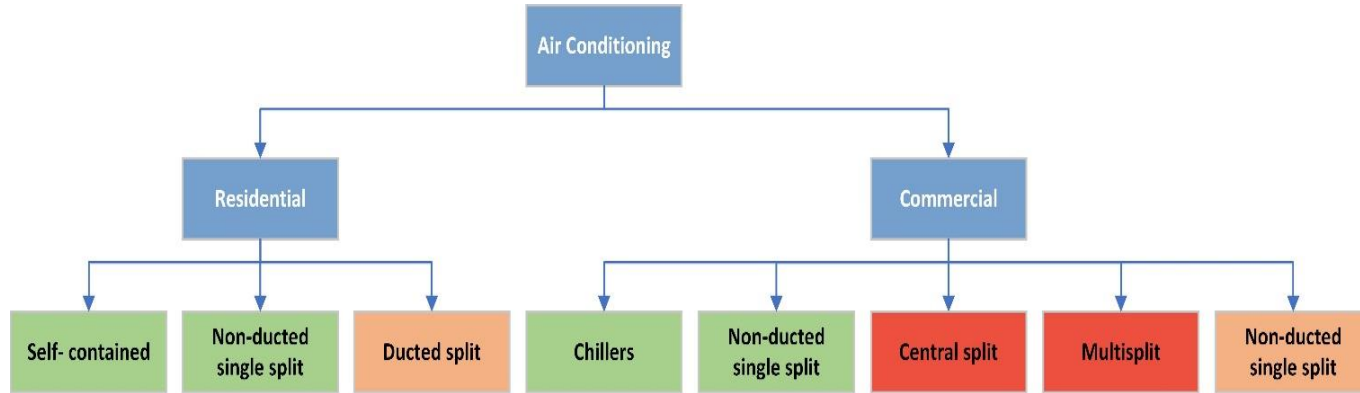


- **Green** – Application already available and state-of-the-art
- **Orange** – Application is possible, but barriers exist
- **Red** – Significant barriers for the application of natural refrigerants

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## Overview of natural refrigerants

# Ease of application of hydrocarbons for the refrigeration sector



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- **Green** – Application already available and state-of-the-art
- **Orange** – Application is possible, but barriers exist
- **Red** – Significant barriers for the application of natural refrigerants

## Overview of natural refrigerants

### Carbon Dioxide - advantages

- It has a favourable pressure ratio and the volumetric efficiency is better than other conventional refrigerants;
- Components such as the compressor and pipe diameters can therefore be much smaller, resulting in shorter defrost times, reduced material usage and system weight is generally reduced;
- Due to the high heat transfer coefficient the heat exchanger can be built relatively small. In addition, due to the low viscosity, relatively low pumping work is necessary in an R744 system. This is particularly advantageous for systems with a long network length (e.g., such as found in supermarkets and in direct evaporating systems for deep cooling).

R744 is most commonly applied in supermarket refrigeration systems, cold storage, and industrial, commercial and domestic heat pumps.

## Overview of natural refrigerants

# Ammonia

- One of the oldest refrigerants with the best thermodynamic properties of all refrigerants.
- It is the only natural refrigerant that is so efficient that industry has always used it.
- Zero ODP and GWP.
- R717 is lighter than air and thus leaks can be buoyant, making it easier to install on the roof.
- Besides the applications in large industrial plants, ammonia is increasingly being considered in projects which in the past have been planned exclusively with synthetic refrigerants (e.g. ammonia chillers in public buildings).

## Overview of natural refrigerants

### Water

- Cooling by evaporation of water is well known and has always been used.
- Water as a refrigerant comes into consideration when large amounts of ice water or pumpable ice slush are needed (e.g. for the food industry, district cooling or cooling of mines).
- The biggest challenge to date has been the enormous volume of water vapour that requires the use of rather expensive turbo compressors.
- The large required pressure ratio requires the use of either axial compressors with a relatively small installation area and many stages, or even series-connected centrifugal compressors that are quite sensitive to load fluctuations and therefore require a fairly constant load.
- Since the operation takes place in deep vacuum, an absolutely hermetic (tight) system is required.
- There is an energy saving potential of 25 % compared to today's available R134a liquid chillers (Research projects with both radial and axial compressors are currently being carried out with prototypes in France and Germany).

## Overview of natural refrigerants

### Air

- Air can be used as a refrigerant in almost any application.
- Typically, energy advantages can be observed if applications require temperatures below  $-50\text{ }^{\circ}\text{C}$ .
- Modern aircrafts flying at high altitudes are equipped with an air conditioning and pressurization system to provide a convenient environment for its passengers. In these systems compressors are coupled with the aircraft engine using the ambient air.
- R732 is suitable for freezer applications from  $-40$  to  $-80\text{ }^{\circ}\text{C}$ . In these systems, the expansion turbine is on the same drive shaft as a turbo-compressor. The energy generated during the expansion is used by the compressor, thus reducing energy consumption. It is for example used in Japan in ultra-low freezing applications for fish.

## Agenda E: Environmental impacts

Introduction

Environmental impact of refrigeration and related policies

Overview of natural refrigerants



Practical implications for technicians

# Practical implications for technicians

- Every skilled worker can reduce the environmental impact by properly planning installations and refrigerant use and following best practice techniques:
  - **Planning of the installation** (Proper dimensioning, cooling load calculation, etc.)
  - **Choosing the refrigerant** (environmentally friendly refrigerant vs. synthetic refrigerants)
  - **Good practice during installation and servicing**
  - **Recovery of refrigerant and decommissioning of the equipment**

## Practical implications for technicians

### Good practice during installation and servicing

- Proper installation and servicing of split AC units considerably support the efficiency and reliability of the equipment over its lifetime, while avoiding additional costs for electricity and spare parts.
- It reduces safety risks by avoiding problems before they even occur or detecting issues at an early stage to prevent accidents.
- An efficient operation of RAC systems relies on regular servicing, including maintenance of the adequate refrigerant charge, and cleaning practices. A system will never run as smoothly and efficiently as under factory or testing conditions if it is not installed well and serviced at regular intervals.

## Practical implications for technical staff and users

# Important points to consider in order to avoid inefficient working of ACs

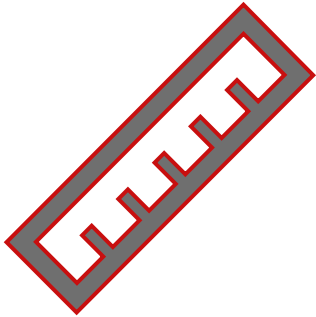


### Building envelope

- Solar gain reduction (shading, blinds etc.)
- Preferably shading on the building exterior
- If possible, modify vegetation to gain additional shading
- Avoid building envelope leaking by uncontrolled exchange of air

## Practical implications for technical staff and users

### Important points to consider in order to avoid inefficient working of ACs



#### Planning stage

- Define correct system size (for many cases systems are oversized (30 % >))
- Cooling load calculation can help to find optimal system configuration
- If applicable consider smaller system
- Choose correct location of outdoor and indoor units
- For chilled water installations, free cooling could be considered
- Consider the integration of occupancy sensors

## Practical implications for technical staff and users

### Important points to consider in order to avoid inefficient working of ACs

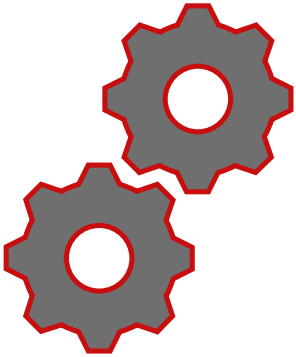


#### Installation stage

- Positioning of IDU and ODU according to manufacturer's specification
- Do not sequence multiple outdoor units (mutual influence)
- Avoid air- leakage on pipework (ductwork)
- Check accurate positioning of return air filter
- Avoid restrictions in refrigerant transfer lines
- Avoid poor insulation of refrigerant and condensate pipes
- Check that controls are correctly positioned and adjusted
- Check that control sensors are placed correctly

## Practical implications for technical staff and users

### Important points to consider in order to avoid inefficient working of ACs

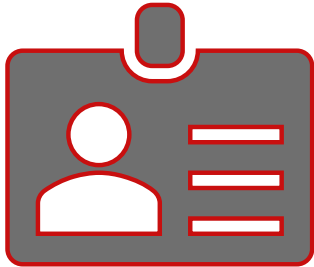


#### Operational system

- Avoid system operation when not required
- Do not operate air conditioning with open windows or passages of the building
- Ensure that manufacturer's user instructions are on site
- Maintenance contract should always be concluded with the user

## Practical implications for technical staff and users

### Important points to consider in order to avoid inefficient working of ACs



#### Maintenance & Servicing

- Avoid that systems set-points are too low ( $\leq 22$  °C)
- Maintain appropriate regular filter cleaning regime (user and service staff)
- Replace defective or worn functional parts promptly
- Execute regular refrigerant leakage testing
- Ensure the use of the correct type of refrigerant
- Do not overcharge the system with refrigerant
- Avoid that heat exchanger fins are blanked off, correct if necessary
- Avoid condenser corrosion or fouling, correct if necessary
- Avoid evaporator corrosion or fouling, correct if necessary
- Avoid lack of air flow through wrong fan rotation or damaged blades

## Practical implications for technicians

# Design and servicing features for natural refrigerants NH<sub>3</sub>, CO<sub>2</sub> and HCs

	NH <sub>3</sub> (R717)	CO <sub>2</sub> (R744)	HCs (R290, R600a ...)
Weight in relation to air	Lighter	Heavier	Heavier
Refrigerant Purity	99.98 % min (3.8) Moisture < 200 ppm	99.995 % (4.5) Moisture < 10 ppm	99.5 % min (2.5) Moisture < 10 ppm
Gauges & Circuit Equipment	Stainless Steel R717 indication	High Pressure R744 indication	As for HCFC / HFC HC indication
Vacuum Pump	Stainless Steel ATEX, Vent Line	Regular Vent line	Regular ATEX, Vent line
Charging	Scale	Scale Pressure	Sensitive Scale (min. 2 gram resolution)
Tubing	Carbon steel, stainless steel	Copper, K65 (CuFe2P) Stainless steel	Copper
Leak Finding	Nose, Gas detector, Litmus paper, Sulphur stick, Bubble test, PPE	Gas detector, Bubble test, PPE	Gas detector Bubble test, PPE
Pressure test Leak Test	Nitrogen 4.0	Nitrogen 4.0 Trace Gas (N <sub>2</sub> /H <sub>2</sub> )	Nitrogen 4.0 Trace Gas (N <sub>2</sub> /H <sub>2</sub> )
Strength test PS x 1.1	Nitrogen 4.0 (Humidity ≤ 30 ppm)	Nitrogen 4.0 (Humidity ≤ 30 ppm)	Nitrogen 4.0 (Humidity ≤ 30 ppm)

## Practical implications for technicians

# Refrigerant recovery, recycling, reclaim

Good practices in refrigerant management during an equipment's lifetime and at its end-of-life ensure environmental and personal safety, reduce emissions, optimize efficiency and performance of systems and accordingly save costs.

### **End-of-life:**

When appliances containing HCFCs or HFCs are decommissioned, due care needs to be taken to recover and dispose of the refrigerant in a legal and environmentally safe manner.

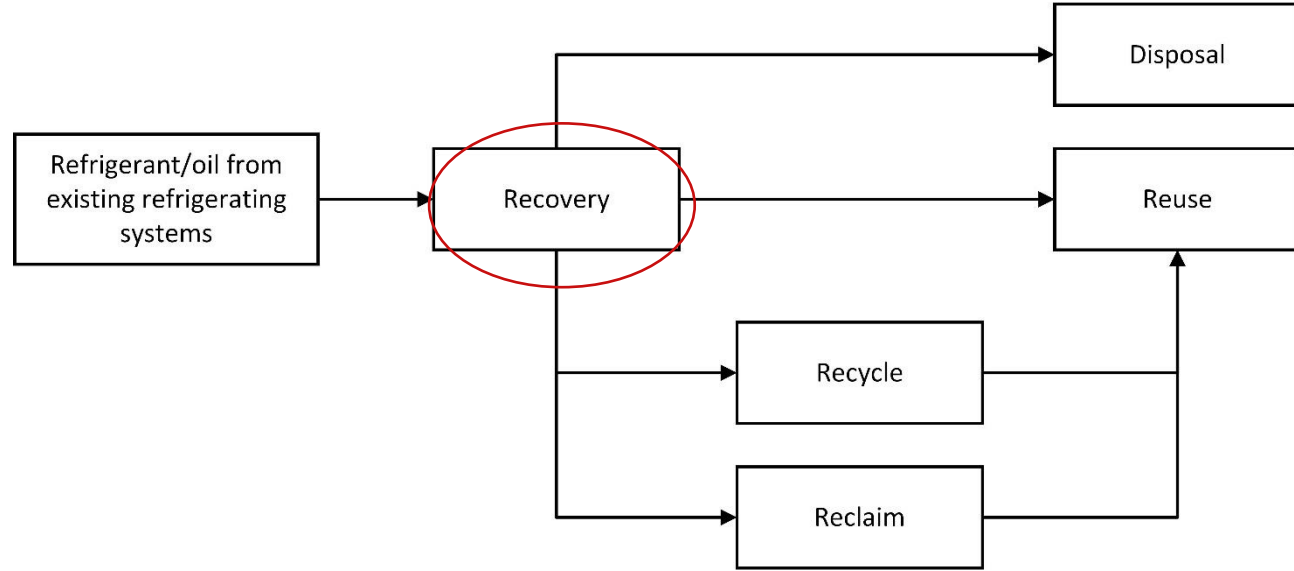
**Venting of ODS and HFCs (releasing them into the atmosphere) is not allowed.** All ODS and HFC refrigerants must be recovered when old equipment is decommissioned and before entering the waste stream.

It is possible to recycle or reclaim used refrigerants and use them again.

# Practical implications for technicians

## Refrigerant recovery, recycling, reclaim

Recovery: Recovery of refrigerant means removing a refrigerant in any condition from a refrigeration system and store it in an external container.

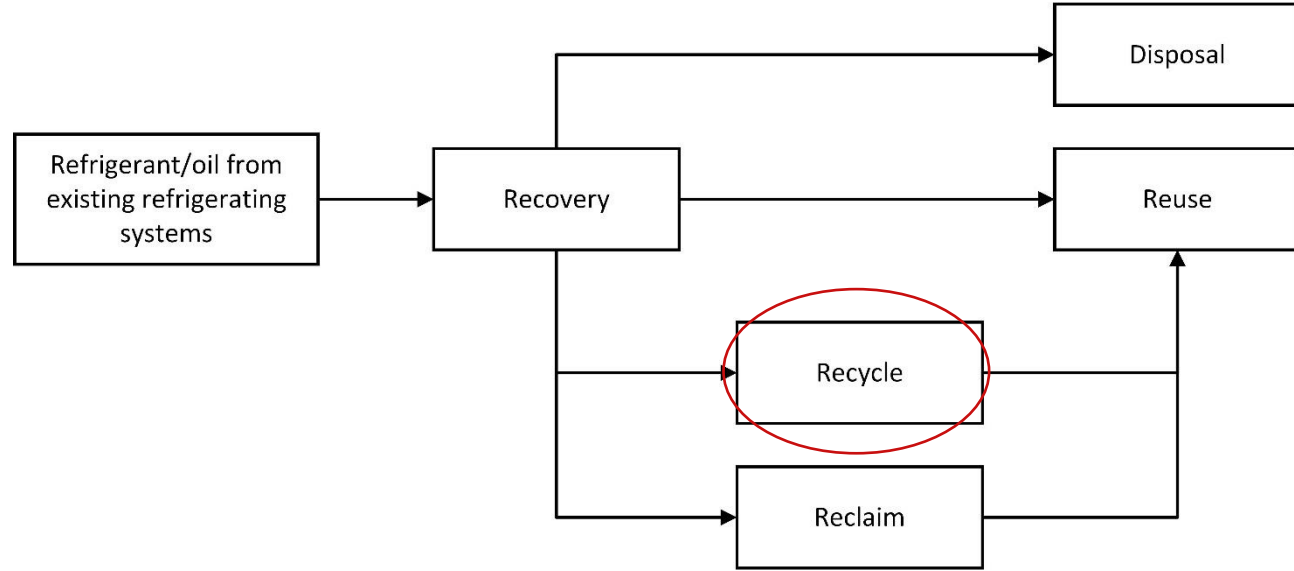


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# Practical implications for technicians

## Refrigerant recovery, recycling, reclaim

Recycling: Recycling means to reduce contaminants in used refrigerants following a basic cleaning process. This process may include separating of oil, removing of non-condensable *gases* (NCG) and using of devices such as filter-driers to reduce moisture, acidity and particulate matter.



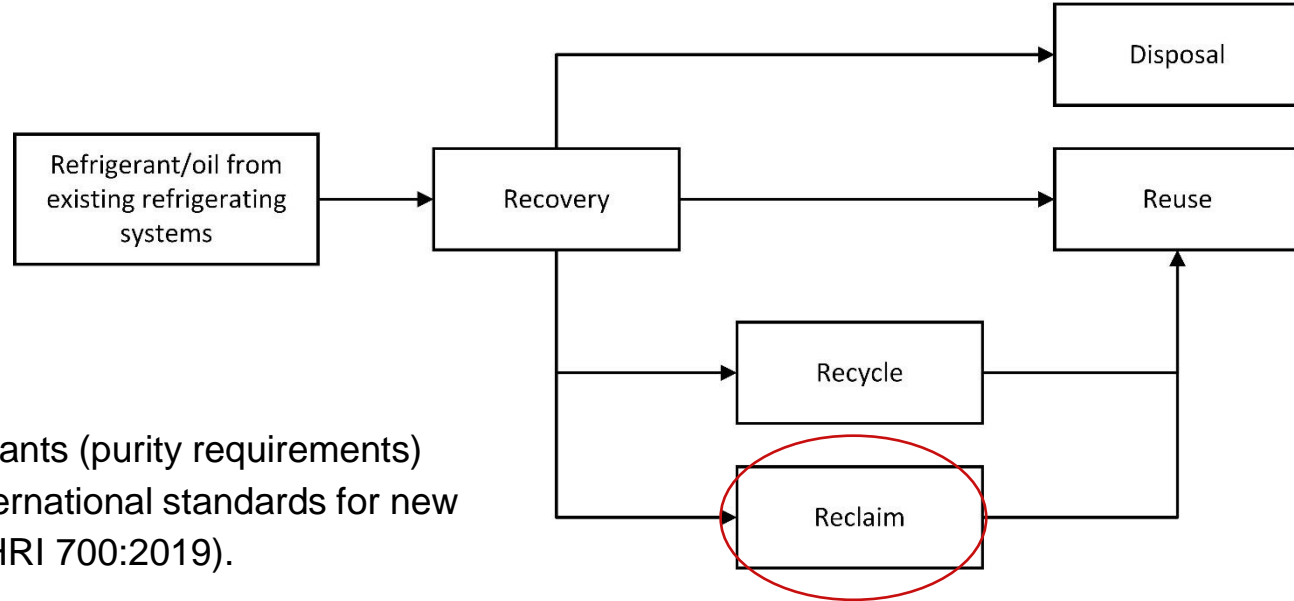
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# Practical implications for technicians

## Refrigerant recovery, recycling, reclaim

Reclaim: Reclaim means the reprocessing of a recovered refrigerant in order to match the equivalent performance of a virgin substance, taking into account its intended use.

Acceptable levels of contaminants (purity requirements) are specified in national or international standards for new product specifications (e.g. AHRI 700:2019).



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