Bu proje Avrupa Birliği ve Türkiye Cumhuriyeti tarafından finanse edilmektedir
This project is co-financed by the European Union and the Republic of Turkey

F-GASES

Awareness Raising on Environmentally Friendly Alternatives to F-Gases

Industry Guideline for the Refrigeration - Air Conditioning & Heat Pumps (RAC&HP) Sector

April, 2019

Technical Assistance for Increased Capacity for
Transposition and Capacity Building on F-Gases

TR2013/0327.05.01-04/001

CFCU

GFA CONSULTING GROUP

Bu proje Avrupa Birliği ve Türkiye Cumhuriyeti tarafından finanse edilmektedir
This project is co-financed by the European Union and the Republic of Turkey

CONTENTS

CONSULTING GROUP

List of abbreviations

AC	Air Conditioning
AHU	Air Handling Unit
CAC	Commercial Air Conditioning
CapEx	Capital expenditure
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide equivalent
EC	European Commission
EU	European Union
F-gas	Fluorinated Gas
GHG	Greenhouse Gas
GWP	Global Warming Potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HF	Hydrogen fluoride
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HP	Heat Pump
ISKID	Air-Conditioning and Refrigeration Manufacturers' Association
KA	Kigali Amendment
kW	Kilowatt
LT	Low Temperature
MP	Montreal Protocol
MT	Medium Temperature
NH_3	Ammonia
NR	Natural Refrigerant
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substances
PFCs	Perfluorocarbons
RAC	Refrigeration & Air Conditioning
R&D	Research and Development
RRR	Reclaim, Recovery, Recycle
TCO	Total Cost of Ownership
TFA	Trifluoracetic
TURKSTAT	Turkish Foreign Trade Statistics
VRF	Variable Refrigerant Flow
VRV	Variable Refrigerant Volume

Aim of the Guideline

This guideline is prepared to guide the Turkish Refrigeration and Air Conditioning and Heat Pump (RAC&HP) industry in the process to adopt the changes ahead of the upcoming new National F-gas Regulation in line with the Kigali Amendment and Regulation (EU) 517/2015, with an emphasis to the low global warming potential (GWP) alternatives to the F-gases.

It is particularly important to make the necessary transitions to the F-gas free alternatives at a time when global temperatures are in constant rise due to accumulation of the greenhouse gases (GHGs) in the atmosphere. Failing to reduce GHG emissions will potentially result in catastrophic consequences.

This guideline is aimed at operators (end-users), service companies and technicians to raise awareness of the environmentally friendly alternatives to fluorinated gases (F-gases). For this reason, it includes information on:

- The low global warming potential (GWP) alternatives to F-gases in RAC&HP sector,
- The international and national F-gas regulations, potentially impacting businesses.

The information in this guideline grouped into four sections:

- **Introduction** with background information on the **climate change, the Montreal Protocol and the Kigali Amendment.**
- **Information on the provisions** of the **EU F-gas Regulation and Turkish National F-gas Regulation**
- Foam sector specific section on the **low GWP alternatives** with information on the equipment types, safety, pricing, barriers to adoption and the availability of low GWP HFC free alternatives
- **Recommendations** for a successful transition to low GWP alternatives.

Further information can be found through the links provided in the refences.

1 Introduction

As a signatory country to Montreal Protocol (MP) Turkey is working towards updating its national fluorinated gases (F-gases) regulation in line with Kigali Amendment (KA) and the Regulation (EU) No. 517/2014. This transition will require a phase-down of the use of F-gases, improved monitoring and reporting, enhanced legal structures and increased national and local capacity.

Alternative technologies using low GWP refrigerants such as Natural Refrigerants (NR) and HFOs are commercially available, cost competitive in many applications and provide better energy performance, with lower life cost, when compared to high GWP technologies. It is vital that RAC&HP sector is informed on these alternatives to stay ahead of the potential implications and upcoming changes relating to the implementation of the revised F-gas regulation.

1.1 Climate Change, Greenhouse Gases

Climate change is the large-scale and long-term changes in the weather patterns and rising temperatures, both of which are damaging life on Earth. It is caused by the greenhouse gases (GHGs) in the atmosphere. Manmade gases such as CFCs, HCFCs, HFCs are potent GHGs and have a significant impact on climate change. HCFCs and CFCs are also potent ozone depleting substances (ODSs). They have high GWPs[1] that can be thousands of times higher than GWP of CO_2 (Table 1).

Table 1: GWP values of some selected gases. (*CO_2 is given as the GWP reference).

Refrigerant	Ozone Depletion Potential	Global Warming Potential
CFCs & HCFCs		
CFC-12 Dichlorodifluoromethane - 100% global production & consumption phased out under the Montreal Protocol	1.0 (high)	10900
HCFC-22 Chlorodifluoromethane - Subject to consumption phase out under the Montreal Protocol	0.05 (medium)	1810
HFCs		
HFC-32 (Difluoromethane)	0	675
HFC-125 (Pentafluoroethane)	0	14900
HFC-134a (Tetrafluoroethene)	0	1430
HFC-152a (Difluoroethane)	0	120
HFC-410A (50% HFC-32, 50% HFC-125)	0	2088
HFC-404A (44% HFC-125, 52% HFC-143a, 4% HFC-134a)	0	3922
HFC-407A (20% HFC-32, 40% HFC-125, 40% HFC-134a)	0	2107
HFC-407C (23% HFC-32, 25% HFC-125, 52% HFC-134a)	0	1774
HFC-407F (30% HFC-32, 30% HFC-125, 40% HFC-134a)	0	2088
HFC-407H (32% HFC-32, 15% HFC-125, 53% HFC-134a)	0	1495
HFOs and HCFOs		
HFO-1234yf	0	4
HFO-1234ze	0	6
HCFO-1233zd	0	4.5
Natural refrigerants		
Ammonia (R717, NH_3)	0	0
HC-600a (Isobutane)	0	3
HC-290 (Propane)	0	3
Carbon dioxide (R744, CO_2)	0	1*

[1] GWP is expressed as the ratio of the amount of heat trapped by a certain mass of the gas in question to the amount trapped by a similar mass of CO_2

F-gases are often used as replacement to CFCs and HCFCs. While they do not deplete the ozone layer, most F-gases are powerful GHGs. HFCs are the most significant F-gas substance class in terms of their wide spread utilization. Figure 1 shows the global use of HFCs in the main five sectors according to the UNEP's April 2015 report, with RAC&HP sector having the largest share. Other than direct emissions from the use of refrigerants, the RAC&HP sector also contributes to climate change through emissions resulting from the use of fossil fuels for power RAC&HP appliances (indirect emissions). RAC&HP appliances have an impact of about 10% of global energy related emissions (GIZ Proklima, 2017).

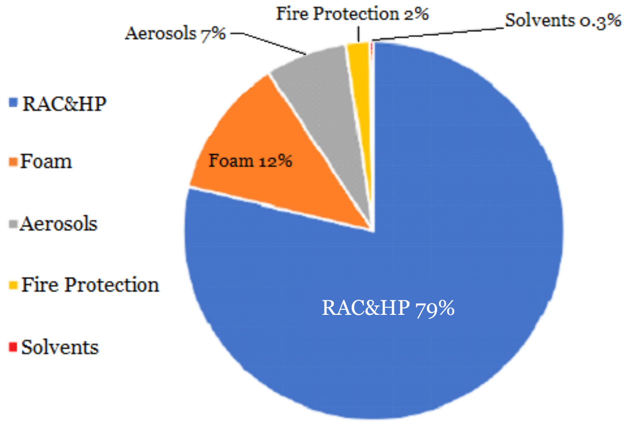

Figure 1: Use of HFCs in the top five sectors (data from UNEP 2015).

1.2 Montreal Protocol and Kigali Amendment

The Montreal Protocol:

The Montreal Protocol (MP) phases out the consumption and production of the ODSs gradually, meeting predefined and agreed targets at different stages, with different timetables for developed and developing countries (Figure 2).

Under the MP, all parties have specific responsibilities related to the phase out of the different groups of ODS, control of ODS trade, annual data reporting, national licensing systems to control ODS imports and exports, and other matters.

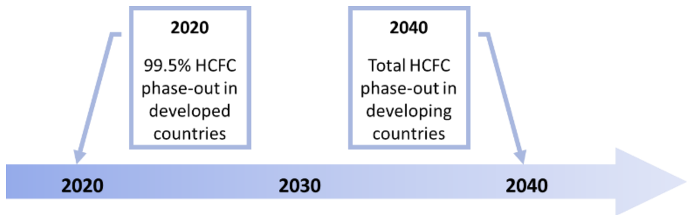

Figure 2. Timeline for the HFCF phase out under the Montreal Protocol.

Turkey became a party to the Protocol on 19 December 1991 and have been adopting all amendments since. Monitoring of all national and international efforts regarding the MP have been implemented and overseen by the Ministry of Environment and Urbanization.

The Kigali Amendment:

The Kigali Amendment (KA) to the MP adds the phase-down of the production and consumption of HFCs to the existing controls of ODS under the MP. It was agreed by all 197 Parties in 2016 and entered into force on 1 January 2019. This landmark international agreement sees that developed countries (Non-A5 countries) take the lead on phasing down HFCs, while developing countries (A5 countries such as Turkey) are allowed to have a delayed start, as shown in Figure 3 with green line.

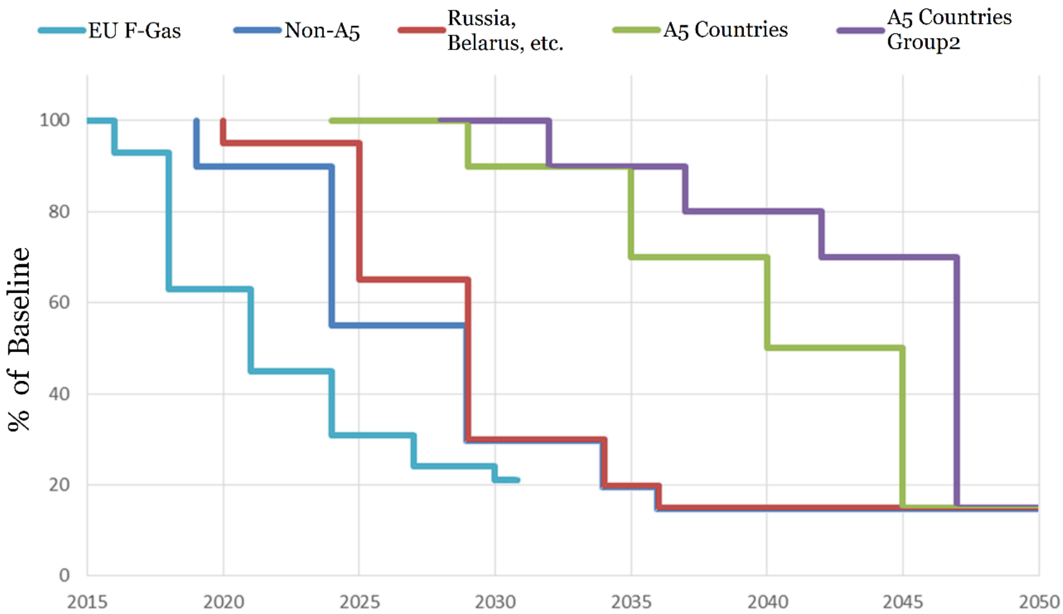

Figure 3. Kigali Amendment HFC phase-down schedules

2 Provisions of the EU and Turkish National F-gas Regulation

EU F-gas regulation:

The EU's F-gas legislation was among the world's first actions to phase down HFCs in favor of low GWP alternatives. In 2014, Regulation (EC) No 842/2006 was replaced by a new Regulation (EU) No 517/2014 on fluorinated greenhouse gases. It aims to decrease the EU's CO_2 e F-gas emissions by 79% by 2030. The scope of the revised regulation was significantly extended to include:

- A list of F-gases supplemented with other fluorinated substances that currently includes: 19 HFCs, 7 PFCs, SF_6, 5 unsaturated HFCs, 33 fluorinated ethers and fluorinated alcohols and 4 other perfluorinated compounds
- HFC phase-down schedule and system of allocation of HFC annual quota for placing on the market of HFCs by producers and importers as well as of transfer of quota and of authorization for using quota by importers of RAC&HP equipment pre-charged with HFCs
- System of registration of undertakings
- Requirements regarding equipment leakage checking, record keeping and reporting on F-gases, labeling of F-gas containers as well as products and equipment containing F-gases and certification of technicians and companies conducting certain activities involving F-gases
- Bans on use of certain F-gases
- Bans on placing on the market products and equipment containing certain F-gases or whose functioning relies upon certain F-gases.

The milestones of this F-gas Regulation are summarized on a timeline in Figure 4, where HFC bans in equipments (i.e. HFC ban on domestic refrigeration) means the bans on placing on the market of that HFC equipment (i.e. ban on placing on the market of domestic refrigeration).

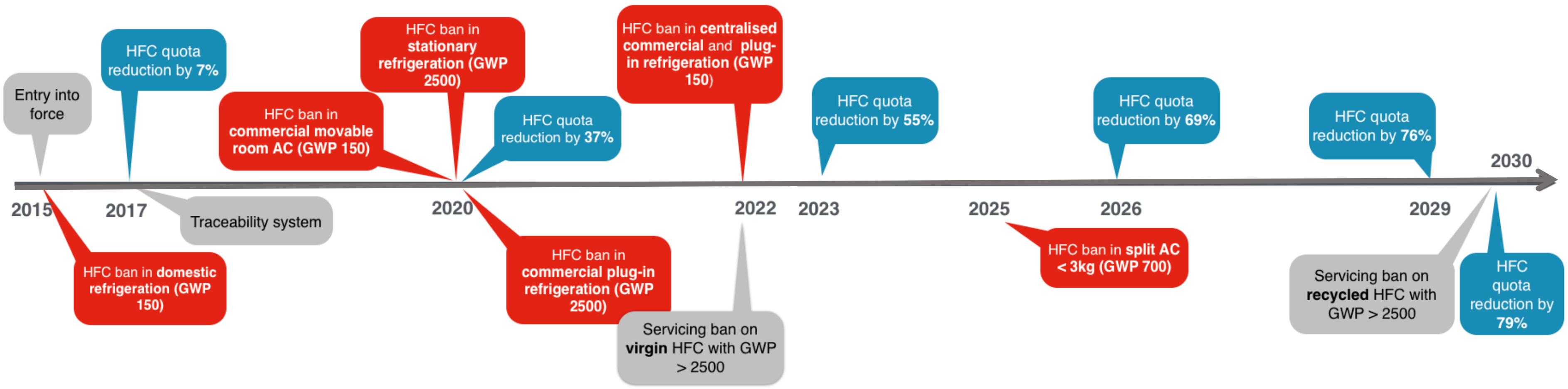

Figure 4. Provisions, prohibitions, quotas and phase-down process for the Regulation (EU) No 517/2014

2.1 Main obligations of operators of RAC&HP equipment

An "operator" is the natural or legal person who uses (i.e. exploits) the equipment which may or may not be the owner of that equipment. Under the Regulation (EU) No 517/2014 operators are legally responsible for preventing GHG emissions by acting on the following steps.

2.1.1 Leak checking

Operators are required to have their equipment tested for leaks regularly by trained and certified service providers. To prevent emissions, any leakage must be repaired as quickly as possible. All heat pumps, stationary refrigeration and air-conditioning equipment, must frequently be checked. The frequency of the leak-checks depends on F-gases in quantities CO_2 e (Table 2).

Table 2. Leak test frequencies under the current F-gas Regulations

Leak Test Frequency*	CO_2 equivalent**
1 year or 2 years	≤ 5
6 months or 1 year	≤ 50
3 months or 6 months	≤ 500
* depending on whether leakage detector is installed **tonnes of CO_2 e = F gas Mass (in tonnes) × GWP of that F gas	

2.1.2 Record keeping

Operators are required to keep records of the:

- Quantity and type of F-gases installed, added or recovered
- Identifications of the company or/and technician carrying on servicing
- Dates and results of leak tests of stationary systems containing the of 5 tons of CO_2 e F-gases or more.

2.1.3 Recovery of F-gases

Operators must arrange for the recovery, recycling, reclamation and/or destruction of the F-gases during any maintenance work or at the end of the equipment's life.

2.1.4 Other obligations

It is the operators' responsibility to ensure that the servicing, maintenance and any repairs of the F-gas equipment are provided by certified service providers. It is also the operator's responsibility that any new equipment is labelled as required by the EU F-gas regulation, indicating the type and the quantity of their content.

2.2 Obligations of service companies and technicians

Service companies and technicians must be certified to install, service, maintain and repair the equipments as well as to test for leakage and to recover/recycle/reclaim F-gases at the end of life of the equipment. Like the operators, the service companies and technicians are required to keep record of the quantity and type of F-gases installed, added or recovered, the details of the company serviced and the dates and the results of leakage checks, unless such data are kept in a central database.

2.3 Bans on placing on the market of products and equipment containing or relying on F-gases

One of the key changes Regulation (EU) 517/2014 introduced is the prohibition on HFC use in certain equipment and on placing on the market equipment containing HFCs in the market. The restrictions and the bans having been introduced over time (Figure 4) and comprised of two categories:

- Bans on placing on the market of products and equipment,
- Service and maintenance bans on existing equipments.

2.4 Turkish National F-gas Regulation

In Turkey, the national F-gas Regulation, which entered into force on 4 January 2018, contains most of the provisions of Regulation (EC) 842/2006. The current national regulation was developed in the framework of the EU Project "Technical Assistance of the Usage of F-gases in Turkey and Harmonisation of Related Legislation" completed in 2014.

The national regulation is comprised of requirements for equipment operators, such as:

- Bans related with release of F-gases into the atmosphere, placing of products and equipment on the market and acceptance at disposal facilities without recovery;
- Requirements related with data entry at the central database of the MoEU;
- Requirements for labeling F-gas-containing products and equipment;
- Requirements for operators on leakage controls;
- Requirements for certification of those who work with F-gas-containing equipment (installation, maintenance and technical service, repair or decommissioning).

The national regulation will be updated with a new version in-line with Regulation (EU) 517/2014 in 2020, which will introduce, *inter alia*:

- HFC phase-down schedule
- calculation of country annual quotas and quota allocation to HFC importers, transfer of annual quotas between importers
- Principles and procedures regarding pre-shipment import licensing

3 Refrigeration, Air Conditioning and Heat Pump (RAC&HP) Sector in Turkey

RAC&HP is a very active industry in Turkey in terms of production, import and export of equipment. It is the major user of HFCs, covering two distinguished areas of consumption:

- Initial filling of new equipment
- Maintenance and servicing of existing equipment

3.1 Refrigerants currently in use & low GWP alternatives in RAC&HP sector

The 2017 average use of refrigerant is split as follows (raw data provided by the TURKSTAT):

High/Medium GWP GWP > 150	ODSs (HCFC-22): 3.26% - Servicing old units (no new installations)
	HFCs: 92.14% - All type of applications
Low GWP GWP < 150	Hydrocarbons: 1.34% -Domestic/Small commercial
	HFOs: 4.28% - Automotive/ heating, ventilation, and air conditioning (HVAC)

Note that the TURKSTAT data for Carbondioxide-R744 (CO_2) and Ammonia-R717 (NH_3) volumes are only available as the total volumes for all industries, so couldn't be included in above numbers.

ODSs: There is still a significant quantity of HCFC-22 (370 tons in 2017) imported for servicing of old units. In Turkey, the HCFC-22 is expected to be completely phased-out by 2022.

HFCs: F-gas based technologies are still, by far, dominating the RAC&HP sector in Turkey (91.16% of imported refrigerants in 2017 according to TURKSTAT data). HFC-134a/HFC-410A/HFC-404A/HFC-152A cover around 86% of the refrigerants in use but these volumes have been decreasing in favour of lower GWP refrigerants such as HFOs, HFC-32 and natural refrigerants (HC, CO_2, NH_3) in recent years. The high-volume percentages of HFCs are driven by the regulatory frame that currently does not impose limitations on the use of HFCs in new appliances and leakage controls for equipment in operations.

"Medium" GWP F-gases: HFC-32 with a GWP of 675 has a significant increase with reaching up to 522 tonnes for the first 9 months of 2018 while in 2017 the total volume only was 21 tonnes. Its main applications are in the split, residential and commercial AC units and heat-pumps.

"Low" GWP F-gases: HFOs are in steady increase, and used in multiple applications such as the automotive mobile air conditioning (MAC) (HFO-1234yf), chillers (HFO-1234ze), etc. (see section 3.5 for more information).

Natural refrigerants: These refrigerants exist in nature (hence the denomination "natural"), nevertheless, processing and production still needed to obtain the required quality. This lowers their environmental impact for the end of life refrigerant treatment and consequently lower cost. They are also patent-free gases. Natural refrigerants have a GWP significantly below 10. In the following the major natural refrigerants are described (see section 3.5 for more information):

Hydrocarbons (R600a, R290): 120 tonnes of HC-600a and 32 tonnes of HC-290 were imported in 2017 which is about 1.34% of the total refrigerants demand in Turkey. Hydrocarbons are mainly used in domestic refrigerators, freezers and small standalone commercial equipment. There is also a significant potential to use hydrocarbons in the split air-conditioning equipment for both residential and commercial types (see section 3.5.1).

Carbon-dioxide (R744): Main application is in the refrigeration sector, such as light commercial equipment, cascade systems, chillers, etc (see section 3.5.2).

Ammonia (R717): Used for industrial applications such as chillers in the food and beverage sector (see section 3.5.3).

The most appropriate alternative must be selected in accordance with the application or the system's design. Table 3 provides an overview of possible replacement fluids together with some of their properties.

Table 3: Properties of selected replacement fluids - HFC-134a is included as an example for reference purposes

	Boiling temperature at atmospheric pressure (˚C)	Critical temperature (˚C)	Flammable	Toxic	GWP*
HFC-134a	-26.1	101.1	no	no	1430
Isobutane (R660a)	-11.7	134.7	yes	no	3.3
Propane (R290)	-42.1	96.7	yes	no	3.3
Propylene	-47.6	91.1	yes	no	1.8
Pentane	36.1	196.6	yes	no	3.3
Ammonia (R717)	-33.3	132.3	(yes)	yes	0
Water	100	373.9	no	no	0
CO_2 (R744)	(-78.4) **	31.0	no	<10% no	1
HFC-32	-51.7	78.35	(yes)	no	675
HFO-1234yf	-29.45	94.70	(yes)	(no)	4
HFO-1234ze	-18.95	109.4	(yes)	(no)	6

* Related to CO_2 with a 100 years' time horizon ** Triple point of CO_2 at 5.18 bar and –56°C

3.2 Equipment types, energy and cost comparisons

In this section, the intent is to draw a clear and comprehensive picture of the RAC&HP industry by type of application and possible low GWP alternatives. For ease of describing the diversified RAC&HP equipment range, the sector is divided it into six main categories.

Stationary air conditioning: Stationary AC equipment (

Table 4) are categorized into the following six different classes:

Table 4: Summary of the stationary air conditioning systems

Equipment	Application	Current HFC refrigerants	Abatement options	Temperature range	Cooling capacity (kW)	HFC refrigerant charge (kg)
Factory sealed	Domestic and commercial	HFC-410A, HFC-152a, HFC-R134a, HFC-32	**HC-290, HC-1270, HFO-1234yf, HFO-1234ze,**	+16°C to +26°C	1 – 10	0.3 – 3
Split AC	Domestic and commercial	HFC-410A, HFC-152a, HFC-R134a, HFC-32	**HC-290, HC-1270, HFO-1234yf, HFO-1234ze,**	+16°C to +26°C	2 – 12	0.5 – 5
Multi-split AC	Mainly commercial	HFC-410A	**HC-290, HC-1270, CO_2, HFO-1234yf, HFO-1234ze, HFC-32**	+16°C to +26°C	10 - 200	5 - 100
Ducted AC	Commercial	HFC-410A	**Ammonia, HFO-1234yf, HFC-32**	+16°C to +26°C	10 - 300	5 - 150
Chillers	Commercial and industrial	HFC-407C, HFC-134a, HFC-410A	**Ammonia, HCs, HFOs, CO_2 & water**	+5°C to +15°C	10KW–20MW	Up to 80 tons

Factory sealed: The global combined production is approximately 16 million units. There is no available data on the production of this type of equipment in Turkey.
Split types: There is a global production of more than 100 million units annually. In Turkey, according to ISKID's collected data, over 471,000 indoor units are produced annually, and around 338,000 are imported. Similarly, 460,000 outdoor units are produced in Turkey and 313,000 are imported. About 80% is for the domestic market and 20% exported principally to Europe, the Middle East and Africa.
Abatement options for both factory-sealed and split type systems are:

a. **Hydrocarbons HC-290, HC-1270** Because of the flammability there are charge size limits related to the size of rooms where the appliances are deployed. Most moveable systems tend to have charges of less than 500g so that limited, or no restriction exist for the deployment of flammable refrigerants (HC-290).
b. **HFO-1234yf, HFO-1243ze or HFC-32 or mixtures of these** could also be used. Charge size limits correspond to about six times that for HCs and therefore they are expected to be used in a large proportion of applications. Energy efficiency performance of HFOs in RAC systems is lower than HC systems.

Multi-Split / VRF: globally, about 3.3 million systems are produced annually. The annual Turkish total production plus import of the VRF indoor units is around 216,000 with circa 6% for export and 94% sold domestically. Concerning the outdoor units, the total (production + import) is at about 31,000 out of which 10% are exported. Low GWP abatement options.

a. **HCs:** HC-290 or HC-1270 with a secondary loop e.g. glycol/water.
b. **HFOs and HFC-32** could be used in direct systems, because of the lower flammability.
c. **Transcritical CO_2**

Ducted stationary air conditioning covers rooftop-ducted systems, central ducted systems, and close-control systems. Largely for commercial use. Around 2.1 million units are globally produced per year.

According to ISKID, over 15,000 units are produced annually in Turkey and 1,800 are imported. Around 76% of the total units are installed in Turkey.

- HFC-410A is commonly used, as well as HFC-32 and HFO-1234yf.
- Ammonia-R717 with a water loop is mainly used for Air Handling Units (AHU).

Chillers cool water which is pumped to provide cooling for industrial processes or for building air conditioning. Approximately 1.8 million chillers are installed globally.

Figure 5: Ammonia chiller for process water.

Any alternative low GWP refrigerants are technically feasible as the distribution in the building is via water loops. Ammonia chillers are widely installed globally, as well as in Turkey, e.g. in the food and beverage industry. Hydrocarbon chillers are installed in many countries. These NH_3 and HC chillers deliver an increased energy efficiency around 10 percent compared to HFC systems (Shwarz et al. 2011, Annex 6).

3.2.1 Commercial refrigeration

Global and European data will be shared in this section (no available data from the Turkish market).

Equipment are categorized into two different classes (
Table 5):

Table 5: Summary of the commercial refrigeration systems

Equipment	Application	Current HFC refrigerants	Abatement options	Cooling capacity	HFC refrigerant charge (kg)
Centralized equipment	Mainly for supermarkets	HCFC-22, HFC-404A, HFC-R134a	**HC-290, HC-1270, CO_2, Ammonia with water loop, HFOs**	20kW – 1MW	40 – 3000
Condensing units	Commercial	HFC-404A, HFC-R134a	**HC-290, HC-1270, HFOs**	2kW – 20KW	1.5 – 25

Centralized equipment, where usually several compressors are mounted on a rack and operated in parallel. Centralized systems are typical refrigeration equipment of supermarkets. Refrigerants used today (globally) are:

- HCFC-22 (which is in the phase-out process in Turkey and no new systems are being installed),
- HFC-404A used for both Medium Temperature (MT) and Low Temperature (LT) systems,
- HFC-134a which is used for MT applications,
- CO_2 (R744) in LT-cascade systems as well as for MT and LT in two-stage booster systems,
- HC-290, HC-R1270 with secondary loop system
- Ammonia-R717 with secondary loop systems.

Most technically feasible abatement options for centralized equipment:

a. **Transcritical CO_2-R744 system**. Two stage (booster) system using CO_2, are considered standard off the shelf solutions by several European manufacturers. Many European supermarket chains have opted for this kind of system for all their new installations. The investment costs are estimated 20% higher than for direct HFC-404A systems. The use of multi ejector system allows this technology to be used in countries with high ambient temperature.

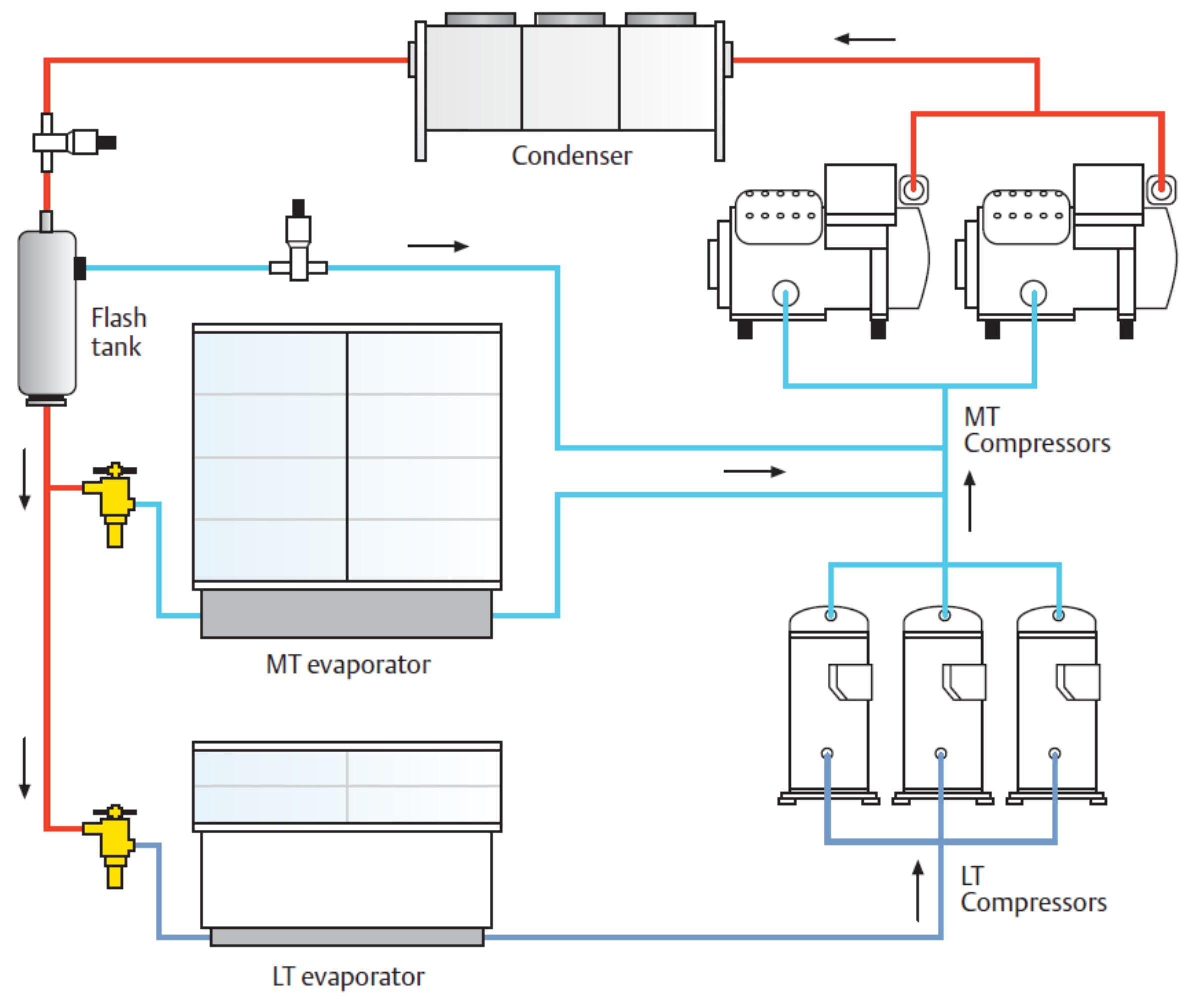

Figure 6: Booster CO2 transcritical system (source: Emerson)

Figure 7: Booster CO2 transcritical system.

b. **HCs or HFOs, and CO_2 pump circulation for MT and CO_2-cascade for LT**. Cascade refrigeration systems with CO_2 show the best climate and energy performance. There are over 1,000 CO_2-R744 cascade LT-systems installed worldwide. For larger supermarkets a CO_2-R744 cascade LT-system can be more cost effective than a standard HFC-404A system due to smaller pipes and components. Subject to the ambient and system conditions, the energy efficiency can be higher deploying natural refrigerants.

Condensing units are typical equipment in the sector of small commercial refrigeration. Refrigerants used today are primarily HFC-404A, HFC-134a, CO_2 and HFOs. An alternative to condensing units is a battery of larger stand-alone units with a water loop circuit. Most technically-feasible abatement options for condensing units:

a. **Direct HC-290 or HC-1270** covering a large extent of condensing unit applications. If safety standards could be adjusted, HCs has the potential to cover virtually the entire range of condensing units. Energy consumption can be up to 10% lower than conventional HFC equipment. Investment cost up to 25% higher due to safety requirements but compensated by the higher energy efficiency.
b. **Transcritical CO_2.** It has higher investment cost and lower energy consumption.
c. **Indirect system with HC or HFO, with liquid secondary refrigerant.**

Figure 8: Indirect system using HC refrigerant

3.2.2 Industrial refrigeration

Industrial refrigeration systems are tailored on-site built and used in food and beverage processing, storage and distribution, industrial processing. Refrigeration capacities range from 10kW to 10MW. The refrigerant charges can also vary between a few kilograms to 80 tons. Typically, these systems operate at evaporating temperatures from -50˚C to +20˚C. About 75% of all industrial refrigeration capacity is installed in the food and beverage industry, the rest in industrial processes and leisure applications (Schwarz et al., 2011). Over 90% of the large industrial refrigeration installations use ammonia (RTOC 2010 assessment). Industrial ammonia systems are in general 15% more energy efficient than HFC counterparts. 40 percent of the European industrial refrigeration systems use ammonia. It's the most popular replacement option to HFC-404A. Increasing number of cascade systems with ammonia-R717 and CO_2 have been installed in the food and beverage industry especially in Europe and North America. Another low GWP option is HFO-1234ze.

3.2.3 Domestic and small commercial refrigeration

These appliances are refrigerators, freezers and stand-alone commercial units (Table 6). Approximately 100 million domestic appliances and 3 million small commercial units are globally produced annually.

Table 6: Summary of small stand-alone refrigeration equipment

Equipment	Application	Current HFC refrigerants	Abatement options	Temperature range	Cooling capacity	HFC refrigerant charge (gr)
Fridges and freezers	Domestic	HFC-134a	**HC-600a**	-20°C to +10°C	50W – 250W	100 – 300
Coolers, vending machines	Commercial	HFC-404A, HFC-134a	**HC-290, CO_2, HFO-1234yf**	-2°C to +10°C	100 – 1500	200 – 1500

For domestic appliances, the main refrigerants used globally are about half/half between HFC-134a and HC-600a. All European refrigerators and freezers are produced with HC-600a whereas other regions use HC-600a to lesser extent. In Turkey, HC-600a represents about 20% of the domestic sales. This percentage is expected to raise to 50% in the coming few years. Additionally, four major food and beverage international companies require hydrocarbon (HC-600a or HC-290) and/or CO_2 refrigerant for their commercial equipment such as coolers, domestic units, automatic dispensers, ice-cream freezers, etc.

3.2.4 Heat pumps

Used for heating spaces, water or as dryers in some domestic applications. For these systems hydrocarbons are a technically feasible option with excellent energy efficiency and typically used for capacities below 20 kW. CO_2 heat pumps as water heaters are marketed especially in Japan. The thermodynamic characteristics of CO_2 with its even higher heat capacity during gas cooling in the transcritical process make it the ideal refrigerant.

3.3 Safety

There is no “one” refrigerant that fits all applications delivering best results. Low GWP refrigerants have major advantages over HFCs, but suffer some disadvantages summarized in Table 7.

Table 7: Low GWP refrigerants: pro's and con's

Refrigerant	Pro’s	Con’s
Ammonia (R717)	Natural ref, GWP<1, zero ODP, low cost, widely available, high energy efficiency, high cooling capacity	Toxic, low flammability
Hydrocarbons (R290, R600a, R1270)	Natural ref, not toxic, GWP<3, zero ODP, low cost, widely available, high energy efficiency, high cooling capacity	High flammability
Carbon-dioxide (R744)	Natural ref, not toxic, not flammable, GWP=1, zero ODP, low cost, widely available, high energy efficiency, high cooling capacity	Higher operating pressure, reduced efficiency at ambient >31°C
HFOs	GWP<10, zero ODP, similar energy efficiency and cooling capacity to HFCs.	Chemical, expensive, environment and health unfriendly by-products (TFA & HF), low flammability

Two elements drive the safety aspect of refrigerants, toxicity and flammability classification summarized below. These classifications are aimed to help designers and manufacturers to adapt the equipment design to the relevant standards with regard to various parameters such as refrigerant charge, ventilation, gas detectors, etc.

3.3.1 Toxicity

- Class A: refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm,
- Class B: refrigerants for which there is evidence of toxicity at concentrations below 400 ppm.

3.3.2 Flammability

- Class 1: refrigerants that do not show flame propagation when tested in air at 21°C and 101 kPa,
- Class 2: refrigerants having a lower flammability limit of more than 0.10 kg/m3,
- Class 3: refrigerants that are highly flammable.

3.4 Pricing

Due to the currently limited number of equipment commercialized with low GWP refrigerant in Turkey, it is difficult to build a comprehensive comparison chart. Low GWP refrigerant solutions, tend to become competitive with conventional systems, once they reach a significant market penetration and production scale. Due to their higher energy efficiency, low GWP alternatives can have lower overall operating costs (lower life cost).

That said, within the residential and commercial split AC sector (about one million units sold in Turkey in 2017), the average price increase when converting from HFC-410A to HFC-32, according to major Turkish manufacturers, varies from zero to 5%. Since Regulation (EU) No. 517/2014 entered into force, prices of HFC refrigerants have risen sharply and a clear correlation between the price and the GWP of the respective refrigerant could be observed. In the industrial sectors, the conversion from high GWP refrigerant's system to ammonia or cascade ammonia/CO_2 comes at higher up-front cost but it delivers lower life cost due to its higher energy efficiency and the lower refrigerant cost.

3.5 Low GWP Alternatives

3.5.1 Hydrocarbons

The most used hydrocarbon refrigerants in the RAC&HP sector are isobutane (HC-600a) and propane (HC-290). They:

- are less expensive than synthetic refrigerants,
- have a GWP of 3 and no ozone depleting potential,
- are non-toxic, nearly odorless,
- can accomplish most of the specifications required for refrigerants,
- have 10 to 15% higher the energy efficiency than comparable HFC-134a units

However, they are classified A3 flammable refrigerants. Hence, specific precautions and system requirements shall be followed when designing equipment containing HC gases. They are prevalent in European and Asian household refrigerators and commercial stand-alone cabinets. For larger charges special requirements are stipulated concerning flammability. Typically, a refrigeration system initially designed for HFC will need about only 40 to 50% of that charge when operating on hydrocarbons. Current plug-in refrigeration units with refrigerant charges below 150 gr may achieve refrigeration capacities up to approximately 1,000 Watt.

3.5.2 Carbon dioxide

Carbondioxide-R744, CO_2, is one of the key natural refrigerant alternatives to HFCs for industrial refrigeration, heat pumps, commercial refrigeration, chillers and cold rooms. CO_2 is

- is colorless, odorless, non-toxic and heavier than air,
- is non-flammable,
- has much higher volumetric efficiency than that of traditional refrigerants allowing system designs and components with smaller volumes
- has better energy efficiency (small pressure drops leads to significantly smaller heat losses)
- operates at higher pressures than other refrigerants requiring special design and stronger materials.

3.5.3 Ammonia

Ammonia-R717, NH_3, has been the standard refrigerant for industrial refrigeration systems for more than 125 years. It is already worldwide used in the food and beverage industry and other processing industries. Ammonia refrigeration systems

- have the lowest GWP (zero) of all refrigerants.
- achieve higher energy efficiency than HFC.
- are commonly applied in larger capacity applications such as cascade systems (e.g. with CO_2), chillers, industrial applications, low temperature applications, cold rooms, etc.

Ammonia is classified as B2L refrigerant due to its toxicity and low flammability, but its pungent odor has a high warning effect.

3.5.4 Hydrofluoroolefins - HFOs

HFO-1234yf and HFO-1234ze are the most common HFOs in the market in recent years, with a GWP values below 10. They are classified as A2L, low flammable gases. Developed to replace HFC-134a in MAC applications, in particular HFO-1234yf. HFOs are either used as single substance, e.g. HFC-1234yf or in mixtures with HFCs, where they reduce the GWP of the blend. They have high reactivities and therefore shorter lifetimes in the troposphere resulting in low GWPs.

However, there are big concerns about the potential environmental impact of large-scale use of HFOs. HFO-1234yf yields more than 90% Trifluoroacetic acid (TFA) (up to 4-5 times as much as HFC-134a). Therefore, even if HFOs are not an immediate threat to the global warming, massive emissions may be a threat for aquatic environments and plants rather than the atmosphere. The processes and by-products involved in the manufacturing of unsaturated HFCs are not well known.

Another concern relates to the decomposition of HFOs during a fire and subsequent recombination can create decomposition products, e.g. hydrogen fluoride (HF), which are toxic to humans – just like decomposition products of any other HFC.

3.6 Examples of low GWP Applications from the EU and Rest of the World

Some of the major international operators and manufacturers in the F-gas sector pledged to reduce their carbon footprint and emissions ahead of the Kigali amendment, in line with their corporate social responsibility plans and marketing efforts.

In 2000, the world largest ice cream producer **Unilever** made a commitment to implement by 2005 a non-HFC purchasing policy for ice cream freezer cabinets in all countries where commercially viable alternatives can be legally used. Unilever has chosen propane HC-R290 as the replacement for HFCs in this application. Since 2003, propane cabinets have been rolled out globally (including in Turkey) exceeding the 1 million unit in 2016, and that the HC-R290 cabinets are more energy efficient compared to the equivalent HFC-R134a versions.

Nestlé states it has phased out more than 90% of refrigerants with high global warming potential from their industrial operations and focuses now on smaller refrigeration systems such as ice cream freezers. A replacement of a 3.2 MW HCFC-R22 refrigeration system by one using ammonia resulted in 40% reduction of energy consumption. As the new plant utilizes heat recovery and water heating by means of an additional heat pump, the total annual cost savings are more than CH1.4 million (roughly about 1.2 million Euros), resulting in a payback time of 2.7 years.

The German food discount chain, **Aldi Süd**, announced in December 2009 that as of January 2010 the company will only install CO_2 refrigeration systems in all new stores in Germany. The company opens around 150 new stores each year.

Marks and Spencer's announced that "from 2010 all new installations will use CO_2 secondary systems wherever possible". By 2030, the company plans to manage without HFCs completely, using CO_2 and hydrocarbons as refrigerants instead. The company is training technicians in developing countries on the use of natural refrigerants.

GEA Grasso has developed an ammonia chiller with smaller footprint, less noise and lower energy consumption than comparable HFC chiller. In particular the part load efficiency has been greatly improved, which is significant since most chillers operate over 90% of the time under part load condition. At 25% capacity the energy consumption is estimated to be less than half that of comparable HFC chillers. The ammonia chiller is also cheaper than an HFC unit with comparable energy efficiency. Ammonia chillers are being used in many public buildings including Copenhagen airport, department stores in Aarhus and Copenhagen, and the state government building in Düsseldorf, Germany.

By the end of 2010 **GIZ/GTZ** had converted a production line to hydrocarbon split air conditioners in a Chinese factory of one of the world's largest manufacturers of split air conditioners. The propane-R290 units achieve 10 to 15% higher energy efficiency. The manufacturer expects to sell 100,000 hydrocarbon split air conditioners annually with hydrocarbon charges up to 330 g for a 3.5 kW refrigeration capacity unit.

In China and India, at least five major manufacturers are now introducing HC-290 production lines or are already producing and selling HC-290 split air conditioners. In India over 600,000 HC-290 air conditioners have been sold so far. **Two UK, one Australian and one Italian manufacturer** have been producing such units for some time. Some other case studies, as well as relevant presentations and technology developments can be found e.g. on the website of the Green Cooling Initiative (www.greencooling-initiative.org).

4 Recommendations

In Turkey, the adoption of low GWP RAC&HP applications shows promising initial action.
There are no major barriers to timely switch a good portion of the RAC&HP sector to low GWP technologies in no longer than 4 to 6 years' time.

Table 8 shows an estimate of time periods needed for different applications to be partially or in full converted to low GWP technologies. These estimates are based on three elements:

1) some of these technologies already exists (manufactured and/or installed) in Turkey e.g. ammonia chillers, R32 split AC, HC domestic refrigerators, HC commercial refrigerators, etc.,
2) conversions (sometimes slow) happened/happening in other regions e.g. the EU, Thailand, Chile, Jordan, etc. and
3) on the experience of the experts. Highlighted in green are the low hanging fruit applications.

These time frames (Short, Mid and Long) are needed for:

a. Equipment development and testing
b. Supply chain development
c. Production line conversion and trainings
d. Field service technicians' training
e. Commercialization and market introduction

Table 8: Projected potential timelines for industry conversion to low GWP technologies

	Short-Term 2 to 3 years	Mid-Term 3 to 4 years	Long-Term 4 to 6 years
Residential AC	X (per max allowed HC charge)		
Commercial AC	X (per the max allowed HC charge)		
Central AC			X
VRF/VRV			X (or longer)
Roof Top		X	
Chiller	X		
Condensing Units		X	
Air Handling Unit (AHU)	X		
Cold Room		X	
Heat Pumps		X	
Industrial Refrigeration	X		
Domestic & Light Commercial	X		
Mobile Refrigeration		X	
Mobile AC (automotive)		X	

It is recommended to prioritize the conversion to natural refrigerants over HFOs where technically and commercially possible; such as for domestic and light commercial (hydrocarbons), chillers (NH_3), industrial refrigeration (CO_2/NH_3), AHUs (NH_3, HC), cold rooms (CO_2) and heat pumps (CO_2 and HCs). For these applications, natural refrigerant alternatives are commercially available and technically proven to be more energy efficient than equivalent HFC versions, they are reliable, with marginal abatement cost and lower life cost.

Figure 9 shows the wide range of the RAC subsectors. In green are the "low hanging fruits" in terms of ease conversion to NR alternatives. In orange are subsectors where conversion is limited due to current standards, mainly limiting the charge of HC refrigerants. In red are the current most challenging subsector for conversion to NR.

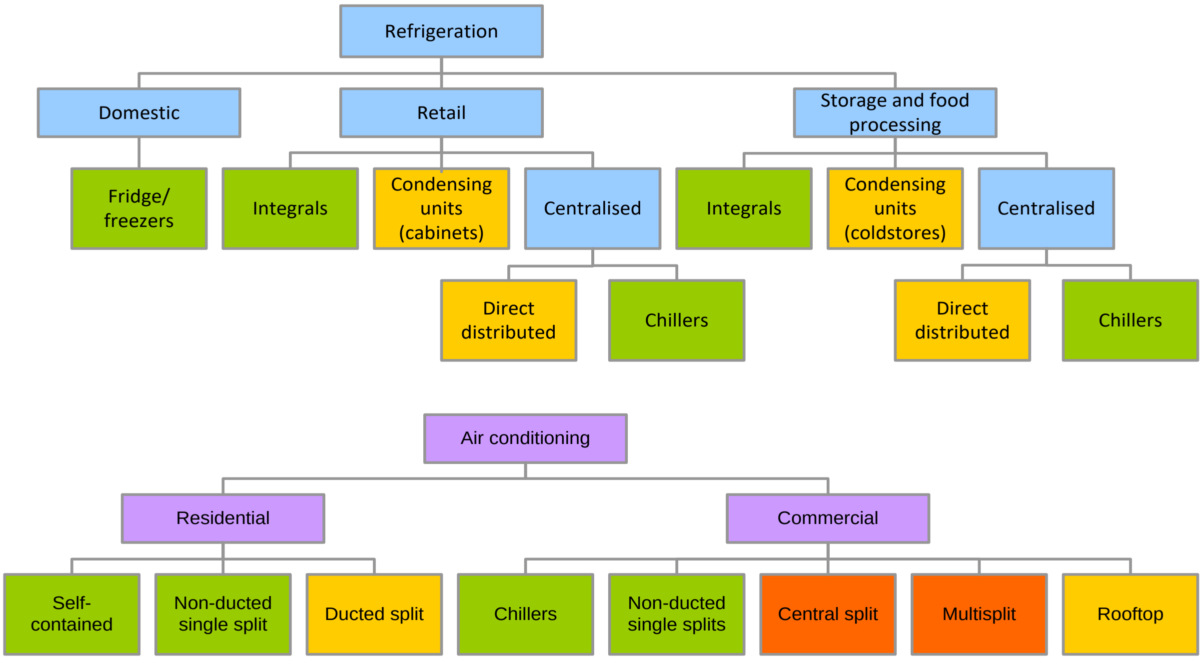

Figure 9: RAC subsectors

In a nutshell:

- With the lesson learned from the EU F-gas regulation, a revised Turkish F-gas regulation will clarify future directions. It will help manufacturers and suppliers to timely plan relevant investments for the conversion of their production lines, to prioritize product development and prepare commercialization and communication plans with end-users.
- Improved HFC reporting system,
- For existing HFC units, set containment requirement to reduce leaks,
- Drop-in replacement with low GWP refrigerants where technically and legally feasible
- Enforcement of an HFC taxes scheme, incentives for environmentally friendly technologies, consumer pressure through an effective awareness campaign,
- Marketing campaign to familiarize end-users with these new low GWP technologies,
- Technical trainings for technicians and development of a relevant after sales service,
- Provide adequate and sufficient facilities for recycling/reclaim/destruction of high GWP gases.

References

1. GIZ Proklima (2018), *Cool Contributions fighting Climate Change: Coordinating finance for sustainable refrigeration and air conditioning*.
2. UNEP (2015), *The Emissions Gap Report 2015: A UNEP Synthesis Report*. Nairobi: UNEP. http://www.unep.org/emissionsgapreport2015/.
3. Schwarz, W., Gschrey, B., Leisewitz, A., Herold, A., Gores, S., Papst, I., Usinger, J., Oppelt, D., Croiset, I., Pedersen, H. P., Colbourne, D., Kauffeld, M., Kaar, K., Lindborg, A. (2011), *Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases Prepared for the European Commission in the context of Service*. https://ec.europa.eu/clima/sites/clima/files/f-gas/docs/2011_study_en.pdf
4. UNEP (2010), *Report of the Refrigeration, Air Conditioning, and Heat Pumps Technical Operations Committee: 2010 Assessment*, UNEP, http://ozone.unep.org/Assessment_Panels/TEAP/Reports/RTOC/RTOC-Assessment-report-2010.pdf
5. TEAP (2016), *Report of the Technology and Economic Asessment Panel*. http://conf.montreal-protocol.org/meeting/oewg/oewg-38/presession/Background.
6. Luecken L., Waterland R., Papasavva S., Taddonio K. N., Hutzell W. T., Rugh J. P., Andersen S. O. (2010), *Ozone and TFA Impacts in North America from Degradation of (HFO-1234yf), A Potential Greenhouse Gas Replacement*. Environ Sci Technol. 1;44(1):343-8.