Annex 54,

Heat pump systems with low-GWP refrigerants

Country report, Sweden, 2023

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Introduction

This is the final country report from Sweden within the IEA HPT Annex 54. In this report we will cover research and development related to heat pumps with low GWP refrigerants done in Sweden during the year 2023 and also give some highlights from the previous years. Naturally, most research projects last more than one year, so some of the projects discussed have been mentioned also in previous country reports. In these cases, we will give a short introduction with reference to these earlier reports.

As this is the final report in the Annex, we will also present what we consider to be the most important developments in Sweden during the entire duration of the Annex. It should be noted that what is reported is an overview of several research projects related to the topic of the Annex. This means that the intention is not to go into detail in each of these projects, but rather to give an overview and, where possible, to give references to other reports where the results are described more in detail.

The projects covered are mostly related to the use of natural refrigerants, primarily hydrocarbons, but projects on low-GWP synthetic refrigerants are also included.

Even though this is a country report from Sweden, some projects and development trends are common to other countries in the EU. Also, sales statistics from the EU-countries is included in some cases as these are in some cases more reliable than the national statistics from Sweden.

The content of the report is structured as agreed with the Operating Agent, in order to facilitate the compilation of the country-reports to one comprehensive final report of the Annex.

The editor of this report has been Björn Palm, professor at KTH Royal Institute of Technology, who has also written chapters 1 – 2 and 4 – 5. Chapter 3 is written by Dr Metkel Yebiyo, at RISE, Research Institutes of Sweden, with support of colleagues. Of course, a large number of persons have been involved in the projects and in the development of the products presented in the report.

1 Summary of Tasks 3 – 5

As agreed with the Operating Agent of the Annex, the reporting for 2023 will focus on the Tasks 3 – 5 as described in the legal text of the Annex.

1.1 Task 3: Review of design optimization and advancement impacts on LCCP reduction (Year 3-5: 2021-2023)

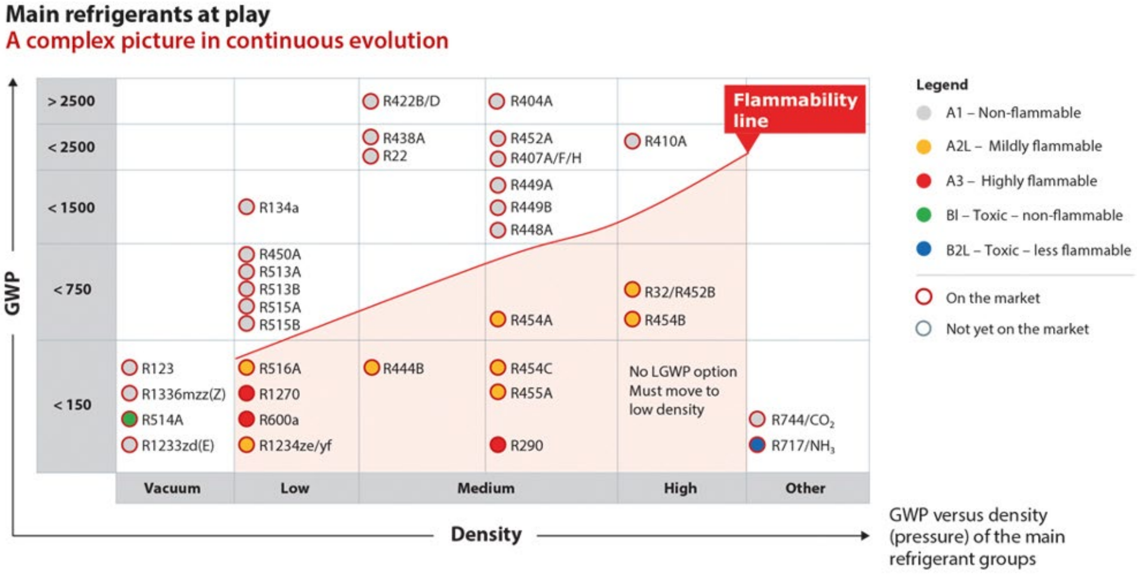


Figure 1: Relation between GWP, density and flammability. (From [1])

As has been shown in several reports, e.g. [1], [2], there are no refrigerants with low GWP with normal pressures which are non-flammable, with the exception of CO2. As flammability is always a risk, the charge of refrigerant in a system should be as low as possible without affecting the energy efficiency of the system. Even with non-flammable, high GWP refrigerants, charge reduction should be considered, of environmental concerns, as the risk of large leakages is greater if the charge is large. However, until recently heat pump and refrigeration systems have not been designed with low internal volume, or low charge, in mind. There has also been statements claiming that low charge/low volume systems should be less energy efficient than systems with larger charge. An interesting graph (Figure 2) of the specific charge vs the seasonal coefficient of performance (SCOP) was presented in [3]. The graph to the left is for Air to Water (ATW) heat pumps with a heating capacity of less than 20 kW and the one to the right for Liquid to Water (LTW) heat pumps with capacities less than 30 kW. The data comes from a database of products on the European market. It is interesting to see the large deviations between the specific charge (kg/kW) even when comparing heat pumps with the same refrigerant, propane. It is also interesting to note that there is no clear correlation between the specific charge and the SCOP. For the LTW heat pumps, the three heat pump models with the lowest specific charge also has the highest SCOP! These graphs clearly demonstrate the possibility to decrease the charge of refrigerant substantially compared to what is common by adjusting the designs wisely, and thereby decrease the risks connected to the flammability.

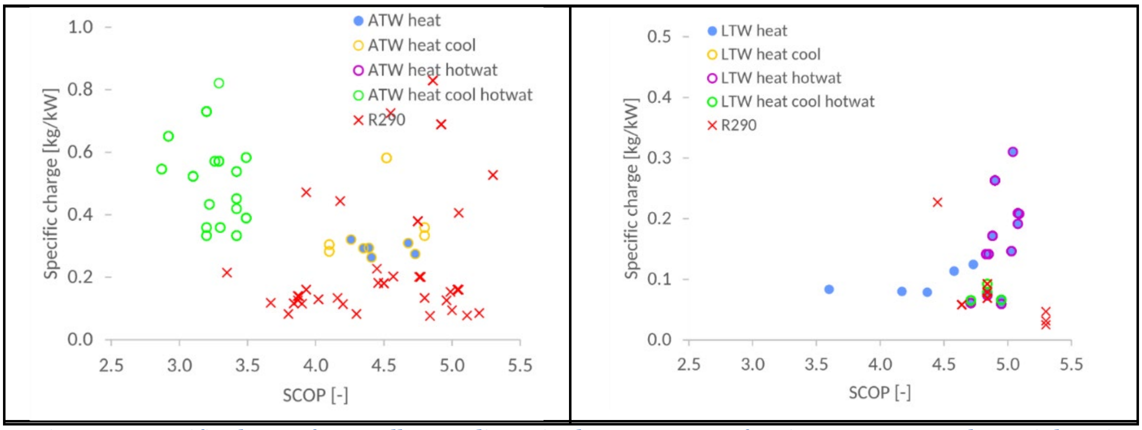


Figure 2: Specific charge for small to medium size heat pumps. Left: Air to Water, <20 kW. Right: Liquid to Water <30 kW. From [3]

To achieve low charges it is necessary to select heat exchangers with small internal charge. Preferably, the cross sectional area of the channels should be small. This can be reached in plate heat exchangers by using smaller pressing depths and by reducing the inlet and outlet headers. It is also possible to substitute conventional circular copper tubes with flat multiport tubes. When moving from HFCs to hydrocarbons it is also important to take into account the lower pressure drops and design the distributors in order to get even distribution of refrigerants between the parallel channels of the heat exchangers.

Other design changes possible besides charge reduction to limit the risks connected to flammability are already included in the new IEC 60335-2-40:2022. According to this standard, heat pumps with flammable refrigerants can be installed indoors without any particular safety precautions if the charge is lower than four times the lower flammability limit (LFL). For propane this corresponds to 150g. Larger charges are also allowed, if any of the following methods of limiting the risks is implemented:

- If the releasable charge is limited, e.g. by sectionizing the system by quick closing valves in case of leakage
- If the heat pump unit is located in a large room
- If the heat pump has a tight ventilated enclosure connected to the ambient

Other methods may also be used if these are tested and proven to be safe.

1.2 Task 4: Outlook for 2030 (Year 5: 2022 – 2023)

In Europe, new legislation is affecting the heat pump market in an important way. The new F-gas regulation was finally adopted in Jan 2024. This regulation includes a phase-out scheme for HFC-refrigerants which is much faster than the one in the previous version of the regulation. It should be noted that HFO is not considered as HFC according to the definition used in the regulation. However, HFOs are considered as F-gases. As seen in Figure 3, the decrease is very fast in the next six years, with a reduction to less than one fourth of the 2024 level in 2030, expressed in CO2 equivalents put on the market. In 2050 no HFCs will be allowed to be put on the market.

In addition to the phase out of HFCs, there are product bans in the F-gas directive dictating the maximum GWP of the refrigerants from certain years, depending on the type of system. For systems <12kW, no F-gases (including HFO) will be allowed from 2035. This regulation is forcing the heat pump industry in Europe to adopt to natural fluids.

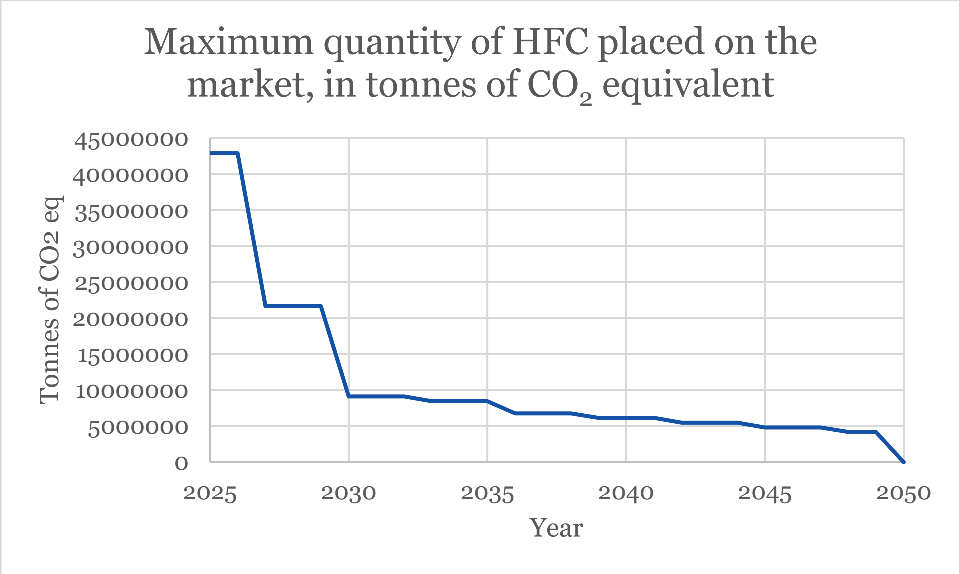


Figure 3: Maximum allowed amounts of HFC to be put on the market in EU according to the F-gas regulation, expressed in CO2 equivalents. (Based on legal text of F-gas regulation)

Another factor related to the choice of refrigerants in the future is a proposal to the EU to ban all PFAS-substances. PFAS is a group of more than 10 000 substances characterized by having fully fluorinated carbon atoms in the molecule, i.e. $–CF_3$ or $–CF_2–$ groups. This means that almost all synthetic refrigerants belong to this group. If this proposal is adopted, the possibility of using HFOs in systems larger than 12 kW (i.e. not covered by the F-gas regulation) will be very limited.

At the same time as the use of synthetic refrigerants is being prohibited for low capacity applications, the EU has taken decisions about electrifying the heating sector. The main reason is to make it possible to reach the commitments according to the Paris agreement, but also to reach the goals of the RePowerEU plan, which has the purpose of decreasing the dependence on fossil fuels, mainly gas, from Russia. A number of countries have also restricted the installation of gas burners and some have also subsidized the installation of heat pumps. Together, this resulted in a boom in the heat pump sales in Europe during 2022 and the first half of 2023, Figure 4. During the second half of 2023, the gas prices were at a much lower level than a year before and the sales of heat pumps decreased substantially. However, it is expected by the industry that this is a temporary dip and that the sales of heat pumps will continue increasing in the coming years. At the moment (beginning of 2024) the EU commission and parliament are negotiating a Heat Pump Action Plan which is designed to accelerate the roll-out of heat pumps on the European market, by new legislation and by ensuring accessible financing. Heat pumps is already the most selected heating technology in northern Europe, but the difference between countries is large. This is clearly seen in Figure 5, where the market share of heat pumps of the total sales of heat pumps and boilers is shown for the European countries. The Scandinavian countries are at the top, with a market share for heat pumps of more than 90%, while UK is at the bottom with only 3%.

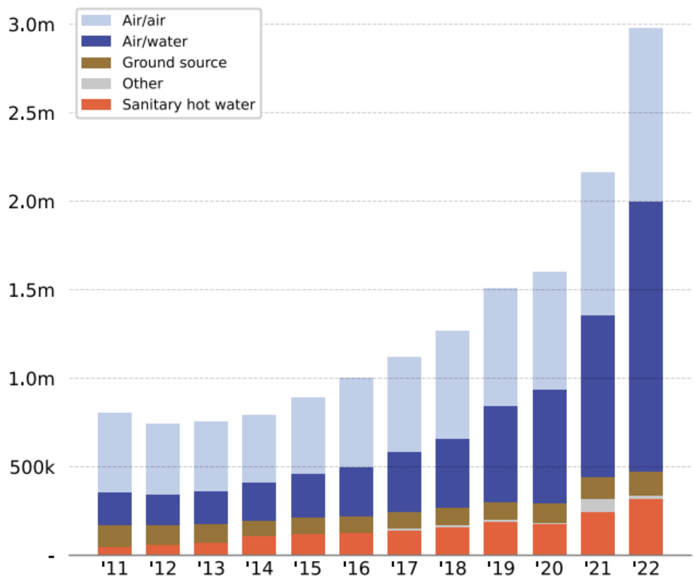


Figure 4: Heat pump sales on the European market 1990 - 2022. [4]

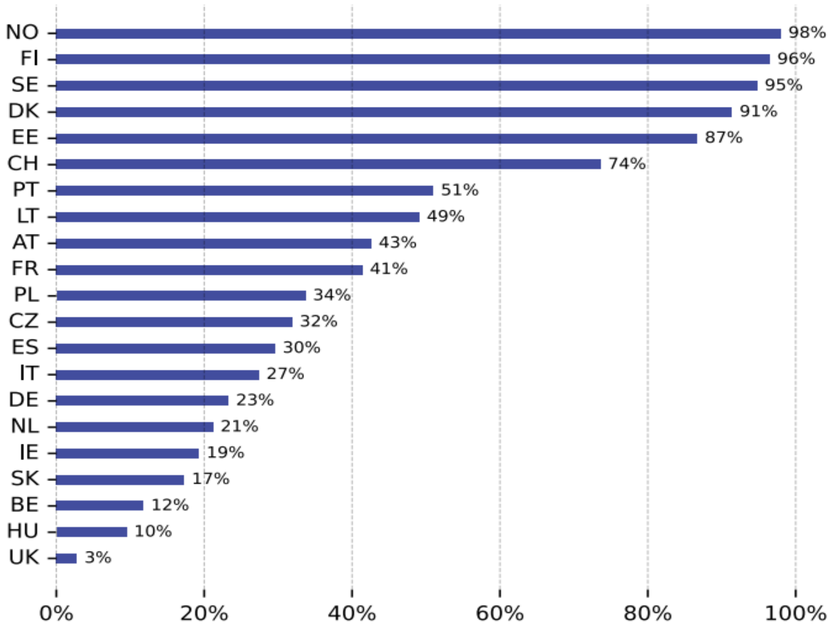


Figure 5: Heat pump market shares in % of combined sales of boilers and heat pumps, for different countries in Europe. [4]

A survey of the Swedish heat pump market is included as a separate chapter, Ch. 4, in this report.

1.3 Task 5: Report and information dissemination (Year 5: 2023)

The major dissemination event in 2023 for research related to heat pumping technologies in general was the IIR International Congress of Refrigeration (ICR) in August in Paris. The following are activities and presentations in conjunction to the ICR:

- A seminar was arranged jointly by KTH and University of Valencia in remembrance of professor Eric Granryd and professor José Miguel Corberan, who were both pioneers in the field of research related to using hydrocarbons as refrigerants in heat pumps and refrigeration systems. During the seminar, their work was summarized and presentations were given by international experts on the state of the art of hydrocarbons as refrigerants.

- A keynote lecture was given by professor Björn Palm, entitled *Importance of heat pumps in the future energy system* [5]. The presentation covered the necessity of electrification of the heating sector to make the phase out of fossil fuels possible. It was also pointed out that going from gas and oil heating, with efficiencies in the range 70 – 90%, to modern heat pumps with COPs of 4 – 5 will reduce the need of energy input to the energy system considerably. The talk also pointed to the need to move to flammable refrigerants as HFCs will be phased down according to international agreements like the Kigali amendment to the Montreal protocol and, in Europe, the F-gas regulation. There are also good reasons to move to natural refrigerants, like hydrocarbon, ammonia and carbon dioxide as there are discussions worldwide about the use of PFAS fluids and the formation of TFA in the decomposition of HFC, including HFO [6], [7].

- A paper was presented by Ph.D. candidate Monika Ignatowicz with the title *Environmentally friendly lubricants for high temperature heat pumps with low GWP refrigerants* [8], co-authored by professor Rahmat Khodabandeh, KTH.

- A paper was presented by Dr Saman Gunasekara with the title *Analysis of Refrigerant R452B in Use-phase versus Pristine Conditions using Gas Chromatography* [9], co-authors were professor Björn Palm, Ph.D. candidate Monika Ignatowicz and M. Sc. Peter Hill. The paper describes the analysis of the low GWP refrigerant blend R452B taken from a heat pump after about 7800 hours of operation and compared to pristine R452B. The analysis was done with a gas chromatograph equipped with TCD and FID sensors. The used refrigerant revealed traces of R134a, moisture, possibly CO2 and small amounts of other light gases which could not be identified.

Other publications related to the Annex 54 work:

- A journal article was written based on the work on the isobutane heat pump with low charge which was described in a previous annual report. The title of the article was *Experimental evaluation of the effect of mechanical subcooling on a hydrocarbon heat pump system* and was published in Energy [10].

- A research area at KTH is the use of CO2 as refrigerant in supermarket refrigeration systems. In one article, the possibility of using the hot side of such systems for heating of buildings by direct connection or through the district heating network was analyzed. The article was published in Applied Thermal Engineering [11]. The first author, S Thanasoulas is a Ph.D. student having associate professor S. Sawalha as main supervisor.

- A Masters thesis was presented entitled *Status Mapping of tank to grave management of Low-GWP refrigerants*. [12]. The thesis uses LCA to analyze the complete life of refrigerants, both natural fluids and low-GWP synthetic fluids are covered. Interviews with stakeholders in different positions are done and conclusions about the expected development regarding the choice of refrigerant is presented. The student’s name is S. Parra Gimeno and the supervisor was assistant professor S. Gunasekara.

- Another Masters thesis was defended concerning the selection of refrigerants in large scale heat pumps of district heating systems [13]. The background is that some of the world's largest sea water and waste water heat pumps are located in Stockholm. Several other cities in Sweden also have large heat pumps supplying heat to district heating networks. These heat pumps all use HFC refrigerants and according to the new F-gas regulation they will not be allowed to service these heat pumps within the coming ten years. It is therefore necessary to find low-GWP alternatives if the systems should be used in the future. In particular, the thesis focuses on systems with heating capacities larger than 10MW now using R134a as working fluid. The conclusion is that ammonia would be the best alternative if the heat pumps are substituted. However, considering the poisonous nature of ammonia, it is recommended that R600a or R152b should be used in the future. The student's name is G. Balyaligil and the supervisor was associate professor S. Sawalha.

1.4 Swedish heat pump market

The Swedish refrigeration and heat pump industry each year send out questionnaires to their members to take the temperature on the market and to identify market trends. The results are found on the organization's web site [14]. Some of these trends will be presented in this section. Some of the questions have been asked annually for several years, making it possible to see the development over time.

The first question was: *How do you think the demand for heat pumps will be during the coming three year period?* As shown in Figure 6, the expectations of more than 90% of the respondents have been on the high side the last six years. However, the trend is declining slightly, and the share answering *Very high* decreased considerably, most probably because the market is close to saturation in Sweden.

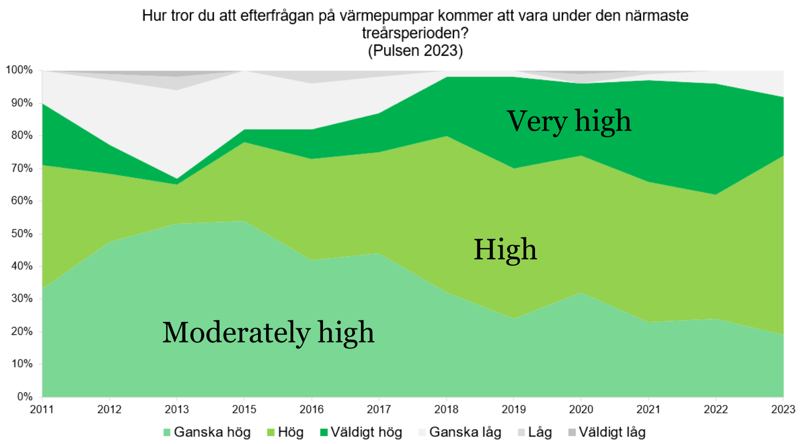


Figure 6: Expectations about the demand on the heat pump market in Sweden in the coming 3 year period [14].

During 2022 and the first part of 2023, the demand for heat pumps in Europe was so high that the customers had to wait to get a unit delivered. As it was the seller's market, this influenced the price of the heat pump installations. Also, the inflation rate was peaking at about 10%, which should be kept in mind when prices are compared. The second question, related to this, was: What would you estimate to be the total cost of a heat pump installation in a house requiring a total of 20 000 kWh per year in your area, for different types of heat pumps? The responses are shown in Figure 7, where the vertical axis shows the cost in Swedish krona (1 US$=10,5 sek). As shown, the expected costs rose quite sharply from 2022 to 2023 for all types, except air to air, for which the cost increase was low. Geothermal heat pumps, extracting heat from a borehole, typically 200m deep, are the most expensive, followed by heat pumps using shallow ground heat exchangers or ground water. It should be noted that geothermal heat pumps are often the only alternative of these three in urban areas as there is no space for digging and no ground water easily available. Air to water heat pumps are expected to be about 25% less costly than geothermal. In the cold climate of Sweden, the geothermal heat pumps are considered more reliable, especially during very cold weather. Exhaust air heat pumps cannot cover the complete power demand of the house and are typically used for production of sanitary hot water and/or for heating the incoming ventilation air. Almost all buildings have a hydronic system, connected to conventional radiators or, less common, to underfloor heating systems. The least expensive solution is the air/air heat pumps, typically single-split units. One unit will only be sufficient if the house has an open floor plan. Also, as the heating capacity is highly dependent on the outdoor temperature, these systems are usually combined with direct or indirect electric heating.

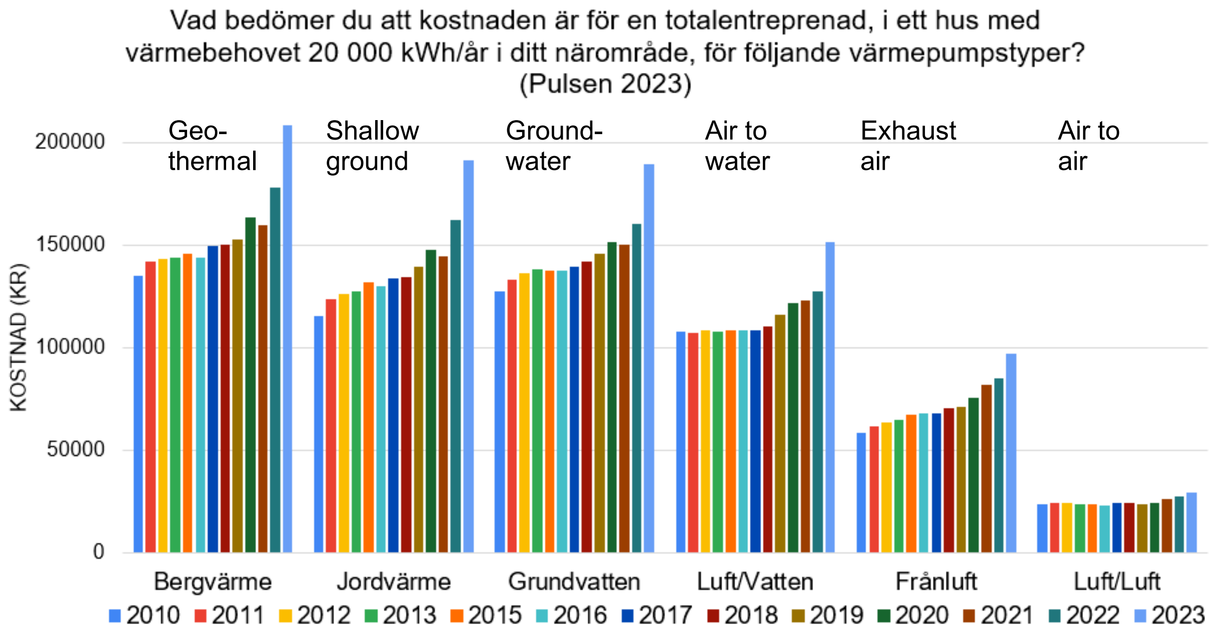


Figure 7: Expected total cost of a heat pump installation in a house with an energy need of 20 000 kWh/year [14].

The next question was: *What type of heating system have the heat pumps installed last year replaced or complemented, in %?* The responses are shown in Figure 8. Several interesting conclusions can be drawn from this figure. Looking at the development over time, it is clear that less and less oil boilers are replaced, simply because they have already been replaced and now very few remain. Second, the trend is increasing for new heat pumps replacing old ones. The expected lifetime of a heat pump is 15 – 20 years, and the trend is just a result of more and more heat pumps being installed during the last decades. Third, the share of heat pumps replacing direct electric heating has increased considerably during 2023. The reason is most probably the extremely high price of electricity during the summer of 2022 and the following winter. It is also interesting to note the low share of gas boilers being replaced. This is totally

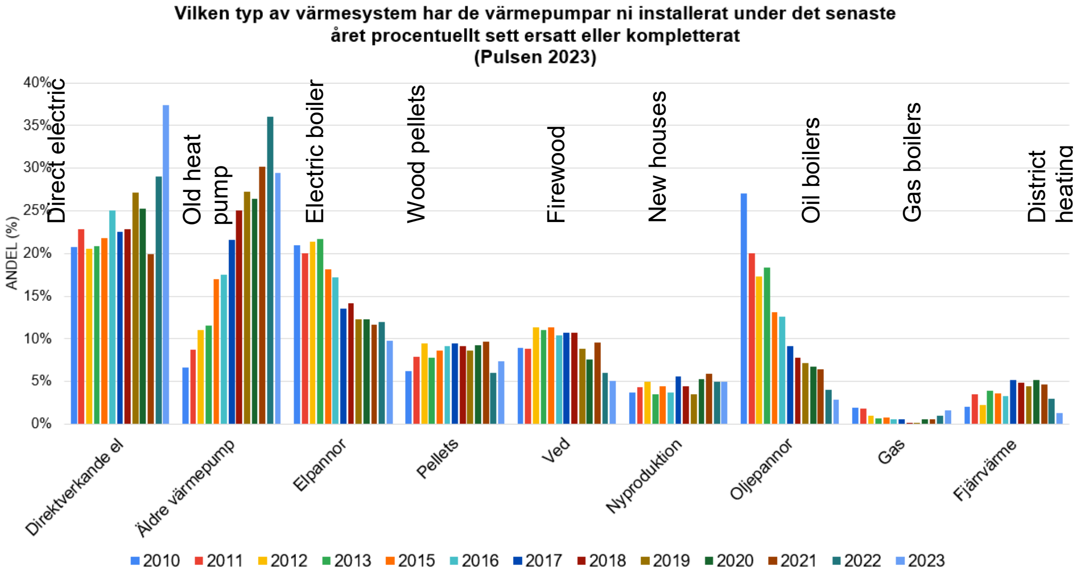


Figure 8: What heating system heat pumps installed 2023 replaced [14].

different from what would be the case in continental Europe, where gas heaters is the most common method of heating. In Sweden, only some areas along the south west coast have access to fossil gas through pipelines, so conversion from gas to heat pumps is a very small share.

Finally, the questionnaire asked about what refrigerants were used in the heat pumps installed during 2023. It should be noted that the numbers are estimates by a limited number of persons taking the survey, and not true sales statistics. The results are shown in Figure 9. As shown, the distribution depends very much on the type of heat pump. For Air/Air, R32 is totally dominating with 88% of the installations. Perhaps interesting to note that a few percent were using propane as refrigerant. For Air/Water heat pumps, R32 is also dominating, with 52% of the installations. Second largest is R410A with 37%, followed by R407C with 10%. A couple of percent use propane as refrigerant.

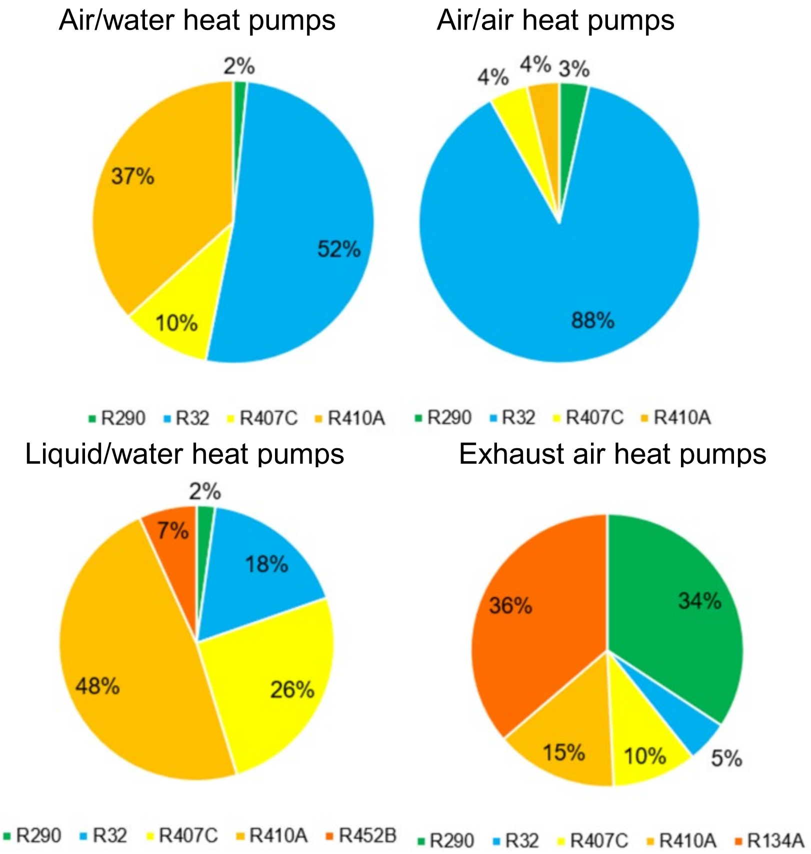


Figure 9: Estimate of refrigerants used in different types of heat pumps installed 2023 [14].

For Liquid/Water heat pumps, the picture is different. In this case R410A is dominating, with 48% of the market, followed by R407C with 26% and R32 with 18%. In this category, we find also a share of 7% of heat pumps with the HFO-blend R452B.

For exhaust air heat pumps, the distribution is again different. In this case, an estimated 36% of the heat pumps use R134a, and almost as large share, 34%, use propane. Propane has been used for this type since at least ten years. The motivation has been that the systems are relatively small, having a limited charge, and that the air flow around both evaporator and condenser is large, which is expected to limit the risks of reaching a flammable concentration in the ducts in case of a leakage. The remaining 30% of the units use R410A (15%), R407C (10%) and R32 (5%).

As mentioned, the distribution in Figure 9 is based on a questionnaire to companies in the business, not on actual sales. Still, it gives an impression of what refrigerants were used in Sweden in new heat pumps during 2023. It is interesting to note that only one of the new HFO-containing blends is visible in the graphs. Also interesting is that the two high-GWP refrigerants R407C (GWP=1774) and R410A (GWP=2088) are still quite common in new systems! The only refrigerant with GWP lower than 600 is propane (R290) with a GWP of much less than 1.

2 Summary of latest results

Many of the research projects on low GWP refrigerants initiated during the last couple of years have continued also during 2023. A few new projects have also been started. Some journal articles, conference papers and student theses related to these projects have been presented in the previous section. The following is a brief presentation of the latest results in the projects not mentioned above.

2.1 Safe use of flammable refrigerants

This project is Sweden's main contribution to IEA HPC Annex 64 and will only briefly be mentioned here as the subjects of the two Annexes partly overlap. The project has recently started and some of the main activities are the following:

- Simulation of leakages of flammable refrigerants in different scenarios.
- Tests of leakages of hydrocarbon refrigerants under realistic conditions
- Design of heat pump systems for minimum risk and maximum efficiency
- Design for minimum charge in systems with flammable refrigerants
- Investigation of leak detectors, functionality, reliability, cost

At this point no publications are available from the project.

2.2 EcoPack project

This project investigates the design of an isobutane (R600a) heat pump for medium to high temperature applications. An initial concept was to design this heat pump as an active de-superheater of a larger heat pump, i.e. to use the subcooling of the refrigerant of the larger heat pump as a heat source for a small heat pump. One possible application would be to produce sanitary hot water at temperatures of 60C or above with the smaller heat pump, while supplying heating at lower temperature with the larger heat pump for a hydronic system. Two articles were presented at the Gustav Lorentzen conference in Trondheim 2022 [15] [16], and one journal article was published in 2023 [10].

The system has a capacity of up to 12 kW and uses a variable speed rotary compressor originally designed to be used for heating or cooling of electric vehicles. The heat exchangers were plate-type and prototype heat exchangers with asymmetric plates were used in order to decrease the charge and maximize the performance. The system has an internal heat exchanger in order to maximize the COP of the system. It has been shown that this system can operate well with as little as 120 g of R600a. During the last year, the project has focused on the control of the expansion device. By careful control of the valve it has been shown that it is possible to locate the sensors of the valve after the internal heat exchanger, i.e. directly before the compressor. Other modes of control are also investigated. No publication has been presented about the last developments, but an abstract is submitted to the Gustav Lorentzen conference at Univ Maryland in August 2023.

2.3 Low GWP refrigerants for high temperature heat pumps

Two different test rigs have been designed for testing different refrigerants in high temperature heat pumps. The aim is to demonstrate stable operation with condensing temperatures above 120 deg C. Theoretical analysis and comparison of the performance with different refrigerants is expected but not yet completed.

2.4 Compressor oils for high temperature heat pumps

Identifying a suitable compressor oil is one of the key questions for the application of high temperature heat pumps, and this is the purpose of this project. Tests will be done in one of the two test rigs mentioned above. In this case, a sensor located inside the compressor will be used to measure the viscosity of the oil during operation. KTH, Department of Energy

Technology, is working together with an industrial partner with the aim of developing a new oil for high temperature heat pumps.

2.5 Energy efficiency of CO2 heat pumps and refrigeration systems

Carbon dioxide is probably the most common refrigerant in large supermarket refrigeration systems in northern Europe. As these systems are located in shopping malls or in close connection to apartment houses there is a possibility of using the heat from the high pressure side of the refrigeration systems as heat source for the building where the supermarket is located or for surrounding buildings. In two projects, both technical solutions and economic barriers for using this waste energy are investigated. Figure 10 shows a possible design of a supermarket refrigeration system with cooling at three temperature levels and heat recovery at two levels.

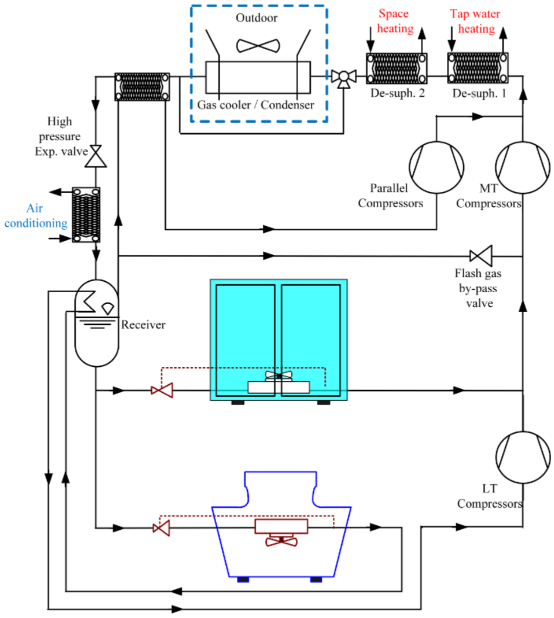


Figure 10: Example of design of supermarket CO2 system with heat recovery.

2.6 Cooperation between supermarkets and apartment house owners

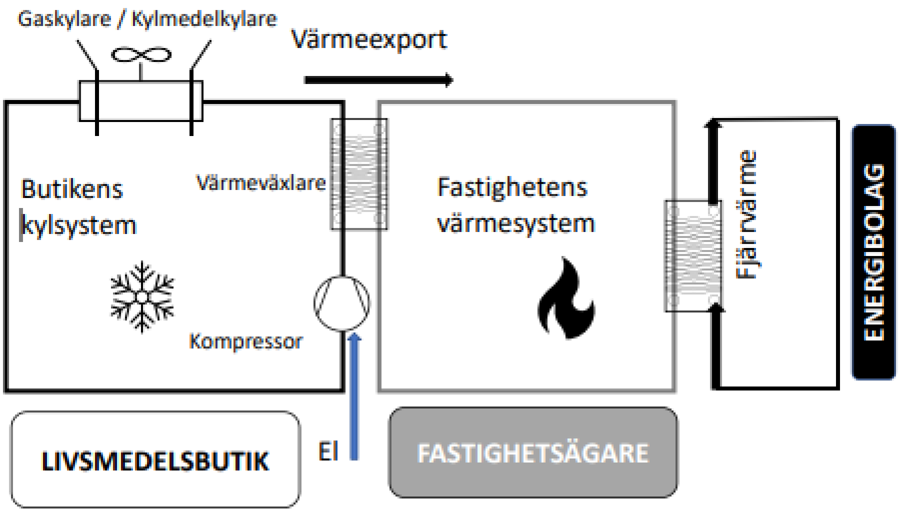


Figure 11: Thermal connections between the supermarket, left, the heating system of the building, middle, and the district heating system, right. [17]

In the second project related to carbon dioxide systems, the overall aim is to demonstrate that collaboration between super market owners and real estate owners can be beneficial for both parties. This is done by modelling, energy measurements, theoretical calculations and business model evaluation. A report (in Swedish) has been published [17]

2.7 Handling of low-GWP refrigerants from installation to destruction

A long list of synthetic refrigerant blends with relatively low GWP has been suggested by the chemical industry during the last ten years. Most of these blends contain HFCs with double bonds, often referred to as HFOs. The advantage of these refrigerants has been considered to be the low GWP-values. These values are low because the molecules are unstable in the natural environment outside of the heat pump system. However, it is of vital importance that any refrigerant is stable for the complete lifetime of the system as long as they are contained inside. One purpose of this project is to investigate possible changes in the composition of the refrigerant blends in actual system over time. For this purpose, used refrigerant from systems which have been in operation for several months or years is collected and analyzed with gas chromatography. The project is also in connection with industry partners concerning problems which may be related to the refrigerant. In one case, a refrigerant bottle containing R513A (56% R1234yf, 44% R134a) gave off a foam when the valve was opened, see Figure 11. This foam was analyzed by FTIR and it was found that the foam had no C=C double bonds. Further analysis will follow, but it seems that the most probable reason is that the R1234yf has polymerized in the bottle. Similar experiences have been reported previously by other sources. One aim of the project is thus to explain under what conditions such polymerization can take place.

Figure 12: Bottle of R513A giving off a white foam when the valve is opened.

2.8 Heat exchanger designs

All refrigerants with low GWP (<150) used or suggested for heat pumps at moderate temperatures are flammable. To reduce the risks with flammable refrigerants it is important to reduce the charge as much as possible. Up to now, charge reduction has not been important for the manufacturers of components or the designers of heat pump systems, but in the future this will most probably be very different. In private communication with manufacturers we hear that many of them have realized this and are now working on new components and systems with lower charge. As a large share of the refrigerant charge is located in the heat exchangers, development of these components are highly important. At KTH three projects are running connected to heat exchangers and heat transfer. The projects are not directly connected to low-GWP refrigerants, but can contribute to better understanding of the processes in the evaporator and condenser of heat pump systems and thereby to enhanced performance of these components and decreased charge of refrigerant.

2.8.1 Evaporative heat transfer in flat channels

To reduce the internal volume of a heat exchanger a natural step is to use flat channels rather than circular channels. This is already implemented e.g. in plate heat exchangers, where the development is now going towards smaller pressing depths and thereby lower volume with maintained surface area. In this project the fundamentals of evaporation in flat channels is investigated. The goal is to increase the understanding of the evaporative process around bubbles in a high aspect ratio (flat) channel. The intention is to use a high speed IR camera to determine the temperatures on the inside surface of the evaporator channel as growing bubbles are passing in the channels. First results are expected by the end of 2024.

2.8.2 High efficient heat exchangers manufactured with additive manufacturing

Additive manufacturing is a new method of producing complex structures, not only in plastic/polymer materials but also in different metals. By this method, complex heat exchanger surfaces like the ones shown in Figure 12 can be produced. In the initial phase of this project, surfaces for single phase heat transfer will be produced and tested, but in the following phase, designs suitable as evaporators and condensers will be developed with the purpose of enhancing heat transfer and reducing the necessary volume of the heat exchangers, thereby reducing the necessary charge of refrigerant.

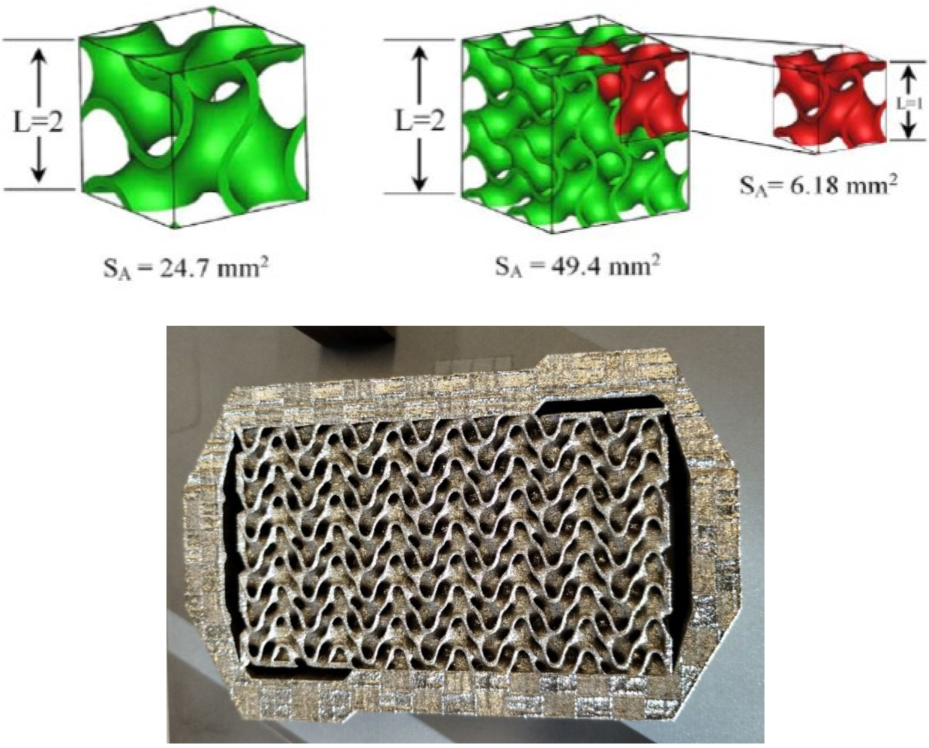
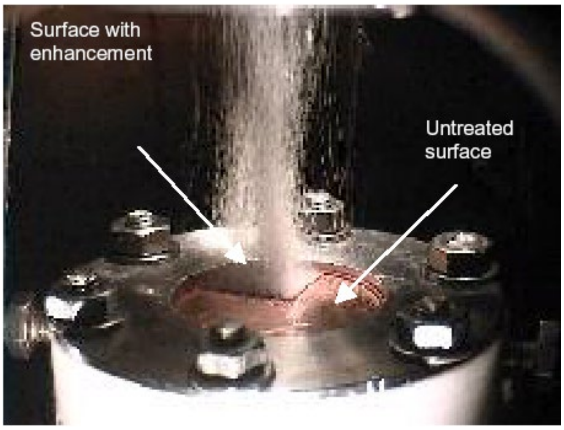


Figure 13: Drawing and photo of heat exchanger with large surface area compared to volume. Prototype in stainless steel produced at KTH using additive manufacturing.

2.8.3 Porous surfaces for enhancing boiling heat transfer

It is well known that boiling heat transfer can be enhanced by using porous surfaces where traces of gas can hide in pores in between the release of bubbles from the surface. In this project, electroplating is used for producing microporous nanostructured surfaces which have been shown to give extremely high boiling heat transfer coefficients, in some cases up to 10 or even 15 times higher than smooth surfaces. Figure 14 shows a picture of a heated plate where one quarter of the surface is covered by this surface. As shown, boiling takes place only on this quarter of the surface. To the right is a photo of the same surface as seen through an electron microscope. Presently, a project is ongoing aiming at optimizing the structure for different refrigerants and different applications.



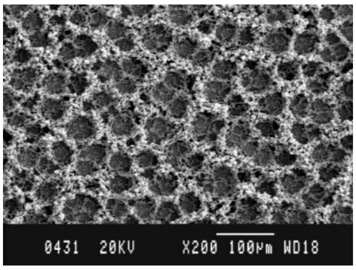


Figure 14: Left: Boiling on surface partly covered by micro-porous nano-structured surface. Right: Photo of surface as seen in electron microscope.

3 A study of Market Opportunities of Low-GWP Refrigerants in Sweden, Analysis of Collected Data from Six Heat Pump Manufacturers

3.1 Introduction

This report is about a survey that was conducted under Work Package 4 to collect data and insights about the outlook of low global warning potential (GWP) refrigerants to 2030. The survey investigated and studied the market opportunities of heat pumps with low-GWP refrigerants and their availability while considering possible standards and bottlenecks for implementing these refrigerants within Sweden. It's important to note that the survey was conducted before the F-gas regulation was accepted, and the knowledge of the IEC 60335-2-40:2022 standard might not have been widely known at that time.

3.1.1 Background

The survey was designed to contribute to market research that investigated the impact of current standards on refrigeration, air conditioning, and heat pump applications. The findings from the study aimed to identify opportunities and research efforts necessary to implement low-GWP refrigerants in order to eliminate existing barriers in the relevant industry standards.

3.1.2 Context and Research Question and Objectives

The target audience for the survey included system manufacturers, end-users, trade bodies, researchers, national authorities, contractors, technicians, distributors, and nonprofit organizations (NPOs). The survey aimed to investigate the status quo and outlook for low GWP refrigerant-based systems, including drivers and barriers for their uptake, energy efficiency, cost compared to HFCs, availability of products using multiple refrigeration circuits, expectations about future use, and willingness to work with higher refrigerant charges.

The research objectives were to study the market opportunities for heat pumps with low-GWP refrigerants and low-GWP refrigerant availability at different levels for 2030. The survey also aimed to identify possible standards and bottlenecks for implementing these refrigerants in Sweden. The findings were intended to contribute to market research that investigated the impact of current standards on refrigeration air conditioning and heat pumps (RACHP) applications and the introduction of low-GWP refrigerant-based technology in particular. Additionally, the survey aimed to identify what opportunities and research efforts were necessary to implement low-GWP refrigerants and eliminate existing barriers in the relevant industry standards.

3.2 Literature Review

The use of refrigerants in heating, ventilation, air conditioning, and refrigeration (HVAC&R) systems significantly impacts the environment. The most common refrigerants in use today, such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), have been found to contribute to ozone depletion and climate change. The Montreal Protocol of 1987 and the subsequent Kigali Amendment of 2016 aimed to phase out the use of these refrigerants and promote the adoption of low GWP alternatives.

Low-GWP refrigerants, such as hydrofluoroolefins (HFOs), hydrocarbons (HCs), and carbon dioxide (CO2), have been identified as potential alternatives to high-GWP refrigerants. HFOs do have GWPs that are up to 99% lower than HFCs, which are commonly used in HVAC&R systems. However, while HFOs have been found to be energy-efficient and safe for use in HVAC&R systems, they may not be universally safe for all applications, and more research is needed to fully understand their potential environmental and health impacts. Additionally, the use of HFOs in HVAC&R systems may require modifications to equipment and infrastructure, which can increase costs. HCs, such as propane and isobutane, are natural refrigerants with GWPs close to zero, and they have been used as alternatives to HFCs in some applications.

Heat pumps are widely used in Sweden for space heating and domestic hot water production, and they can also be used for cooling. The market opportunities for heat pumps with low-GWP refrigerants have been growing in recent years. With the phasing out of high-GWP refrigerants, there is a need for heat pumps that use low-GWP refrigerants. The European Union's F-gas Regulation has set out a timeline for the phasing down of HFCs, which is expected to create a market opportunity for low-GWP refrigerants.

Existing standards and regulations for low-GWP refrigerants vary by country and region. In Sweden, the Swedish Environmental Protection Agency (EPA) has set out regulations for the use of refrigerants with low GWP in refrigeration and air conditioning systems. The regulations require a gradual phase-out of HFCs and other high-GWP refrigerants and the adoption of low-GWP alternatives. However, there are still barriers to the implementation of low-GWP refrigerants, including concerns about safety, compatibility with existing systems, and availability. There are, of course, EU laws and directives that apply to all EU members. The F-gas regulation will influence all these countries.

In addition, the adoption of low-GWP refrigerants is also dependent on the availability of these refrigerants, i.e. synthetic fluids (HFOs). The availability of low-GWP refrigerants at different levels for 2030 is a critical consideration for manufacturers of HVAC&R equipment, including heat pumps. The availability of low-GWP refrigerants will depend on several factors, including the rate of production and the ability to scale up production to meet demand.

The implementation of low-GWP refrigerants in Sweden also requires compliance with existing standards and regulations. There are several relevant industry standards in Sweden, including the European standard EN378 and the Swedish standard SIS CEN/TR 16247. These standards provide guidelines for the safe use of refrigerants in HVAC&R systems, including heat pumps. Compliance with these standards can be a barrier to the adoption of low-GWP refrigerants, as manufacturers may need to modify their systems or obtain certification to ensure compliance.

Overall, the literature suggests that the adoption of low-GWP refrigerants in heat pumps presents significant market opportunities but also faces several barriers related to standards, regulations, and availability when it comes to synthetic refrigerants. The findings of this study aim to contribute to the existing literature by identifying the perspectives of Swedish heat pump manufacturers on the market opportunities and barriers to the implementation of low-GWP refrigerants in their products.

3.3 Methodology

The research employed a mixed-methods approach that included both qualitative and quantitative data collection methods. The study involved conducting one-to-one interviews with six Swedish heat pump manufacturers or having them complete an online survey. The survey included both open-ended and close-ended questions to collect data on various aspects of the heat pump manufacturing process. The use of both qualitative and quantitative methods allowed the researchers to collect comprehensive data that captured both subjective experiences and objective measurements.

3.3.1 Sample Selection and Data Collection Methods

The sample for this study comprised six Swedish heat pump manufacturers: CTC/Enertech, Bosch Thermoteknik AB, Qvantum Energi AB, Enrad AB, NIBE, and Thermia. The researchers chose these companies based on their market share and the number of units sold. The sample size was relatively small due to the limited number of heat pump manufacturers in Sweden. The data were collected through one-to-one interviews or online surveys. The researchers used a semi-structured questionnaire that included both open-ended and close-ended questions. The interviews were conducted by the researchers themselves and lasted approximately 30 minutes, while the online survey took around 14 minutes to complete.

3.3.2 Data Analysis Techniques

The researchers used both qualitative and quantitative data analysis techniques. The qualitative data collected from the open-ended questions in the interviews and surveys were analyzed using thematic analysis. The thematic analysis involved identifying patterns, themes, and categories in the data. The researchers used a deductive approach to identify themes and categories based on the research objectives and the literature review. The quantitative data collected from the close-ended questions were analyzed using descriptive statistics, such as mean, median, and mode. The data were analyzed using statistical software to identify patterns and trends. The researchers used a mixed-methods approach to integrate the qualitative and quantitative data to provide a comprehensive understanding of the heat pump manufacturing process in Sweden.

The questionnaire was distributed online to individuals and organizations involved in the heat pump industry in Sweden. The questionnaire consisted of multiple-choice questions, rating scales, and open-ended questions.

The questionnaire asked the companies to provide information about the current refrigerants they use and the alternative low-GWP refrigerants they are considering for high-pressure, medium-pressure, low-pressure, and refrigeration applications. In addition, the questionnaire asked about the demand for low-GWP refrigerants, the short-term, medium-term, and long-term barriers to market penetration, the growth opportunities, and the factors that have been decisive in the selection of refrigerants.

The companies were also asked about the short-term, medium-term, and long-term growth drivers for market penetration of low-GWP refrigerants, as well as issues related to flammability, toxicity, and lubricant compatibility. The questionnaire also asked about the knowledge that is needed regarding the new refrigerant, both within the company and in the industry, and whether additional developments are needed for existing product or service offerings. The companies were also asked about their commitment to the transition to low-GWP refrigerants, their interest in contributing to standardization and safety measures for the new low-GWP refrigerants, and the top players/companies of the refrigerant market in Sweden.

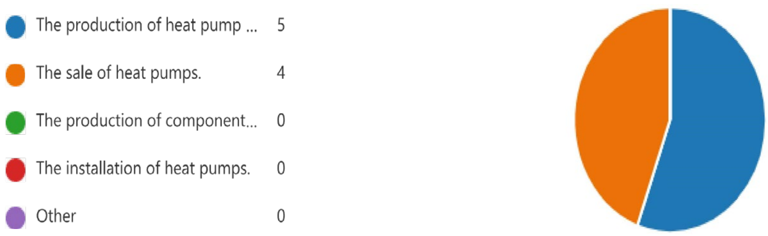
3.4 A Study of Market Opportunities of Low-GWP Refrigerants in Sweden: Analysis of Collected Data from Six Heat Pump Manufacturers

This section provides a comprehensive analysis of data collected from six leading Swedish heat pump manufacturers - Bosch, Qvantum, Thermia, Enrad AB, Enertech, and NIBE. The manufacturers vary in size, and all of them are engaged in the production and sale of heat pumps. The aim of this report is to present an in-depth analysis of the market opportunities for heat pumps with low-GWP refrigerants, availability of low-GWP refrigerants at different levels for 2030, standards and bottlenecks for implementing low-GWP refrigerants in Sweden, industry perspectives on the impact of current standards on RACHP applications, and opportunities and research efforts necessary to implement low-GWP refrigerants and eliminate existing barriers. This section will delve into each of these topics in detail, providing insightful findings and recommendations for stakeholders in the heat pump industry.

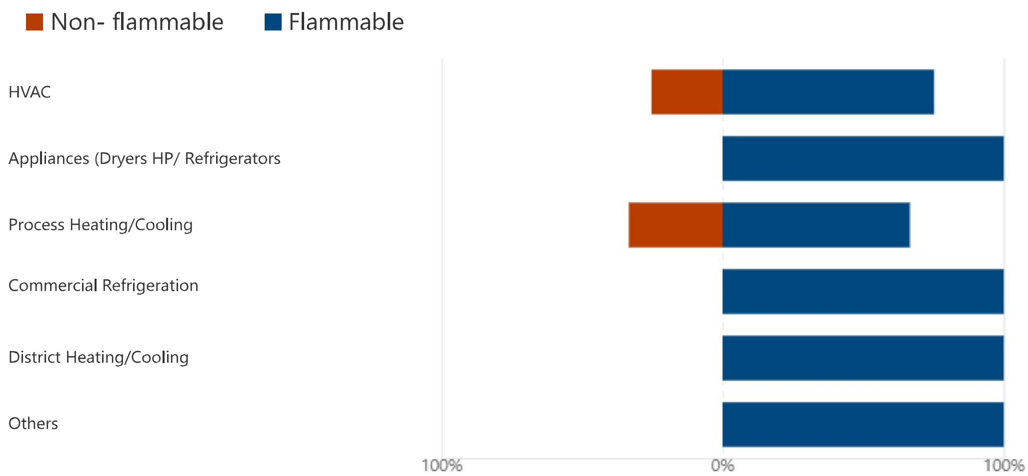
3.4.1 Results and Analysis of data collected.

The purpose of this report is to analyze the data obtained from a questionnaire designed to investigate the market opportunities of heat pumps with low-GWP refrigerants and the availability of these refrigerants in Sweden. The study was conducted with a focus on the year 2030 and the possible standards and bottlenecks for implementing these refrigerants within the country. Below each question will be discussed based on the results obtained from the manufacturers.

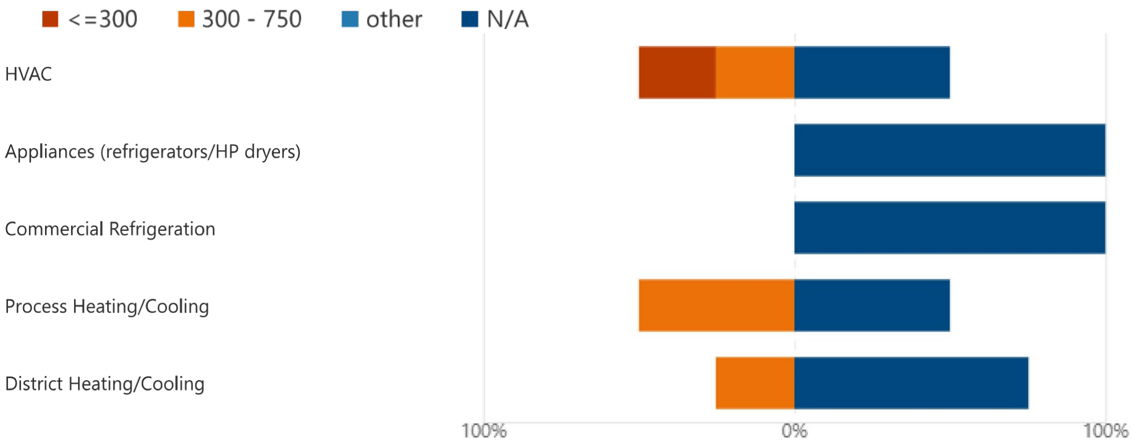
This question asks for the number of employees the company has, with three answer choices: less than 50, between 50 and 250, and more than 300. There were 4 respondents who selected "more than 300", and one company selected between 50 and 250.



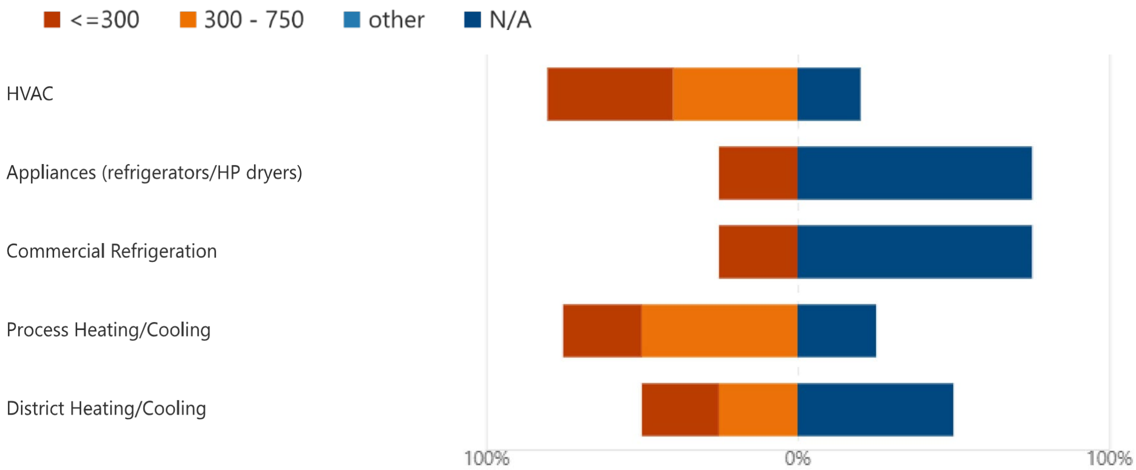
This question asks which of the following the company deals with: the production of heat pumps, the sale of heat pumps, the production of components, the installation of heat pumps, or "other". There were 5 respondents who selected "the production of heat pumps" and 4 who selected "the sale of heat pumps".



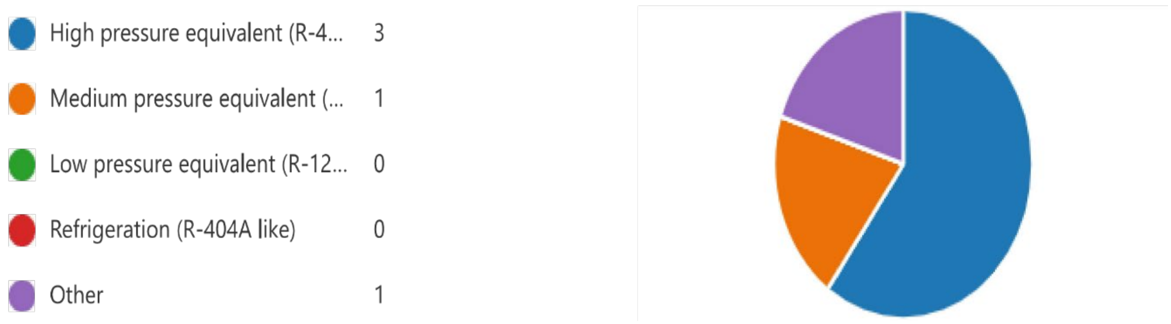
This question asks which end-uses the respondent considers their primary target(s) to support the global transition to low-GWP refrigerants, with options including HVAC, appliances (dryers/HP refrigerators), process heating/cooling, commercial refrigeration, district heating/cooling, and "others". There is also a choice between non-flammable and flammable refrigerants. The respondent can choose multiple answers.



This question asks which GWP range the respondent is currently targeting for alternative low-GWP non-flammable refrigerants for HVAC, appliances (refrigerators/HP dryers), process heating/cooling, commercial refrigeration, and district heating/cooling, with answer choices including <=300, 300-750, "other", and N/A.



This question is similar to the question above but for low-GWP flammable refrigerants.



This question asks which low GWP refrigerant substitutes the respondent is working on, with answer choices including high-pressure equivalent, medium-pressure equivalent, low-pressure equivalent, refrigeration (R-404A-like), and "other". The majority of respondents (3 out of 5) are working on developing high-pressure equivalent refrigerants. One respondent is working on developing medium-pressure equivalent refrigerants.

5

Responses

Latest Responses

"R-410A R290"

"R410A, R452B, R454B"

"R32"

This question asks respondents to list the current refrigerant and the alternative low-GWP refrigerants they are considering for each of their **high-pressure applications**. There are 5 responses for this question, which mentions R407c replaced by R454c or R290 and R410A replaced by R290, (R407C -> R290), R32, (R410A R452B, R454B) and (R-410A, R290) as their high-pressure applications.

2

Responses

Latest Responses

"R32, R513"

"R290"

This question asks respondents to list the current refrigerant and the alternative low-GWP refrigerants they are considering for each of their **medium-pressure applications**. There are 2 responses for this question, which mention R290 (R32, R513) considered as their medium-pressure applications.

3
Responses

Latest Responses
"R-410A R290"
"R290, R452B, R454B, R32"
"R290"

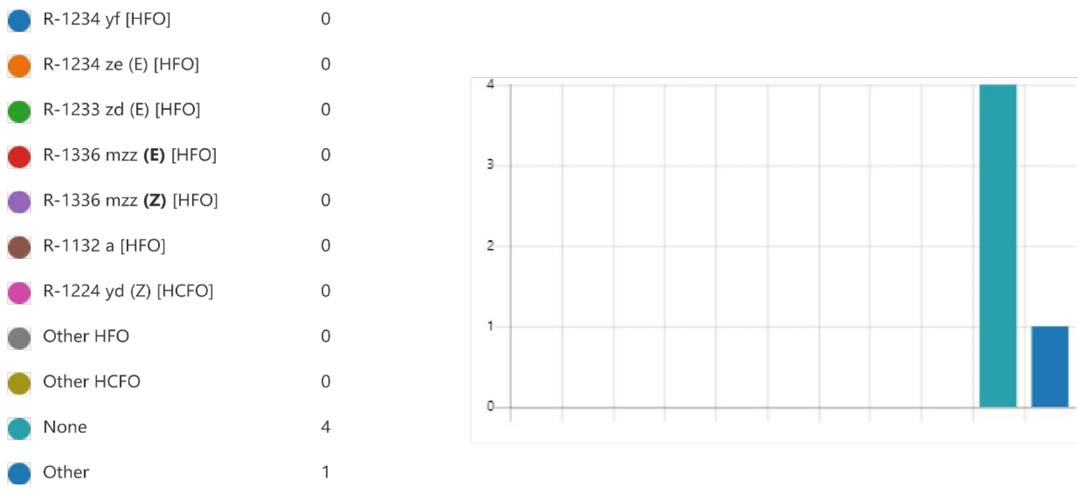
This question asks to list the current refrigerant and the alternative low-GWP refrigerants the respondents are considering for each of their refrigeration applications. There are 3 responses for this question, which mention R407c replaced by R454c or R290 and R410A replaced by R290, R32, R452B, R454B and (R-410A, R290) for their considered refrigeration applications. R290, R452B, and R454B were identified as the alternative low-GWP refrigerants that are being considered for high-pressure applications. For medium-pressure applications, R32 and R573 are being considered as alternative low-GWP refrigerants. R290, R4528, R4548, and R32 are being considered as alternative low-GWP refrigerants for refrigeration applications.

2
Responses

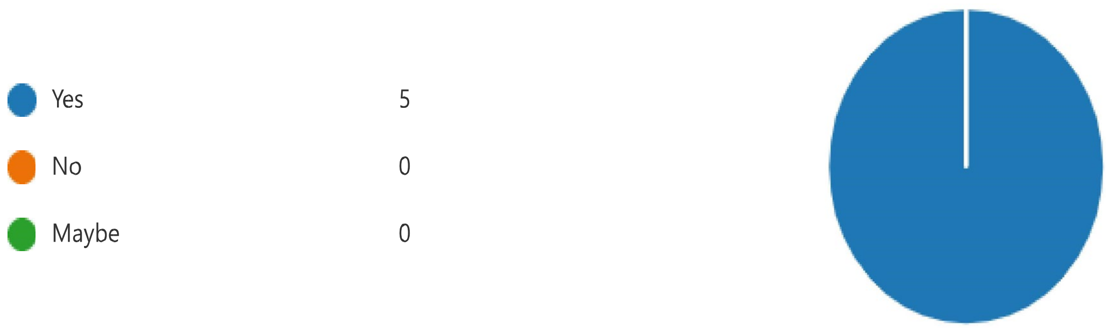
Latest Responses
"N/A"
"R290, R32"

Please list the current refrigerant and the alternative low GWP refrigerants you are considering for any other applications. There are 2 latest responses for this question, both of which mention R290 and R32 as alternative low GWP refrigerants.

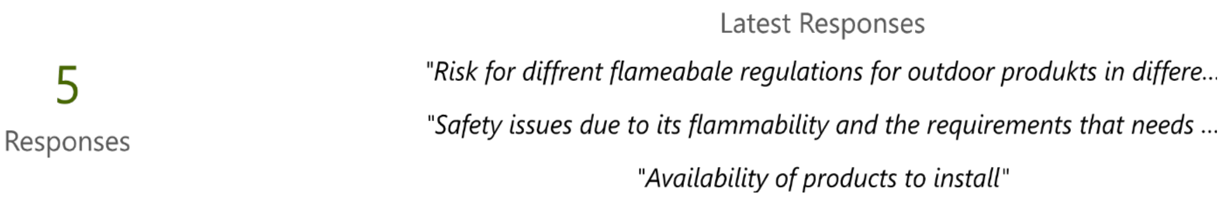
This question asks for the approximate percentage of the respondent's production facilities that are capable of producing products which use low GWP refrigerants with a GWP <700, with answer choices including less than 25%, 25-50%, 50-75%, and 100%. Out of the 5 responses, 3 companies reported that 50-75% of their production facilities are capable of producing products which use low GWP refrigerants. In contrast, 1 company reported that 100% of their production facilities are capable of producing products which use low GWP refrigerants. One company reported less than 25%, and no company reported 25-50% of their production facilities as capable of producing low GWP refrigerants.



This question asks which low GWP single-component refrigerants the respondent produces, with answer choices including R-1234 yf [HFO], R-1234 ze (E) [HFO], R-1233 zd (E) [HFO], R-1336 mzz (E) [HFO], R-1336 mzz (Z) [HFO], R-1132 a [HFO], R-1224 yd (Z) [HCFO], other HFO, other HCFO, none, and "other". Out of the 5 responses, 4 companies reported that they do not produce any of the listed low GWP single-component refrigerants.



This question asks whether the market demand for low-GWP refrigerant is growing, with answer choices including yes, no, and maybe. All 5 companies responded that the market demand for low-GWP refrigerants is growing.



This question asks the respondent to identify the greatest short-term barrier to market penetration of low-GWP refrigerants. The 5 latest responses for this question mention the following as the greatest short-term barrier to market penetration of low-GWP refrigerants:

- Safety issues due to its flammability and the requirements that need to be fulfilled for higher charges, mainly related to R290
- Different flammable regulations for outdoor/indoor products in different countries,
- Availability of products to install
- Regulation, e.g. critical charge volumes of mildly flammable refrigerants and

- Availability of mature and reliable components

5

Responses

Latest Responses

"Risk for diffrent flameabale regulations for Indoor produkts in differen...

"Safety issues due to its flammability and the requirements that needs ...

"availability of installers and service technicians with proper training t...

This question asks the respondent to identify the greatest medium-term barrier to market penetration of low-GWP refrigerants. Similarly, the 5 latest responses for this question mention the following as the greatest medium-term barrier to market penetration of low-GWP refrigerants:

- Safety issues due to its flammability and the requirements that need to be fulfilled for higher charges, mainly related to R290
- Different flammable regulations for outdoor/indoor products in different countries,
- Availability of products to install
- Regulation, e.g. critical charge volumes of mildly flammable refrigerants and
- In case HPs using low-GWP refrigerant cause accidents in the near future, it will be very detrimental for this technology

5

Responses

Latest Responses

"Efficiency of heat pump"

"Safety issues due to its flammability and the requirements that needs ...

"National legislation blocking installation of flammable refrigerants"

This question asks the respondent to identify the greatest long-term barrier to market penetration of low-GWP refrigerants. The 5 latest responses for this question mention the following as the greatest long-term barrier to market penetration of low-GWP refrigerants:

- The efficiency of the heat pump
- Safety issues due to its flammability and the requirements that need to be fulfilled for higher charges and mainly related to R290.
- National legislation blocking the installation of flammable refrigerants
- Regulation, e.g. critical charge volumes of mildly flammable refrigerants
- Ban of synthetic refrigerants might limit the refrigerant choice

5

Responses

Latest Responses

"R290 , R-744"

"R290"

"HC, NH3, C02"

Which type of refrigerant presents the major growth opportunity in your business over the next five years? Of the 5 responses, 3 companies mentioned R290 and one mentioned "Natural refrigerants". Two companies mentioned CO2, and another mentioned Hydro Carbons (HC) and Ammonia (NH_3) as the major growth opportunity in their business over the next five years.

3

Responses

Latest Responses

"More climate friendly."

"Customers requesting products that are environmental friendly and w...

In response to the question, "What do you see as the greatest short-term opportunities for market penetration of low-GWP refrigerants?" Two companies responded that customers are increasingly requesting products that are environmentally friendly, and one company mentioned that the revision of the FGAS regulation would push the industry towards low-GWP refrigerants.

3

Responses

Latest Responses

"Supports the green deal."

"increasing costs of high GWP refrigerants will make products with low...

Regarding the greatest medium-term opportunities for market penetration of low-GWP refrigerants, two companies responded that increasing costs of high-GWP refrigerants would make products with low-GWP refrigerants more competitive, and one company mentioned that low-GWP refrigerants support the green deal, and one company mentioned the revision of the REACH (2025) and the possible ban of PFAS.

3

Responses

Latest Responses

"Supports the green deal."

"Big scale replacement of gas and oil boilers with heat pumps require l...

For the greatest long-term opportunities for market penetration of low-GWP refrigerants, one company responded that low-GWP refrigerants support the green deal. One company mentioned that there would be a big-scale replacement of gas and oil boilers with heat pumps that require low-GWP refrigerants. One company mentioned most of the HP will use low GWP refrigerants: components will be widely available, and costs will drop, the installer will be trained, and HPs will become the norm.

5

Responses

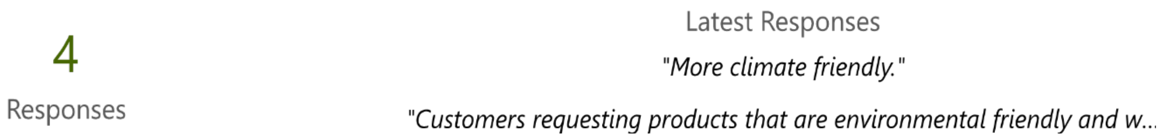
Latest Responses

"EU Regulations . "

"The level of GWP and flammability."

"Fulfilling future regulations and gives high efficiency"

In response to the question, "Please describe what has been decisive in the selection of refrigerant?" three companies mentioned fulfilling future regulations and ensuring high efficiency, and two companies mentioned EU regulations and the level of GWP and flammability.



The greatest short-term growth drivers for market penetration of low-GWP refrigerants, according to four companies:

- The revision of the FGAS regulation
- End-customer expectations of regulatory need to shift to low-GWP in combination with the end-customer internal sustainability targets
- Customers requesting products that are environmentally friendly and will fulfill future regulations
- More climate-friendly

The greatest medium-term growth drivers for market penetration of low-GWP refrigerants, according to four companies:

- they are more climate-friendly and
- the upcoming F-gas regulations
- Tightening regulation for high-GWP refrigerants and enabling regulation for low-GWP
- Obligation to minimise the environmental footprint of HPs

The greatest long-term growth drivers for market penetration of low-GWP refrigerants, according to four companies:

- they are more climate-friendly and
- have a competitive cost of products and installations

- Tightening regulation for high-GWP refrigerants and enabling regulation for low-GWP
- Our own will to make more sustainable products

In response to the question, "We have sufficient knowledge within the company regarding the new refrigerant, for example:

- Flammability", four companies agreed, and one company responded Neither agree nor disagree
- Toxicity", one company agreed; two companies selected Neither agree nor disagree and one company responded disagree, and one company selected Strongly disagree
- Lubricant compatibility ", Two companies agreed, and three companies responded Neither agree nor disagree

3

Responses

Latest Responses

"Increased knowledge within the area of PFAS and toxicity."

"how to handle high flammability refrigerants"

Regarding the knowledge needed within the company and industry regarding the new refrigerant, one company responded that increased knowledge within the area of PFAS and toxicity is needed, one company mentioned knowing how to handle high flammability refrigerants, and one company mentioned knowledge in thermodynamic and mechanical design are needed.

5

Responses

Latest Responses

"mayor changes in factory and commpressor units . "

"Don´t know"

"Yes, most of the time completely new products"

In response to the question, "Are additional developments needed for the existing product or services offerings or do the existing products meet the customer demands?" one company responded that major changes in factory and compressor units are needed, one company said that they do not know, one company said that most of the time completely new products are needed, and one company mentioned need to reduce the charge size and to ensure compliance with safety standards.

In response to the question, "Do you trust that the compressor manufacturer has full knowledge of the choice of lubricating oil?" four companies answered yes, and no companies answered no.

4
Responses

Latest Responses
"Yes"
"Do not use refrigerants in the to be banned list in new products"

Regarding PFAS/TFA in refrigerants, one company responded yes, which is a topic we are closely following. One company responded yes and mentioned not using refrigerants in the to-be-banned list in new products.

5
Responses

Latest Responses
"LOW GWP and high efficincy "
"Safety issues and fulfill the requirements of ventilation."
"requirement of GWP < 150 in products to be installed indoors with > ...

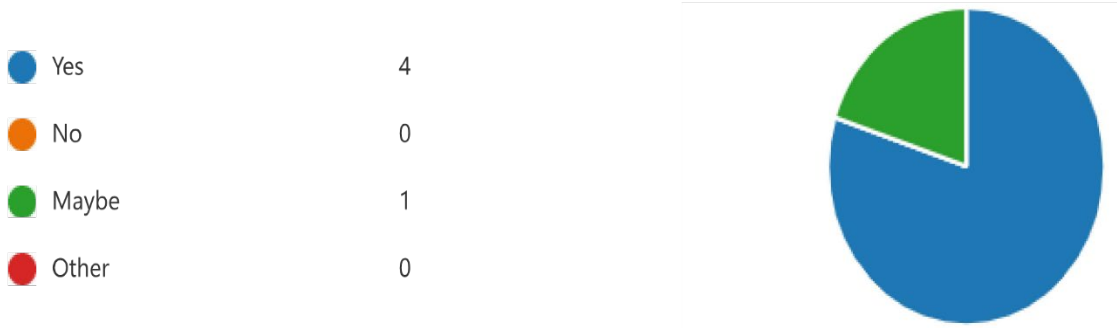
When asked about the most difficult legal requirements to deal with, five companies mentioned low GWP and high efficiency, and one company mentioned safety issues and fulfilling the requirements of ventilation. One company mentioned the requirement of GWP < 150 in products to be installed indoors with > 12 kW. One company mentioned Critical charge levels, and one responded with Compliancy with the safety directives.

2
Responses

Latest Responses
"?"
"Safety concepts for highly flammable refrigerants"

In response to the question, "What are the recent innovations in the market?" one company mentioned safety concepts for highly flammable refrigerants.

Regarding commitment to the transition to low-GWP refrigerants, three companies responded as 10/10 committed, and two companies responded as 8/10 committed.



When asked if they were interested in contributing to standardization and safety measures for the new low GWP refrigerants, four companies answered yes, and no companies answered no.

3.5 Discussion

The survey results showed that R290 is the most widely considered low-GWP refrigerant substitute, followed by R32, R454B, R452B, and R513. For high-pressure applications, R290 is considered a substitute for R407C and R410A, while R290 and R32 are considered substitutes for R513 in medium-pressure applications. For refrigeration applications, R290 is the most commonly considered substitute, followed by R452B, R454B, and R32. R290 and R32 are also considered as alternative refrigerants for other applications.

All six Swedish heat pump manufacturers interviewed acknowledged the growing demand for low-GWP refrigerants in the market. It's important to note that the survey was conducted before the F-gas regulation was accepted, and the knowledge of the IEC 60335-2-40:2022 standard might not have been widely known at that time.

They all agreed that there is a significant market opportunity for heat pumps that use low-GWP refrigerants, especially in commercial and industrial applications. The manufacturers indicated that they were investing in research and development to produce heat pumps that meet the growing demand for low-GWP refrigerants. Around 70% of the respondents believed that there would be a significant increase in the demand for heat pumps with low-GWP refrigerants by 2030. The narrative brings up a critical point regarding the potential application of low-GWP refrigerants in domestic heat pumps. Despite the regulatory framework favoring low-GWP refrigerants and their evident market potential, the respondents' divergence in opinion suggests a gap in understanding or strategy. The restriction on HFCs and HFOs for systems below 12kW underscores the significance of targeting this segment for low-GWP refrigerants, yet the reasons for the respondents' differing views warrant exploration. Understanding the rationale behind their perspectives could shed light on potential barriers or opportunities in the domestic heat pump market, facilitating informed decision-making and strategic planning for industry stakeholders.

The survey results also revealed the greatest short-term barrier to market penetration of low-GWP refrigerants to be the availability of mature and reliable components, followed by regulation, availability of products to install, and safety issues due to flammability and requirements that need to be fulfilled. For the medium-term, the greatest barriers are regulation, availability of installers and service technicians with proper training to handle flammable refrigerants, and safety issues due to flammability and requirements that need to be fulfilled. For the long term, companies reported that the ban of synthetic refrigerants might limit the refrigerant choice, national legislation blocking the installation of flammable refrigerants, and the efficiency of heat pumps as major barriers to market penetration.

Furthermore, the results also show that the lack of government policies and regulations was the most significant barrier. Around 45% of the respondents believed that the lack of regulations and policies was the most significant challenge. Other bottlenecks for synthetic refrigerants included the high cost of low-GWP refrigerants, lack of training and awareness, and the limited availability of low-GWP refrigerants.

The heat pump manufacturers identified several standards and bottlenecks that could hinder the implementation of low-GWP refrigerants in Sweden. However, the IEC and F-gas regulations will change this once implemented. They mentioned the need for new regulations and policies to support the use of low-GWP refrigerants, as well as the need for standards to be updated to reflect the use of these refrigerants. They also noted that the lack of awareness and knowledge about low-GWP refrigerants among end-users and installers was a significant bottleneck.

The heat pump manufacturers identified several opportunities and research efforts necessary to implement low-GWP refrigerants and eliminate existing barriers. They mentioned the need for increased research and development of low-GWP refrigerants and heat pumps that use these refrigerants. They also highlighted the importance of education and awareness campaigns to increase knowledge and understanding of low-GWP refrigerants among end-users, installers, and policymakers. Additionally, they emphasized the need for regulations and policies to support the use of low-GWP refrigerants and reduce the use of high-GWP refrigerants.

3.6 Conclusions and Recommendations: Key Takeaways from the Survey

The survey aimed to collect data and insights about the outlook of low GWP refrigerants to 2030. The findings were intended to contribute to market research investigating the impact of current standards on RACHP applications and low GWP refrigerant-based technology. The survey identified opportunities and research efforts necessary to implement low-GWP refrigerants and eliminate existing barriers in the relevant industry standards. The survey was available online, and heat pump manufacturers could participate through interviews or by completing the online survey.

Based on the responses provided, it appears that the companies are interested in transitioning to low-GWP refrigerants, but there are some short-term, medium-term, and long-term barriers to market penetration. The companies identified the availability of mature and reliable components, ban of synthetic refrigerants, and legal requirements as some of the challenges that need to be addressed. However, the companies also identified the revision of the FGAS regulation and the transition to low-GWP refrigerants as growth opportunities.

In addition, the medium-term barrier was identified as a safety issues due to flammability and the availability of installers and service technicians with proper training. The long-term barrier was identified as the difficulty in finding skilled workers with knowledge and experience to work with low-GWP refrigerants.

The survey results suggest that the market demand for low-GWP refrigerants is growing, and HVAC is identified as the primary target for the transition to low-GWP refrigerants. The greatest short-term barrier to market penetration of low-GWP refrigerants is the risk of different flammable regulations for outdoor products in different countries, while the greatest medium-term barrier is safety issues due to the flammability of low-GWP refrigerants and the requirements that need to be met. Lack of government support and incentives is the greatest long-term barrier to market penetration of low-GWP refrigerants.

All companies reported that they were working on high-pressure equivalent substitutes for their applications, and only two companies reported working on medium-pressure equivalents. In contrast, no companies reported working on low-pressure equivalents or refrigeration substitutes. Regarding the production of low-GWP single-component refrigerants, none of the companies reported producing them.

The survey results reveal that low-GWP heat pumps and refrigerants are gaining momentum in the Swedish market, and the demand is expected to grow in the future. However, there are several barriers to market penetration, especially related to regulation, safety issues, and the availability of mature and reliable components. **The companies that participated in the survey are working on low-GWP refrigerant substitutes, mainly R290, and are considering it as a substitute for various applications**. The availability of products to install and the efficiency of heat pumps are also major factors that need to be considered for the long-term success of low-GWP refrigerants. Overall, the findings of this survey suggest that the Swedish market has significant potential for low-GWP heat pumps and refrigerants, and further research and development efforts are required to overcome the barriers to market penetration.

The study concludes that there is a significant market opportunity for heat pumps with low-GWP refrigerants in Sweden. However, the lack of government policies and regulations is a significant bottleneck for implementing these refrigerants. The study recommends that the Swedish government introduce new regulations and standards to promote the use of low-GWP refrigerants. Additionally, the study suggests that more training and awareness programs be initiated to increase the knowledge and understanding of low-GWP refrigerants among stakeholders in the heat pump industry.

Overall, the questionnaire provides valuable insights into the market opportunities and challenges related to the transition to low-GWP refrigerants in Sweden. The information collected can be used to inform policy decisions, promote the development of new technologies and products, and guide the efforts of companies in the HVAC, appliances, process heating/cooling, commercial refrigeration, and district heating/cooling sectors.

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4 Highlights of the most significant accomplishments during the entire Annex 54 period

The most important event for the introduction of low-GWP refrigerants during the Annex 54 period from a European point of view is probably not a research accomplishment or a new product. Instead, it is the formulation of the new F-gas regulation, which was finally negotiated in October 2023 and signed by the European parliament and the Council of Ministers in the beginning of February 2024. This regulation will force the phase down of the use of HFC refrigerants at a rapid pace in the coming six years, and a total phase out until 2050. For units below a nominal capacity of 12 kW, there will be a ban also for the use of HFOs from 2035. The regulation has been negotiated for a couple of years and the industry has known what changes were coming. Many producers of heat pumps have therefore already started the development of new, low-charge systems with propane as refrigerant. One example is the Spanish company EcoForest which offers liquid to water propane heat pumps with capacities from 6 to 16 kW. The 6 kW unit has a charge of 150 g of propane. The larger units have about 500 g. The larger units are built to comply with the IEC 60335-2-40:2022, having a tight enclosure which is ventilated to the ambient in case of a leakage inside the enclosure. At least one other company has already a propane unit for placing indoors on the market. Air to water units are usually placed outside and the use of propane is thereby not restricted. Statistics of the applications for government support for heat pump installations in Germany indicate that the share of propane heat pumps was above 20% already in 2022. It is thus clear that the F-gas regulation, and the concerns for the environment connected to the use of HFC and HFO refrigerants is having a direct impact on the type of refrigerant used in heat pumps in Europe. The development may be similar to that of the household refrigerator market, where isobutane systems completely forced the CFC and HFC systems out of the market in a few years. The effect of this regulation is thus larger than any research result or technical invention.

Regarding the research done in Sweden during the cause of the Annex, two projects should be mentioned in particular, EcoPack and Propac. Highlights from these two are described more in detail below.

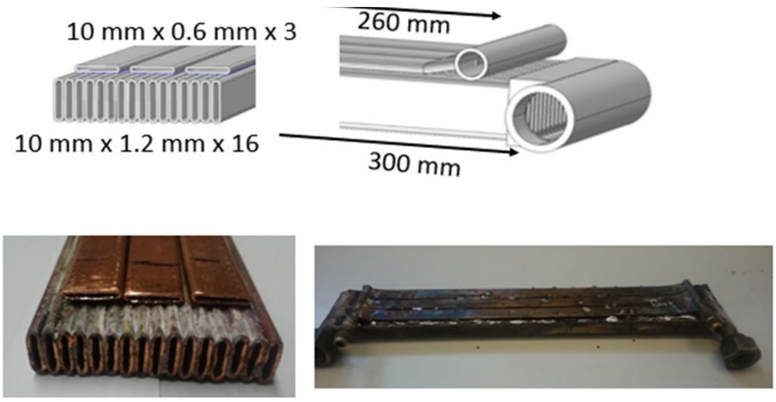

Figure 15: Design of internal heat exchanger prototype [15]

In the EcoPack project it was demonstrated that a heat pump with a heating capacity of 12 kW could be designed to use only 120 g of isobutane as refrigerant [15], [16]. We believe this may the lowest charge per capacity ever recorded, or at least on par with previous records. This was reached with a good thermal performance in terms of COPs. The low charge was achieved by using asymmetric plate heat exchangers with low pressing depths as evaporator and condenser and a rotary compressor with small internal volume and extremely low oil charge. The compressor was of a type normally used for air conditioning of electric vehicles. A prototype desuperheater was used to achieve better performance of the system even though this increased the charge slightly. Figure 15 shows drawings and pictures of this heat exchanger.

Figure 16: Compressor, Sanden SHS33, used in EcoPack and ProPac projects

The project called ProPac investigated the possibility of designing a split AC unit with 3,5 kW cooling capacity with less than 150g of propane [18]. This project partly built on the experiences of EcoPack described above, and the same compressor was used, see Figure 16. A major challenge in this case was the design of the air coil evaporator and condenser. To reduce charge, multiport flat aluminium tubes were used, but the volume of the headers still was a problem, as indicated in Figure 17. Several solutions were investigated, but inevitably these heat exchangers required larger charge of refrigerant than the plate heat exchangers used in the EcoPack project. Within the project, a new prototype subcooler was also produced, see Figure 17, based on the first prototype shown in Figure 15. With a connecting tubing of 6 m between the indoor and outdoor unit, the system could run with only 147g of propane, which may be a record for this type of system.

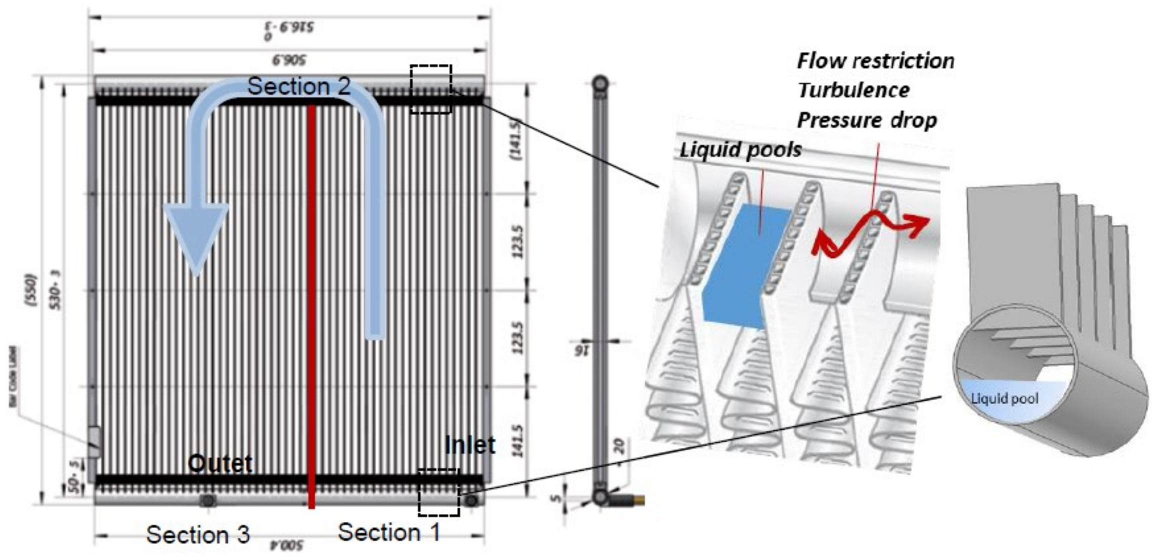

Figure 17: One of several condenser designs tested in ProPac.

Figure 18: Prototype internal heat exchanger, design based on the experiences from the one shown in Figure 15.

Finally it should be stated that the market investigations done by RISE, and presented in chapter 3 of this report as well as by the Swedish refrigeration and heat pump association, presented in chapter 1.4, clearly show that the interest for low-GWP refrigerants, and in particular natural refrigerants has increased substantially during the four years of the Annex 54.

5 Suggestions for tasks for follow-up Annex

From a European perspective it is quite obvious that the market will be forced to use low-GWP refrigerants within the coming ten-year period. This is the result of the new F-gas regulation which will force a fast phase down and then a slow phase out of HFC-refrigerants. This regulation will also prohibit the use of any F-gases, including HFOs, in systems with capacities below 12 kW, which is the majority of the consumer market. The industry has been complaining about this “fast” change to flammable refrigerants, and there is therefore a need for support in terms of research to realize this change.

Independently if HFOs or natural fluids are used, the future refrigerants for normal temperature ranges will be flammable (with the exception of CO_2). For this reason, safety aspects will be an interesting area for continued research. This is also specifically the target for the newly started Annex 64. Mentioning tasks for future research will therefore include some topics covered by that Annex. Some topics we think may be interesting for the future are the following:

- Compressor designs for low charge
- Heat exchanger designs for low charge
- Selection of oil for low-charge systems
- Methods of mitigating risks in case of leakages

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