Interreg
Sudoe
KET4F-Gas

EUROPEAN UNION

Good practices handbook for industry and waste managers

Contents

Chapter 1:

An overview on F-gas current situation

KET4F-Gas is a European project that aims at the reduction of the environmental impact of fluorinated gases (F-gases) in the SUDOE area, using Key Enabling Technologies (KETs) to facilitate companies and waste managers to comply with EU F-gas regulations. The main objective of this project is to help the implementation of the most efficient option for the separation and recovery of F-gases used in refrigeration and air conditioning equipment. The KET4F-Gas solution is based on the most efficient treatment systems and designed according to the principles of green chemistry.

What will you find in this chapter?

The problems related to the uncontrolled emissions of F-gases.

The benefits of using F-gases, if controlled correctly.

The existing and historical co-relation between climate change and F-gases emissions .

The EU efforts to tackle F-gases market availability, emissions and selective recycling.

F-gases emissions consequences and phase-down in SUDOE areas.

KET4F-Gas objectives and solutions to the outlined problems.

F-gas Environmental Impact and Current Situation

The problems of the uncontrolled emissions of F-gases in few words:

F-gases represent about 2% of the total greenhouse gases emissions in the EU.

F-gases are powerful greenhouse gases, showing a global warming potential up to 23000 times higher than CO_2.

The EU28 countries emitted in 2016 the astonishing amount of 110 million tonnes of CO_2-eq of F-gases.

Their emissions have increased 60% since 1990.

HFCs emissions are projected to grow by nearly 140% between 2005 and 2020.

Even if some compounds have a short-life cycle, some can remain in the atmosphere for thousands of years.

The uncontrolled use of HFCs can lead to these gases to represent 12% of the total greenhouse gases emissions by 2050 as the global energy demand for cooling equipment is expected to triple by 2050 due to global warming.

The use of F-gases, if controlled correctly, can also have benefits:

F-gases are not toxic from a chemical point of view and they are still widely used as they are not very reactive and non-flammable.

F-gases are valuable materials which are especially suitable for recycling and reclamation due to their high stability.

Only 1% of F-gases are collected at the end of their life cycle in Europe (about 1200 tonnes in 2015) even though recycling units do exist. This means that there is a great window of opportunity for improvement for reclaimed F-gases and their integration into EU circular economy market.

F-gases are man-made compounds which can be improved, recycled safely and re-used improving the energy efficiency of the systems and their overall cost-effective life cycle. If done correctly, F-gases environmental impact can be reduced to a minimum under the EU circular economy principles.

Reclaimed F-gases are not subjected to additional taxation, while new alternatives, because of their status as new products, are protected by industrial patents, which represent an additional cost for their use.

F-gases selective recycling is fundamental to reduce the industry's dependence on higher GWP refrigerants, reduce overall prices and alleviate the pressure on the whole market chain.

Climate change is already a reality that affects the entire planet. Global temperature is raising every year, mostly due to the increasing concentrations of atmospheric GHG (greenhouse gases). Although carbon dioxide (CO_2) accounts for at least two-thirds of the global GHG emissions, F-gases such as the families of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), as well as sulphur hexafluoride (SF_6), are also major contributors to global warming. While the majority of GHG are by-products of several processes, like the combustion of fossil fuels, F-gases are a family of man-made gases widely used for several industrial applications (e.g. air-conditioning systems, industrial refrigeration, fire extinguishants, solvents). Due to their utility and industrial application, the worldwide production of these compounds is expected to increase for the foreseeable future. The emissions of F-gases are released intentionally or through leakages in the systems and these emissions have increased 60% since 1990. HFCs emissions are projected to grow by nearly 140% between 2005 and 2020. The increase in emissions of F-gases is contributing largely to global warming which affects not only the ecosystems but also human life due to the increase of floods, heat waves events and rising sea levels.

Since the development of refrigerants in the 19th century, continuous research has been performed aiming to develop more efficient, less dangerous, and more environment-friendly compounds. In 1987, the Montreal Protocol determined the phasing-out of second-generation refrigerants, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which cause ozone depletion. Therefore, the utilization of man-made greenhouse F-gases, in special HFCs, has increased drastically for refrigeration and air conditioning applications since 1990. These third-generation refrigerants are energetically efficient, non-toxic and exhibit low levels of flammability while not causing harm to the ozone layer. However, they are potent GHGs, with a global warming potential (GWP) 23000 times greater than that of carbon dioxide and have an extensive atmospheric lifetime up to 50000 years. This implies that small atmospheric concentrations of these F-gases induce large effects on global temperature and, consequently, on climate change. While the emissions of all other GHGs in the EU have decreased, the emissions of F-gases have increased. Indeed, previous studies showed that in the European market the most used refrigerants include R-134a (1,1,1,2-tetrafluoroethane) as pure gas, and blends containing R-32 (difluoromethane), R-125 (pentafluoroethane), and R-134a, such as R-404A, R-407F and R-410A refrigerants.

The European Union transition towards fourth-generation refrigerants, with low GWPs, is underway. Great efforts have been made in the research on natural refrigerants (with toxicity and/or flammability problems), hydrofluoroolefins (HFOs, with efficiency energy problems), HFCs with lower GWP, and on HFC-HFO blends (with low toxicity and null flammability). Some HFC-HFO blends are already replacing HFCs in commercial and industrial refrigeration. Examples of those are R-448A and R-449A, (blends of the HFCs R-32, R-125, and R-134a with the HFOs R-1234yf and R-1234ze), and R-450A and R-513A (blends of the HFC R-134a with the HFOs R-1234ze and R-1234yf, respectively). It needs

to be considered as well that, these new alternatives because of their status as new products, they are protected by industrial patents, which represents an additional cost for their use, while reclaimed F-gases are not subject to additional taxation.

The actual lack of developed technologies to recycle F-gases dramatically affects the refrigeration sector because most F-gases are incinerated, thereby increasing the atmospheric emissions of these gases. The by-products of F-gases degradation in atmosphere, hydrogen fluoride (HF) and trifluoroacetic acid (TFA), are directed to the surface of earth dissolved in water, and upon significant accumulation may present potent eco-toxicity effects. This said, there is a fundamental necessity to not only reduce the release of F-gases into the atmosphere but also to separate and recycle pure HFCs at the end of the refrigeration and air conditioning equipment life, to reuse and recycle in the subsequent production of fourth-generation refrigerants, applying circular economy. The research on technologies based on environmentally benign materials that efficiently capture, separate, and recycle F-gases is vital to develop sustainable processes to reduce the environmental impact of refrigerants based on F-gases. The environmental impact resulting from the release of F-gases is prompting the development of these new technologies to recover and recycle them. The adaptation to climate change is a key climate policy in the EU and the development of green technologies, such us the efforts done by KET4F-Gas, is encouraged.

The SUDOE area (France, Spain and Portugal) is especially suffering the consequences of global warming being the main responsible behind the current context of persistent drought, heat waves and more and more difficult fire events worsened by the high wings. Following the global tendencies, the data from the European Environmental Agency shows that the F-gas GHG emissions and removals in France and Spain have increased substantially since 1990 (France +43.6% and Spain +51.5%). However, the latest data related to 2018, show that the SUDOE area has slightly reduced their emissions (this is official data that does not include the emissions coming from the illegal market as they are not declared): Portugal -4.6%, France -4.0% and Spain -1.8%. This reduction is due to efforts of these national governments that have put in place a set of fiscal, regulatory, voluntary and informative measures following the Global agreements and, more specifically, the European regulations that are described in chapter 2.

Despite these preliminary first steps, a reshape of thinking needs to be set in place to tackle cost-efficiently the adaptation to the F-gas phase-down in the SUDOE area, stop the advance of illegal trade, correct practices in the waste management of F-gas

and optimize the recycling efforts. For these Southern European regions there is a special great room for improvement as the recycling percentages are extremely low. This is a great opportunity for SUDOE waste managers and companies to optimize their systems, comply with F-gas regulations to avoid penalties and adapt and contribute to the market of the future under circular economy principles. Technologies such as the KET4F-Gas system give an advantage to companies as there is an urge to develop efficient and sustainable technologies to selectively capture F-gases and to recycle them into new environmentally sustainable refrigerants to avoid the combustion or incorrect treatment of this waste that would ultimately increase emissions and taxes.

In short International and European legislations limit the global use of fluorinated greenhouse gases, control their production, release and management and incentivise the development of a new generation of refrigerants with lower global warming potential. Therefore, there is an urge to develop efficient and sustainable technologies to selectively capture F-gases and to recycle them into new environmentally sustainable refrigerants. This project aims at real implementation of technologies to efficiently separate and recycle HFCs at the end of the refrigeration and air conditioning equipment life. The recovered F-gas will be used in new gas blends with lower GWP, applying circular economy and reducing the needs of new F-gases. Then, KET4F-Gas will contribute greatly to reduce the F-gases emissions by valorising the residues. The recycling and reclamation of refrigerants proposed in this project, based on adsorption and membrane technologies, leads to an environmentally friendly separation process of pure F-gases, as alternative to the distillation which is a process that requires the use of considerable amounts of energy. KET4F-Gas project proposes the real implementation in the industrial sector of refrigeration and air conditioning, of separation, purification and capture processes of one of the GHG families that most contribute to global warming. The capture and separation of F-gases from commercial refrigerants is a still poorly explored area.

Main takeaways:

International and European legislations limit the use of fluorinated greenhouse gases, control their production, release, and management and incentivise the development of a new generation of refrigerants with lower global warming potential.

F-gases are man-made compounds which can be improved, recycled safely and re-used improving the energy efficiency of the systems and their overall cost-effective life cycle. If done correctly, F-gases environmental impact can be reduced to a minimum under the EU circular economy principles.

SUDOE areas are specially affected by the effects of Global Warming and have a great room for improvement as the recycling percentages are extremely low.

There is an urge to develop efficient and sustainable technologies to selectively capture F-gases and to recycle them into new environmentally sustainable refrigerants.

This is a great opportunity for SUDOE waste managers and companies to optimize their systems, comply with F-gas regulations to avoid penalties and adapt and contribute to the market of the future under circular economy principles.

KET4F-Gas proposes a step forward to a real implementation throughout the industrial sector of refrigeration and air conditioning, separation, purification and capture processes of one of the GHG families that most contribute to global warming.

This project has developed technologies to efficiently separate and recycle HFCs at the end of the refrigeration and air conditioning equipment life. The recovered F-gas will be used in new gas blends with lower GWP.

Chapter 2:

How does the current F-gas regulation affect waste managers? A global look from policy to market

The EU has become in recent years a reference in the fight against climate change and in the mitigation of the HFC impact on the atmosphere. It is a priority for the European Commission the development of technologies and research initiatives, such as KET4F-Gas, that help to efficiently separate and recycle HFCs at the end of the refrigeration and air conditioning equipment life, to reuse and recycle in the subsequent production of fourth-generation refrigerants following the principles of the circular economy. The venting of refrigerants into the atmosphere is explicitly prohibited and subject to penalties. At the end of equipment's lifetime or when retrofitting existing installations, the refrigerant must be recovered for re-use or destruction.

What will you find in this chapter?

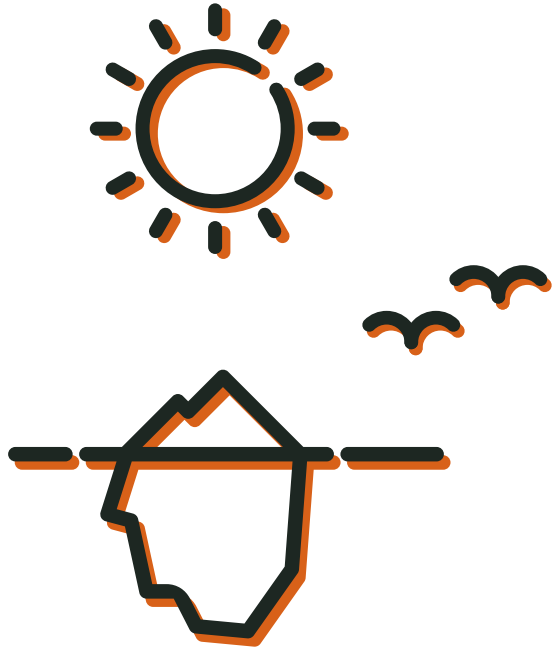
An overview of the two environmental policy regimes at an International level regarding HFCs (Montreal and Kyoto Protocols and the Kigali Amendment).

European Union F-gas regulations outline, 2014 F-gas directive and HFCs phase down .

2014 F-gas directive impacts on the F-gas Industry and waste managers: fourth-generation refrigerants, new alternatives, selective recycling.

Transposition of the 2014 F-gas regulation into national law in SUDOE countries: characteristics, penalties, taxation.

Why is it important for waste managers and operators to recycle, reuse and reclaim F-gases?



At an international level, there are two environmental policy regimes regarding the management of HFCs. On the one hand, the Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol (1987) determined the phasing-out of ozone depleting substances, such as chlorofluorocarbons (CFCs), with the objective to *"protect human health and the environment against the adverse effects resulting from modifications in the ozone layer"*. On the other hand, the Kyoto Protocol and the Paris Agreement aiming at stabilizing *"greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"*. According to the agreements of the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the 525/2013 EU regulation for the monitoring of emissions of greenhouse gases, each country committed to elaborate an Inventory of Greenhouse Effect Gases (GEGs) Emissions, reporting all details concerning the type of emitted substances and economic activity related with the emissions. The reports issued in 2018 contained data for EU28 countries for the time series from 1990 to 2016. With the Kigali Amendment to the Montreal Protocol that entered into force on 1 January 2019 covered by the UNFCCC, it was established the first international regulation to decrease the amount of F-gases emissions. This deal includes: (i) provisions to prohibit and/or restrict countries

that have ratified the protocol or its amendments from trading controlled substances with states that have not yet ratified the protocol; (ii) specific targets and timetables to replace HFCs with more environmental friendly alternative refrigerants; (iii) and an agreement by rich countries to help financing the transition of poor countries to alternative safer products. The European Union has been a leading force and a global leader in the signature of these international agreements.

The European Union has gone a step forward and it has imposed additional strong regulations to the international agreements to control the manufacture and utilization of F-gases. The first F-gas *Regulation was the so-called Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases*, created under the EU Low Carbon Roadmap agenda that aimed at reducing emissions stemming from F-gases. The directive that is currently in place is the Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. This new regulation included additional requirements and fully replaced the regulation set in place in 2006. This new F-gas directive reformulates drastically the way industry deals with HFCs and it introduces new mechanisms to ensure an effective emission reduction. The gases mainly affected by this EU Regulation are HFCs, PFCs and SF_6 (fluorinated greenhouse gases). It needs to be taken into account that the phase-down provisions only affect HFCs. Unsaturated HFCs are an exception as they are not included in the phase-down but are subjected to reporting obligations.

The HFC phase-down will gradually reduce the availability of these gases in the European market through the allocation of quotas by the European Commission following the target of decreasing HFC consumption in 79% by 2030. This is an extraordinary effort that will impulse industry and users towards the transition of refrigerants with a lower GWP and solutions under the circular economy principles such as recycling.

This directive regulates the use of F-gases in new equipment, its maintenance and the recovery and correct treatment of these gases at the end of the system´s life. This said, the F-gas regulation does not apply in three scenarios: (i) when alternative gases are not available, (ii) if the energy efficiency gains during the operation generate emissions that are lower than an equivalent system that does not contain HFC and (iii) if the use of technically feasible and safe alternatives would result in disproportionate costs.

Regarding the alternatives to F-gases, the EU is making a transition towards fourth-generation refrigerants, with low GWPs with special focus on HFCs with lower GWP, hydrofluoroolefins (HFOs), and on blends of traditional HFCs with HFOs. However, for the EU it is a priority not only the search for F-gases alternatives but also the development of technologies, such as KET4F-Gas, that help to efficiently separate and recycle HFCs at the end of equipment or refrigerant blends lifetime, to reuse and recycle in the subsequent production of fourth-generation refrigerants following the principles of the circular economy.

Operators and the overall supply-chain actors are required to prevent emission of F-gases by all means necessary, including its recovery, reclaim or

destruction during the system operation and at the end of the equipment life. The HFC phase-down has showed an increase interest in the use of recycled and reclaimed gases. Indeed, the release of F-gases into the atmosphere is explicitly prohibited and are subject to penalties. At the end of the equipment life or when retrofitting existing installations, F-gases must be recovered for re-use or destruction. The level of the penalties for infraction are defined by each EU Member State, however, the European Commission ensures that the sanctions must be *effective, proportionate and dissuasive*. By 2017, all EU Member States had to introduce the 2014 F-gas Regulation into national law.

Coming up:

In 2020, the Commission will publish a report assessing whether cost-effective, technically feasible, energy efficient and reliable alternatives exist and a report on the availability of refrigerants on EU market.

The European Commission will also carry out, by the end of 2022, a comprehensive review to assess the effectiveness of the legislation in light of new developments and international commitments.

EU directives, such as the 2014 F-gas the rules, are a legal act that needs to be incorporated into national law by EU Members before a giving deadline and the EU must be notified about it. This type of legal act sets out goals that Member States must achieve while giving them the discretion as to how to reach them.

▶ **Portugal** made the transposition of the 2014 F-gas Directive on 30 November 2017 in their *Diário da República*, Executive Order nº nº 145/2017. The Agência Portuguesa do Ambiente is the competent authority to study the relevance of containment measures for the correct recovery and reclaim of F-gas equipment at the end of the life of products and equipment that contain F-gases for their recovery and reuse or for their recovery, in order to minimize the impacts associated with its end-of-life management. Article 19 of this decree on the recovery of fluorinated greenhouse gases establishes that operators must *a) use a certified technician to recover F-gas before any decontamination, waste treatment of electrical equipment and electronic (EEE) and non-contaminated fractions, recovery and elimination of fractions from end-of-life equipment; b) ensure the correct management of end-of-life equipment as an EEE in accordance with the provisions of the legal regime applicable to the management of EEE waste, and recovered F-gas.* In Article 23, it is considered as a serious environmental offense, punishable under the terms of Law no. 50/2006, of 29 August the practice of the following act: *Non-compliance with obligations relating to recovery, interventions in containers, equipment and systems containing fluorinated greenhouse gases, in violation of the provisions of articles 19 to 21.* Sanctions for non-compliance can go from 2000 to 48000 Euros for a natural person and from 15000 to 48000 Euros for a legal person. In case of severe infraction, fine quantities can go up to 37500 Euros for a natural person and up to 2500000 for a legal person.

▶ **In Spain**, the transposition of the EU legal act took place on 17 February 2017 through a Royal Decree Law 115/2017. This decree establishes that the recovery of F-gases from refrigeration equipment, air conditioning and its correct management are mandatory. However, intervention in the equipment that requires the handling of these gases is restricted to maintenance companies, they are in charge of taking the appropriate measures for the recovery of the gases through a person who has been accredited, to guarantee its recycling, regeneration and destruction

when necessary and to avoid its emission into the atmosphere. The recovery of recycled procedures, regeneration and destruction of F-gases will be carried out during repair and maintenance. Also, once the appliance has been disposed of at the end of its useful life, the gas must be recovered before disassembling or removing it for final disposal. The penalties derived from inadequate management of F-gases from air conditioning equipment or heat pumps are significant. In the first place, it should be noted that Law 22/2011 on waste and contaminated soils establishes the general legislative framework on waste, defining various types of infraction, such as dumping or sale of waste. The sanctions for these infractions can range from economic sanctions, which range between 901 and 1750000 euros, through the disqualification or revocation of the authorization to practice professionally on a temporary basis between 1 and 10 years, to temporary closure or definitive.

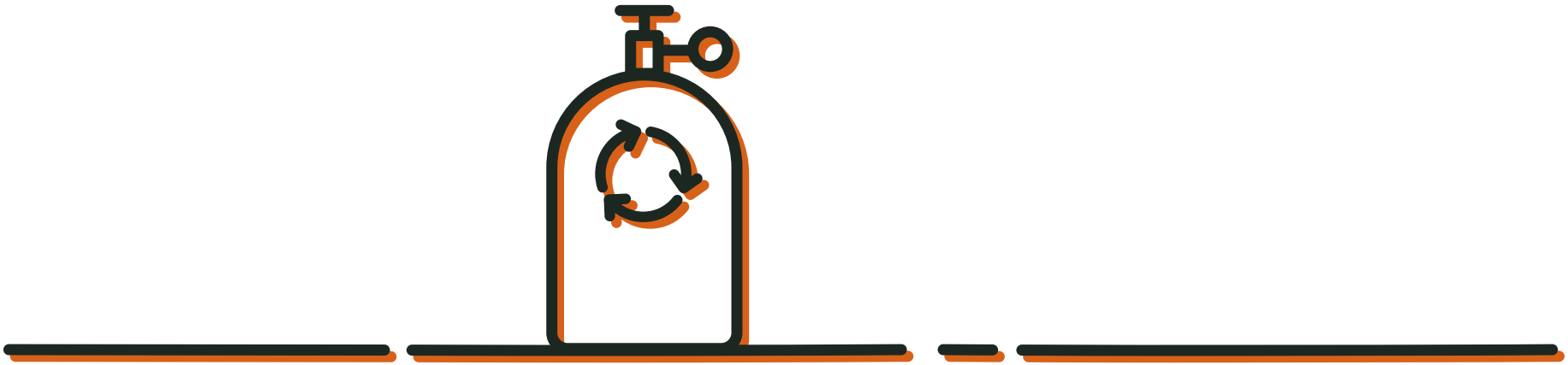
The Spanish government has also implemented fiscal measures such a tax regime on the use of greenhouse F-gases created under the article 5 of the Law 16/2013. However, part of the quantity can be reimbursed if the correct waste management of the equipment is certified. There is also a voluntary agreement for the correct use of SF_6 done by the Ministry of Agriculture, AFBEL, REE and other stakeholders to reduce the emissions of SF_6 including the correct waste management of the systems containing SF_6.

▶ **In France**, the national F-gas regulation is essentially contained in articles R .543-75 to R. 543-123 of the environment code and in the decrees of February 29, 2016 and in the *French Climate Plan* presented in July 2017. It is worth mentioning the F-gases Observatory that has the mission to control the quantities of different types of F-gases put on the market, used, recycled or destroyed and to control actors in the sectors concerned, in particular in the refrigeration and air conditioning sector. At the non-state level, the French regulation imposes obligations on distributors of refrigerants that perform, in a professional capacity, any operation requiring the handling of refrigerants. Producers of refrigerants and equipment pre-loaded with refrigerants must recover them at no additional cost, process them or have them processed in authorized facilities on the national territory or abroad to allow their reuse in accordance with the requirements of their original specifications, or to have them destroyed in case of impossibility of compliance or prohibited reuse. In Article R. 543-122 and 123 of the environment code are covered the penalties companies will face in case of infraction: the fine is 3000 € maximum (legal persons), double in the event of recurrence. This sanction will be applied to, among others, the owners of equipment that have not been checked for leaks or whose leaks have not been controlled. The owners that carry out degassing into the atmosphere, except when necessary to ensure the safety of people, are also sanctioned.

Recycling, reusing and reclaiming: Why is it important for waste managers and operators?

There is an urge to not only reduce F-gases emissions into the atmosphere but also to separate, recycle and reclaim pure HFC at the end of the refrigeration and air conditioning equipment life. Due to the new quota system set by the European Commission, it is essential, in order to maintain sufficient quantities of virgin refrigerant available, that significant effort is made in recycling existing stock wherever possible. The more refrigerant gas recycled (that has previously been placed on the market), the less virgin refrigerant is needed and, consequently, the pressure on the supply chain to maintain stocks and supplies is lower. This is a key point since the HFCs phase down became a reality, leading to an increase in the prices of new virgin refrigerants. Where recycling is not possible or practical then reclamation should be considered.

In 2018, the first significant reduction on the quota took place, reaching a value of 37%. Considering that the next reduction comes in 2021, the industry´s ability to reduce, recycle and innovate becomes fundamental. Indeed, under the F-gas regulations, only refrigerants that are newly 'placed on the market' are included in the quotas, meaning that the use of recycled products will reduce the industry's dependence on higher GWP refrigerants. Up until now, the recycled refrigerants have represented a small part of the total used each year, primarily because new refrigerants were freely available at a low cost. Improving the reclamation and reuse of recovered products should be a key focus for the industry to help ensure a secure refrigerant supply. The research on technologies based on environmentally benign materials that efficiently capture, separate, and recycle F-gases is vital to facilitate the transition of the actors to the new EU restricted market.



Main takeaways:

The EU 2014 F-gas directive reformulates drastically the way industry deals with HFCs and it introduces new mechanisms to ensure an effective emission reduction. The gases mainly affected by this EU Regulation are HFCs, PFCs and SF_6: fluorinated greenhouse gases.

The 2014 F-gas regulation implies the effective phase-down of HFCs. This gradually reduces the availability of these gases in the European market through the allocation of quotas by the European Commission following the target of decreasing HFC consumption by 79% in 2030.

Operators and the overall supply-chain actors are required to prevent emission of F-gases by all means necessary, including its recovery, reclaim or destruction during the system operation and at the end of the equipment life and are subject to penalties for non-compliance with the national transposition of 2014 F-gas regulation.

Considering that the next reduction of the F-gas quota comes in 2021, the industry´s ability to reduce, recycle and innovate becomes fundamental. Indeed, under the F-gas regulations, only refrigerants that are newly 'placed on the market' are included in the quotas, meaning the use of recycled products will reduce the industry's dependence on higher GWP refrigerants.

KET4F-Gas can efficiently separate and recycle HFCs at the end of the refrigeration and air conditioning equipment life, to reuse and recycle in the subsequent production of fourth-generation refrigerants following the principles of the circular economy.

Chapter 3:

Do you need to deal with F-gas waste management? We have the solution!

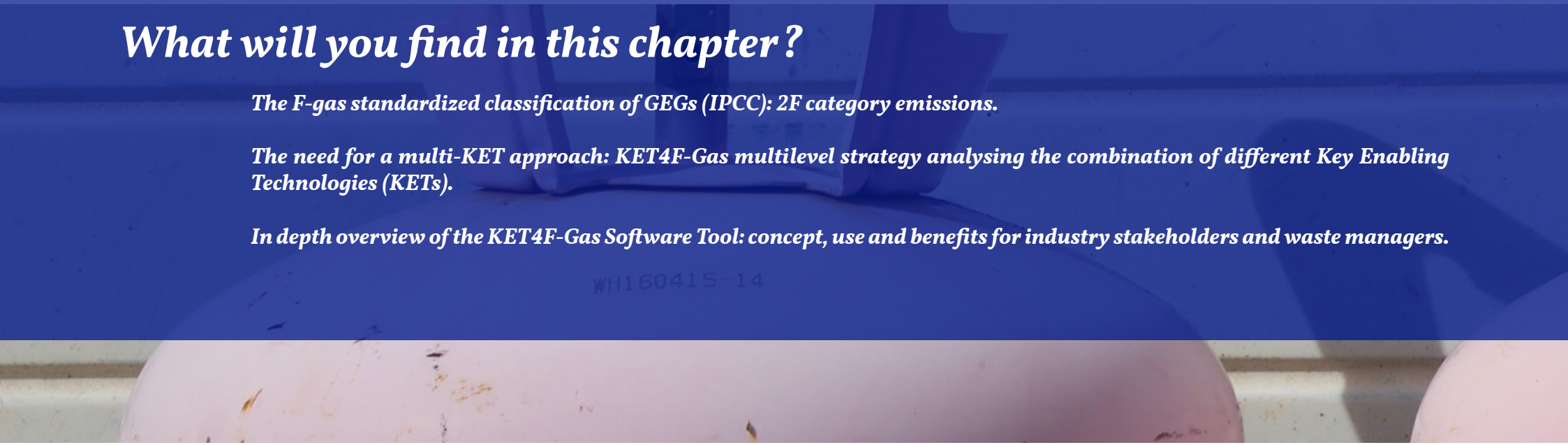
Under the scope of the KET4F-Gas project, an online tool was developed to classify wastes according to the European method, and to identify the impact of F-gases to global warming and the best treatment solutions based on the available Key Enabling Technologies (KETs). In the waste classification section, the user can classify a specific waste by its source, obtaining the corresponding 3-letter European waste code.

What will you find in this chapter?

The F-gas standardized classification of GEGs (IPCC): 2F category emissions.

The need for a multi-KET approach: KET4F-Gas multilevel strategy analysing the combination of different Key Enabling Technologies (KETs).

In depth overview of the KET4F-Gas Software Tool: concept, use and benefits for industry stakeholders and waste managers.



F-gases are mostly used in applications such as refrigeration and air conditioning, fire extinguishing, aerosols and in isolating foams. Atmospheric emissions of F-gases occur during the life cycle of equipment, but also during their fabrication process and as a consequence of non-treated waste.

The Intergovernmental Panel on Climate Change (IPCC) has established a standardized classification of GEGs, categorized by the sectors and particular applications where they are used. For its direct connection with KET4F-Gas objectives, the category denoted as 2F is the one more relevant, as it includes ozone depleting substances substitutes, as HFCs and PFCs. Category 2F includes refrigeration and air conditioning substances (subcategory 2F1), foaming agents (2F2), fire extinguishers (2F3) and aerosols (2F4).

Just to give an order of magnitude, the EU28 countries emitted in 2016 the astonishing amount of 110 million tonnes of CO_2-eq of F-gases. It is evident that this represents a very serious environmental issue demanding urgent global action. Among the cited subcategories, refrigeration and air conditioning concentrated in 2016 an 84.18% of total F-gas emissions, underlining the relevance of this particular 2F subcategory as primary target for the F-gas emission control policies.

Taking into consideration the time evolution of 2F category emissions, their values in SUDOE area have increased continuously from 1995 to 2013, when an inversion of the trend occurred, due to the new taxing policies on the use and emission of these substances issued by each country. Nevertheless, the relative weight of F-gases, compared to the total amount of GEGs, has increased in the SUDOE area. Thus, considering the evolution from 1990 to 2013, F-gases contribution to the total GEGs has increased from 1.5% to 3.5% in Spain, from 2% to 5% in France, and from 0% to 5% in Portugal. These values are above the 3% average for EU28 countries, evidencing a worse scenario in these three countries.

In short, the amount of F-gas atmospheric emissions in SUDOE area represents today a major environmental threaten due to their accumulated global warming potential. The present levels of F-gas emissions must be drastically reduced. In order to meet the international agreements, that have established severe deadlines to phase out the use of F-gases, urgent actions are needed. This entails intensive research and development efforts on the recuperation and recycling of F-gases, and minimization of their atmospheric emissions.

Multi-KET approach

The scenario described demands innovative scentific and technical solutions, considering in any case constructive and synergetic approaches. In this context, KET4F-Gas project proposes a multilevel strategy, analyzing the combination of different Key Enabling Technologies (KETs). The development of reliable separation methods for individual gases is a remarkable scientific challenge, and in this case the number of candidates to be dealt with is large. Existing separation and recovery technologies are not suitable for most F-gases, and this has produced that incineration turns out to be the final fate for too many of these substances after the end of their life cycle.

This fact demands the precise design and implementation of reliable hybrid separation techniques for each of the F-gases. Within the project, the KETs were used and combined to develop specific separation routes, the cross fertilization due to the combination of the different individual KETs will be shown to enhance the overall performance of the process, looking for effective and cost affordable solutions adapted to each target substance.

KET4F-Gas Software Tool

Under the scope of the KET4F-Gas project, an online tool was developed to classify wastes according to the European method, to identify the impact of F-gases to global warming, and to select the best treatment solutions, based on the available KETs.

In the waste classification section, the user can classify a specific waste by its source, obtaining the corresponding 3-letter European waste code. This code is essential for the waste management.

In the section of the treatment technologies, the user selects a pure F-gas (by its R number or by its chemical name) or a F-gas blend (by its R number). After that, the user is redirected to a page containing information on the composition of the commercial F-gas blend and the global warming potential (GWP) as well as the respective impact level of each refrigerant. The impact level was designed similarly to an energetic efficiency scale, to be more familiar to the users. According to the GWP of each refrigerant, it is classified from A (lowest GWP) to G (highest GWP).

This online tool also allows to identify the F-gas blends in which each F-gas is present, and to identify the technologies that are available for the separation of each blend into its pure components. The presented KETs are divided into three major categories: Advanced Materials (including alternative solvents, solid porous matrices and MOFs), Advanced Manufacturing Technologies (including membrane technology) and Nanotechnology (including nanoparticles suspensions). After selecting each technology, the user is asked to provide email, name and organisation. This information complies with the data protection laws and is used only to assess the utilization of the online tool. Finally, the technical sheet of each technology is presented. These sheets include an explanation of the technology, its advantages and the gas blends to which this technology applies. Finally, a list of references is presented, including a small description of the results.

The concept

Reducing the environmental impact of F-gases through the development and implementation of Key Enabling Technologies is the main objective of the KET4F-Gas project.

Nowadays, the internet is a tool accessible to everyone and a source of information on various topics.

For this reason, a software was developed to support this theme, which allows the user to:

- Classify waste;
- Identify treatment technologies for F-gas mixtures and determine the Global Warming Impact.

Also, it was important that the software could be available in at least four different languages, so everyone is able to experience it.

Characteristics

On the top of the platform there are three main links to access to different pages:

KET4F-Gas

This is the home page of the platform where you can read a brief presentation about it and where you can access the official website.

Interreg Sudoe
KET4F-Gas

Home Partnership Events News Results

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Tool for the selection of Key Enabling Technologies

This computer tool allows the classification of waste according to the European method (EWL – European Waste List) and a better understanding of the impact of fluorinated gases, as well as the best solutions available for their treatment using Key Enabling Technologies (KETs).

The tool has been developed in the framework of the European project KET4F-Gas, co-financed by the European programme Interreg Sudoe through the European Regional Development Fund (ERDF).

Classification of waste

Selection of technologies treatment

Waste Classification

The waste classification was constructed according to the European Waste List and is functional for all types of waste, not only for waste containing fluorinated gases.

The list consists of 20 chapters, numbered from 01 to 20. Each chapter gathers different types of waste related to a specific area of waste-generating activity, namely industrial, urban, agricultural and hospital, or simply related to production processes.

Residue Classification

00 Waste Classification

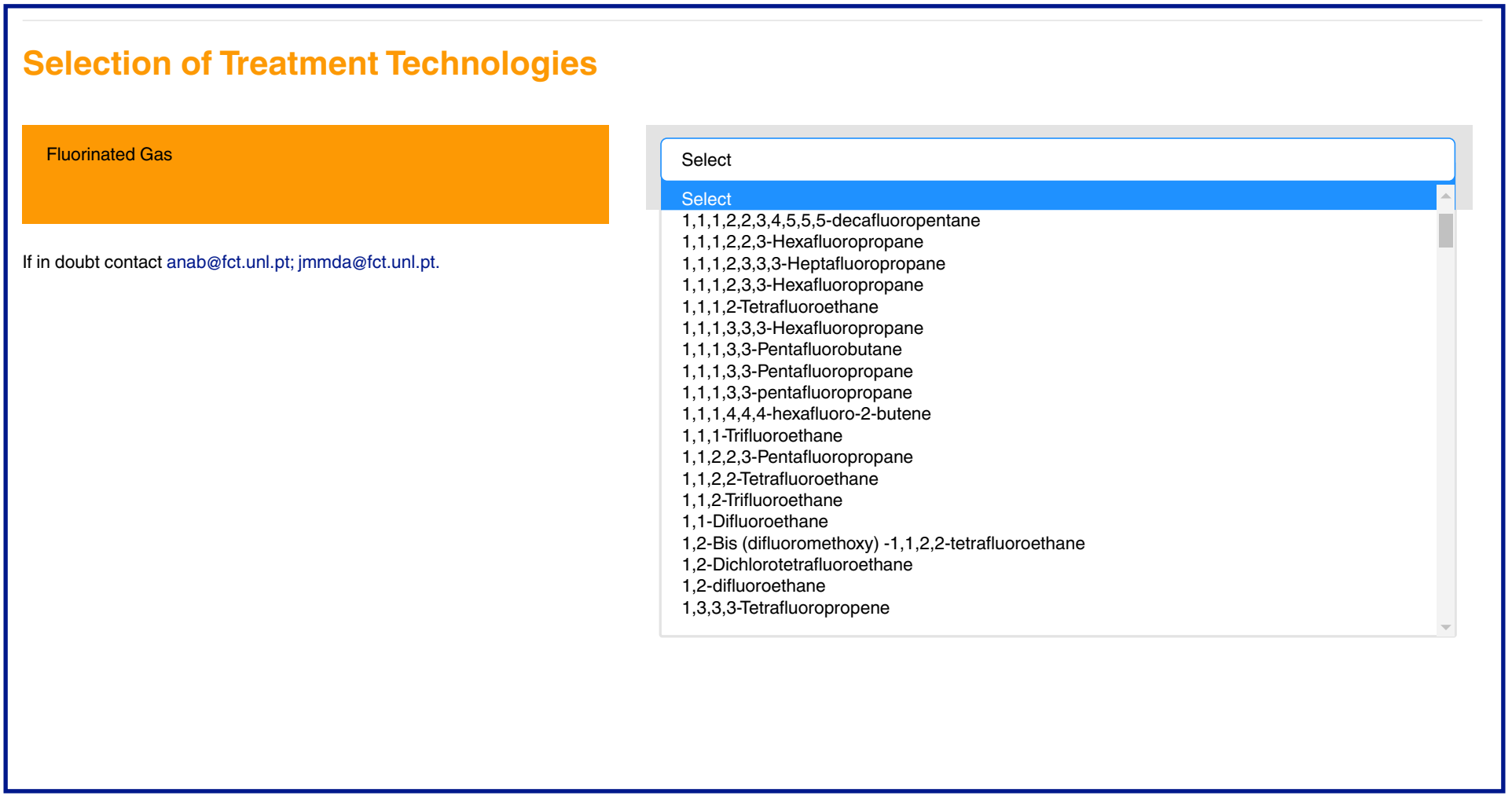
Select a waste source

- 01 - Wastes resulting from exploration, mining, quarrying, physical and chemical treatment of minerals
- 02 - Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing
- 03 - Wastes from wood processing and the production of panels and furniture, pulp, paper and cardboard
- 04 - Wastes from the leather, fur and textile industries
- 05 - Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal
- 06 - Wastes from inorganic chemical processes
- 07 - Wastes from organic chemical processes
- 08 - Wastes from the manufacture, formulation, supply and use (MFSU) of coatings (paints, varnishes and vitreous enamels), adhesives, sealants and printing inks
- 09 - Wastes from the photographic industry
- 10 - Wastes from thermal processes
- 11 - Wastes from chemical surface treatment and coating of metals and other materials; non-ferrous hydro-metallurgy
- 12 - Wastes from shaping and physical and mechanical surface treatment of metals and plastics
- 17 - Construction and demolition wastes (including excavated soil from contaminated sites)

Technologies

The technologies page was created to allow the user to get information about a specific F-gas.

The first thing to do is to identify the F-gas you want to know more information about. The selection box has different gases in their chemical or commercial names, for example:



Once the gas is chosen, for example R-32 in the case of a pure F-gas or R-410A in the case of a gas mixture, the user gets the information below:

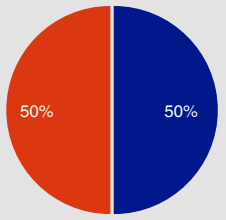
Chemical composition or composition of the mixture;

Example: Pure F-Gas (R-32)

Fluorinated Gas	R-32
Chemical composition / Gases mixture	Difluoromethane

Example: F-Gas mixture (R-410A)

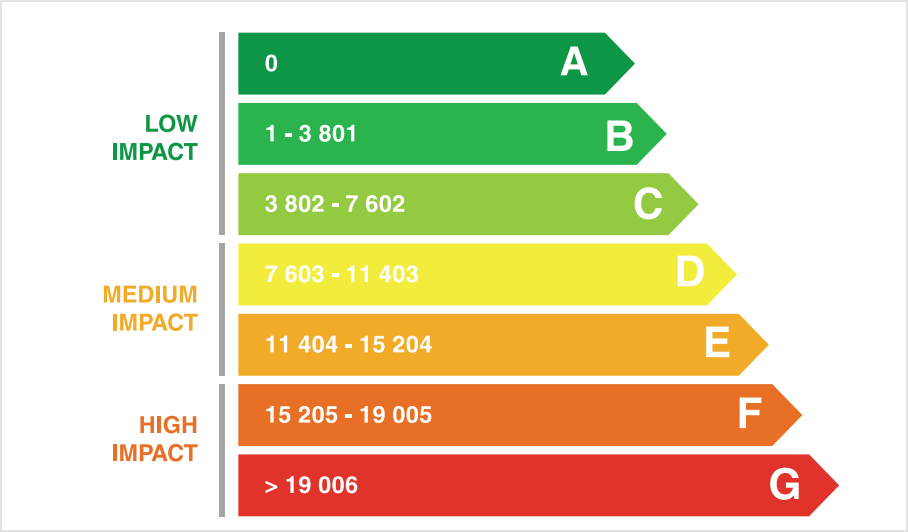
Fluorinated Gas	R-410A
Chemical composition / Gases mixture	R-125 (50%); R-32 (50%);



Global Warming Potential (GWP) and the impact scale (A to G);

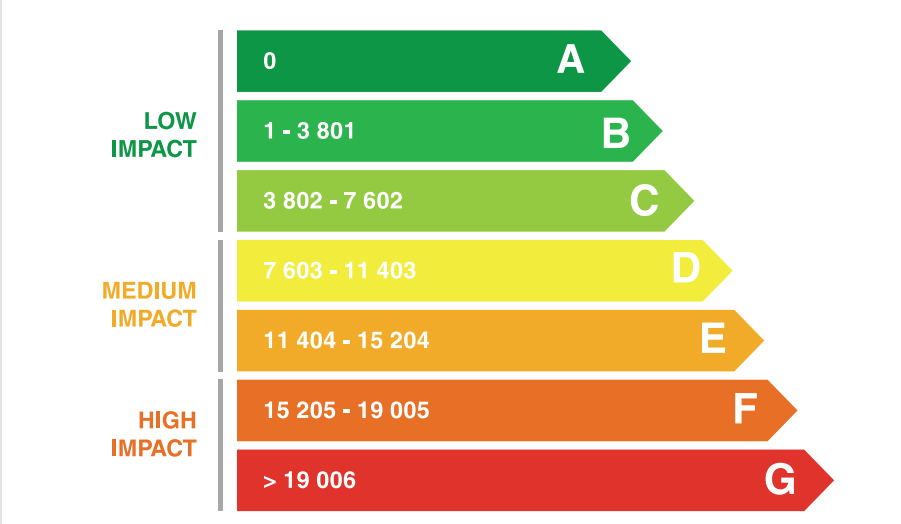
Example: Pure F-Gas (R-32)

Global Warming Impact (GWP)	675.000
Impact level	The selected gas is at the point **B** of the impact scale



Example: F-Gas mixture (R-410A)

Global Warming Impact (GWP)	2087.500
Impact level	The selected gas is at the point **B** of the impact scale



Key Enabling Technologies (only applicable for gas mixtures);

Example: Pure F-Gas (R-32)

Treatment technologies	Not applicable
This gas can be found in the following mixtures of fluorinated gases.	R-407A; R-407B; R-407C; R-407D; R-407E; R-407F; R-410A; R-410B; R-425A; R-427; R-438A; R-43A; R-442A; R-444B; R-448A; R-449A; R-452A; R-453A; R-455A; R-458A; R-504;

Example: F-Gas mixture (R-410A)

Treatment technologies	Advanced Materials Advanced Materials - Alternative Solvents; Advanced Materials - Solid Porous Matrices; Advanced Materials - MOFs; Advanced Manufacturing Technologies Advanced Manufacturing Technologies - Membranes; Nanotechnology Nanotechnology - Nanoparticles Suspension;

How stakeholders can benefit from it

The access to the KET4F-Gas platform is already available on its official website ("Results").

The KEF-Gas platform is simple, accessible to everyone, free of charge and it is a great tool to get information for a specific F-gas. The benefits from the platform include:

- **Learning** – The platform contains a lot of valuable information about the F-gases.
- **Helps on decision-making** – There are different gases and different treatment technologies. Stakeholders can choose between two gases, which have lesser or greater impact and can know in advance which technologies can be used for the recovery of the components of the chosen gas mixtures.
- **Saving time** – Stakeholders may find all the information needed on the digital platform.
- **Trust** - The platform is constantly being updated. There are contacts available to answer questions from stakeholders.

Main takeaways:

The values of 2F category emissions in the SUDOE area have increased continuously from 1995 to 2013 with values above the 3% average for EU28 countries. This evidences a worse scenario in these three countries.

Existing separation and recovery technologies are not suitable for most F-gases. Therefore, incineration turns out to be the final fate for too many of these substances after the end of their life cycle.

KET4F-Gas project proposes a multilevel strategy, analysing the combination of different Key Enabling Technologies (KETs) to design and implement reliable hybrid separation techniques for each of the F-gases, enhance the overall performance of the process and look for effective and cost affordable solutions adapted to each target substance.

Under the scope of the KET4F-Gas project, an online tool was developed to classify wastes according to the European method, and to identify the impact of F-gases to global warming and the best treatment solutions, based on the available KETs.

The KEF-Gas platform is simple, accessible to everyone, free of charge and it is a great tool to get information for a specific F-gas. The benefits of the platform include: a lot of valuable information about the F-gases, guidance for informative decision-making, all information needed available in one place that is trust-worthy and regularly updated.

Chapter 4:

A Success Case - The KET4F-Gas System

The KET4F-Gas prototypes are based on two different advanced separation processes - an adsorption column filled with activated carbon and a membrane system containing two stacked flat polymeric membranes functionalized with ionic liquids - providing high yelds with low energy requirements. These technologies are easy to apply in a waste management facility due to the small amount of space required, and due to their modularity and scalability. Moreover, these systems require low maintenance and have long lifetime.

What will you find in this chapter?

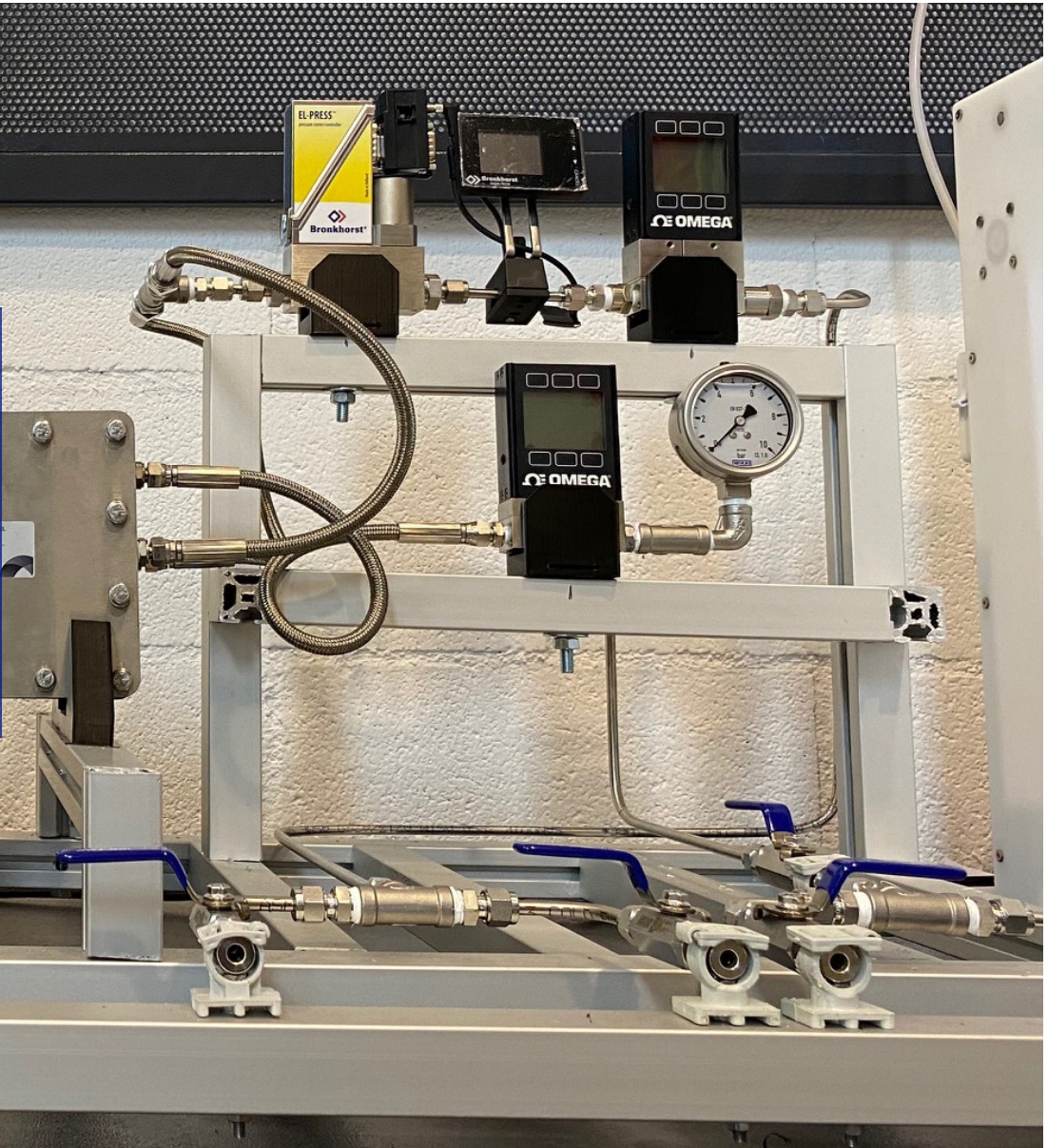
A description of characteristics and applications of the KET4F-Gas system.

Technical information on the KET4F-Gas prototypes.

Advantages of the system implementation.

The elimination of depleted HFCs blends collected from end-of-life equipment poses environmental concerns and their incineration is currently considered the best practice. However, incineration generates CO_2 and harmful by-products such as hydrogen fluoride (HF) and trifluoroacetic acid (TFA). If released to the

environment, these compounds are dissolved in water and directed to the earth surface by precipitation. Moreover, TFA acidifies the water, which may lead to a significant eco-toxicity upon accumulation in the ecosystems. This practice implies a waste of resources as the components of HFCs blends are highly valuable products that can still be used to produce new environmentally friendly refrigerant blends exhibiting much lower GWP, which are allowed to be used under the current legislation as substitutes to the old HFCs blends with high GWP.



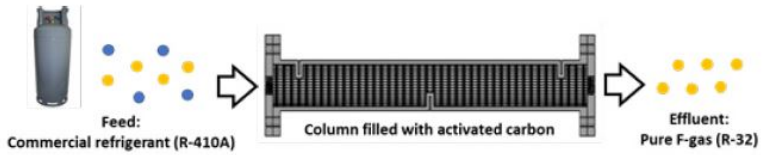
The development of techniques that efficiently recover and recycle HFCs present in gas blends is essential to significantly reduce the emissions of HFCs, and to promote circular economy, through the waste valorisation. According to the data collected under the scope of KET4F-Gas project, the costs of incinerating refrigerants are high (between 2000 and 3000 €/ton of gas plus transport costs). Therefore, by recovering and reusing HFCs, the costs associated with waste elimination and with the taxes on new HFCs are reduced.

For example, R-410A, one of the most used refrigerants in residential and commercial air conditioners, is a near-azeotropic system of pure F-gases R-32 and R-125, with an azeotropic composition at 91 mol% in R-32. Therefore, the separation of the individual HFCs of the system by conventional energy-driven processes (e.g., conventional distillation) is impossible.

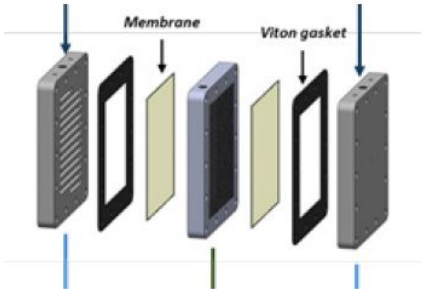
Under the scope of the KET4F-Gas project, two prototypes have been constructed for the efficient recovery of value-added HFCs (such as R-32) from high-GWP refrigerant blends (R-410A) contained in end-of-life equipment or refrigerant blends, for reutilisation purposes in novel environmentally-friendly refrigerant mix-tures with low-GWP. These two prototypes are based on two different advanced separation processes – adsorption on porous materials and membrane technology – that provide high yields and have low energy requirements.

In adsorption processes, one of the components of the mixture is preferentially adsorbed into a porous material, while the remaining leaves the adsorption column. Then, the adsorption column is regenerated to recover the compound that was selectively adsorbed. In the membrane gas separation process, one com-pound of the mixture is preferentially permeated through highly selective thin films due to differences in the size of the gas molecules and to gas-membrane interactions.

Adsorption process, using solid porous matrices, for the selective separation of gases.



Membrane process, using membranes functionalized with ionic liquids, for the selective separation of gases.



As mentioned before, the KET4F-Gas prototypes consist of an adsorption column filled with activated carbon and of a membrane system containing two stacked flat polymeric membranes functionalized with ionic liquids.

These technologies are easy to apply in a waste management facility due to the small amount of space required, and due to their modularity and scalability. Moreover, these systems require low maintenance and have long lifetime. For example, the systems are highly selective for the separation of R-410A, resulting in a high separation performance and high R-32 purity (>99%) when both prototypes are used in series.

Main takeaways:

Under the scope of the KET4F-Gas project, two prototypes have been constructed for the efficient recovery of value-added HFCs (such as R-32) from high-GWP refrigerant blends (R-410A) contained in end-of-life equipment and refrigerant blends, for reutilisation purposes in novel environmentally-friendly refrigerant mixtures with low-GWP.

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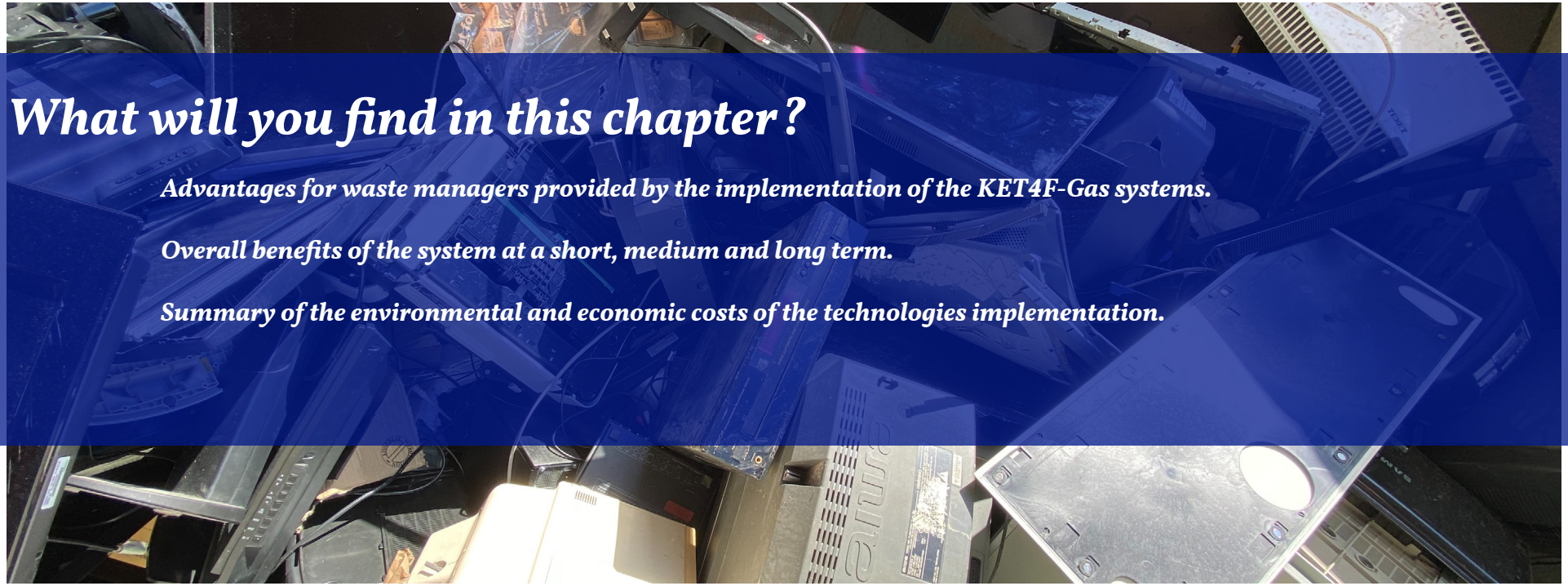
Chapter 5:

How does the KET4F-Gas benefit waste managers?

The presented KET4F-Gas prototypes will provide many advantages to waste managers, as they represent a realistic alternative to current recovery, transport and incineration process. The possibility of recycling R-32 with a minimum purity of at least 98% weight will permit to reuse this gas as many times as desired. In addition, the two prototypes presented in this guide have relative low implementation cost and represent a huge benefit from an environmental perspective.



What will you find in this chapter?

Advantages for waste managers provided by the implementation of the KET4F-Gas systems.

Overall benefits of the system at a short, medium and long term.

Summary of the environmental and economic costs of the technologies implementation.

Benefits of the system

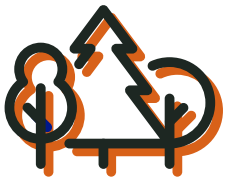
KET4F-Gas new recovery systems for refrigerant R-410A have plenty of advantages as they allow a full reuse of R-32 at low cost. The main benefits are listed here.

High purity rates:

Both prototypes present high purities of at least 98% weight for R-32.

Low environmental cost:

The new prototypes are clean technologies whose life cycle analysis reveals a saving of more than 60% in terms of greenhouse gas emissions when compared to a benchmark case where R-410A is not recovered.



Low materials cost:

In both cases, the membranes and the adsorbents have low prices in the market.

Other benefits

The most important benefit of using these technologies is the possibility to recover and reuse the lower Global Warming Potential (GWP) R-32, considering the current European regulation that will prohibit the fabrication of new hydrofluorocarbons with high GWP in refrigeration equipment. These technologies represent a short-term alternative during the transition towards newer refrigerants with lower GWPs.

Assuming a horizon time of 10 years, the benefits in terms of environmental impact can be summarized in the following numbers:

An approximate quantity of 3200 kg of R-410A can be treated for separation.

The **main environmental cost** is in terms of CO_2 emissions, which are low, in a range of **6 to 8 kg CO_2 emitted per kg R-32 recovered.**

Considering that the GWP of R-410A is 2088, the environmental saving in terms of CO_2 emissions **makes this technology a 60-70% greener than any current alternative and more than 95% better in terms of ozone depletion.**

Implementation Costs

The Implementation Costs of the KET4F-Gas system will depend on the refrigerant flow that needs to be treated per day. However, in general terms, the design of the operation units does not require expensive equipment, as all materials needed have a low cost. The capital costs are a function of the dimensions of the unit to treat more or less gas. **The operational costs are in the range of 32€ per kg R-32 recovered.**

Main takeaways:

The KET4F-Gas prototypes represent a realistic alternative to current recovery, transport and incineration processes.

The most important benefit of using these technologies is the possibility to recycle and reuse R-32 gas, considering the current European regulation that will prohibit the fabrication of new hydrofluorocarbons with high Global Warming Potential in refrigeration equipment. The possibility of recovering R-32 with a purity of 98% weight will permit to reuse them as many times as desired, with a minimal loss.

The implementation costs will depend on the refrigerant flow that needs to be treated per day. However, in general terms, the design of the operation units does not require expensive equipment, as all materials needed have a low cost.

FAQ

- ***What are the global and European regulatory frameworks on HFC?***

The requirements imposed by international regulations are clear:

The Kigali Amendment to the Montreal Protocol on HFC (2016): 197 industrialized countries pledged to reduce by 45% the use of HFCs by 2024 and by 85% by 2050. Taking this into account, developing countries began to cap and reduce their consumption of HFC starting in 2024.

The EU regulation 517/2014 on F-gases and phase-out of HFC (2014): planned the phasing out of the placing on the market between 1995 and 2015 of the CFC and HCFC F-gases and the category of gases with a GWP greater than 2500, in particular HFC. The reduction requirements by 2024 of the European Regulation are stronger than those of the Kigali Amendment: 69% against 45%. By 2025, a schedule for gradually decreasing the placing on the market of these substances is set in place to reduce emissions a 21% compared to the period 2009/2012.

The European quota system for placing HFC on the European market: as from 2017, all HFC refrigeration, air conditioning and heat pump equipment are covered by a quota mechanism. This quota allocation is re-evaluated every three years.

- ***What is the monitoring of the application of the European regulations on F-gases?***

All European operators must report annually all movements of the year in question by fluid type (stored-purchased-recycled-regenerated-destroyed). The European Commission will publish in December 2020 a report on the availability of HFCs on the market. In 2022 a global report including a forecast of HFC demand until 2030 and beyond will be released.

- ***Are there penalties for non-compliance with the EU regulation on the recycling need of F-gases?***

Yes. In the transposition to National Law of the EU regulation 517/2014 on F-gases non-compliance with obligations relating to recovery and correct treatment systems containing fluorinated greenhouse gases is subject to penalties. The quantity of each sanction is up to each Member State.

In **Portugal**, sactions for non-compliance can go from 2000 to 48000 Euros for a natural person and from 15000 to 48000 Euros for a legal person. In case of severe infraction, fine quantities can go up to 37500 Euros for a natural person and up to 2500000 for a legal person.

In **Spain** the sanctions for these infractions can range from economic sanctions, which range between 901 and 1750000 euros, through the disqualification or revocation of the authorization to practice professionally on a temporary basis between 1 and 10 years, to temporary closure or definitive.

In **France** companies will face in case of infraction: the fine is 3000 Euros maximum (legal person), double in the event of recurrence.

- ***Why is it important for waste managers and operators the correct treatment of F-Gas?***

Apart from the penalties stated above, due to the new quota system set by the European Commission, it is essential, in order to maintain sufficient quantities of virgin refrigerant available, that significant effort is made in recycling existing stock whenever possible. The more refrigerant gas in use that has previously been placed on the market, the less virgin refrigerant is needed and, consequently, the lower the pressure on the supply chain to maintain stocks and supplies as the phase down becomes a reality while avoiding the increases in the prices of refrigerants. Improving the reclamation and reuse of recovered products should be a key focus for the industry to help secure refrigerant supply.

- ***Why the KET4F-Gas Software can be a solution for waste managers and operators?***

This tool is available to everyone in four different languages and it is free of charge. It allows the user to classify waste and identify treatment technologies for F-gases and determine their Global Warming Impact.

- ***What do the KET4F-Gas system prototypes consist of?***

The KET4F-Gas prototypes consist of an adsorption column filled with activated carbon and of a membrane system containing two stacked flat polymeric membranes functionalized with ionic liquids.

- ***Can the KET4F-Gas system prototypes be placed in my premises?***

Yes, these technologies are easy to apply in a waste management facility due to the small amount of space required, and due to their modularity and scalability. Moreover, these systems require low maintenance and have long lifetime.

Chapter 7:

Takeaways

In recent years, the development of efficient and sustainable technologies to selectively capture F-gases and to recycle them into new environmentally sustainable refrigerants has now become particularly urgent. Following International mandates and the European Union F-Gas regulation of 2014, transferred to national laws in 2017, operators and the overall supply-chain actors are required to prevent emission of F-gases by all means necessary, including its recovery, reclaim or destruction during the system operation and at the end of the equipment life. The release of F-gases into the atmosphere is explicitly prohibited and is subjected to penalties determined by each Member State under the guidance of the European Commission.

The HFC phase-down has showed an increased interest in the use of recycled and reclaimed gases. Due to the new quota system set by the European Commission, it is essential, in order to maintain sufficient quantities of virgin refrigerant available, that significant effort is made in recycling existing stock whenever possible. The more refrigerant gas in use that has previously been placed on the market, the less virgin refrigerant is needed and, consequently, the lower the pressure on the supply chain to maintain stocks and supplies as the phase down becomes a reality while avoiding increases in the prices of refrigerants.

In 2018, the first significant reduction on the quota took place, reaching a value of 37%. Considering the next reduction comes in 2021 the industry´s ability to reduce, recycle and innovate becomes fundamental. Indeed, under the F-Gas regulations, only refrigerants that are newly 'placed on the market' are included in the quotas, meaning the use of recycled products will reduce the industry's dependence on higher GWP refrigerants. Up until now, the recycled refrigerants have represented a small part of the total used each year, primarily because new refrigerants are available at a high cost and usually are subjected to patents. Improving the reclamation and reuse of recovered products should be a key focus for the industry to help ensure a secure refrigerant supply. The research on technologies based on environmentally benign materials that efficiently capture, separate and recycle F-gases is vital to facilitate the transition of the actors to the new EU market.

KET4F-Gas aims at real implementation of technologies to efficiently separate and recycle HFCs at the end of the refrigeration and air conditioning equipment life. The separation of third-generation refrigerants proposed in this project leads to an environmentally friendly separation process of pure F-gases, as alternative to the distillation, which is a process that requires the use of considerable amounts of energy. KET4F-Gas project proposes a step forward real implementation, in the industrial sector of refrigeration and air conditioning, of separation, purification and recycling processes of one of the GHG families that most contribute to global warming. The separation and recycling of F-gases from refrigerant blends at the end-of-life is a still poorly explored area.

The KET4F-Gas software: Under the scope of the KET4F-Gas project, an online tool was developed that allows to classify wastes according to the European method and to identify both the impact of F-gases to global warming and the best treatment solutions based on the available Key Enabling Technologies (KETs). In the waste classification section, the user can classify a specific waste by its source, obtaining the corresponding 3-letter European waste code. The KET4F-Gas software is available in at least four different languages (PT, ES, FR and EN).

The KEF-Gas software is simple, accessible to everyone and free of charge. The benefits from the platform include:

- **Learning** – The platform has a lot of interesting information about the F-gases.
- **Helps on decision-making** – There are different gases and different treatment technologies. Stakeholders can choose between two gases, which have lesser or greater impact and can know in advance which technologies can be applicable to separate the components of the mixtures.
- **Saving time** – Stakeholders can find all the information needed on the digital platform.
- **Trust** - The platform is constantly being updated. There are contacts available to answer questions from stakeholders.

The KET4F-Gas system is based on two prototypes that have been constructed for the efficient recovery of value-added HFCs (such as R-32) from high-GWP refrigerant blends (R-410A) contained in end-of-life equipment, for reutilisation purposes in novel environmentally-friendly refrigerant mixtures with low-GWP. These two prototypes are based on two different advanced separation processes – adsorption and membrane technology – that provide high yields and have low energy requirements. KET4F-Gas new recovery systems for refrigerant R-410A have plenty of advantages as they allow a full reuse of R-32 gas at low cost. The main benefits are listed below:

- High recovery and purity rates: both prototypes present high recovery rates and allow reaching purities at least 98% weight for R-32.
- Low environmental cost: the new prototypes are clean technologies whose life cycle analysis reveals a saving of emissions when compared to a benchmark case where R-410A is not recovered.
- Low materials cost: in both cases, the membranes and the adsorbents have low prices in the market.

The most important benefit of using these technologies is the possibility to recover and reuse R-32 considering the current European regulation that will prohibit the fabrication of new hydrofluorocarbons with high Global Warming Potential in refrigeration equipment. These technologies represent a short-term alternative during the transition towards newer refrigerants with lower GWPs.

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- The **main environmental cost** is in terms of CO_2 emissions, which are low, in a range of **6 and 8 kg CO_2 emitted per kg R-32 recovered.**
- Considering that the GWP of R-410A is 2088, the environmental saving of avoiding the production **makes this technology a 60-70% greener than any current alternative.**

The Implementation Costs of the KET4F-Gas system will depend on the refrigerant flow that needs to be treated per day. However, in general terms, the design of the operation units does not require expensive equipment, as all materials needed are affordable. The capital costs are a function of the dimensions of the unit to treat more or less gas. **The operational costs are in the range of 32€ per kg R-32 recovered.**

Do you have any question? Contact us!

KET4F-Gas is a European project co-funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF). Coordinated by the NOVA School of Science and Technology of NOVA University of Lisbon (FCT NOVA), the partnership currently involves other 13 partners and 6 associated partners from Portugal, Spain, France and United Arab Emirates.

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PARTNERSHIP

ASSOCIATED PARTNERS


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