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DECARBONISATION THROUGH INNOVATION

Development of refrigeration and air-conditioning technologies for practical use of next-generation low-global warming potential refrigerants

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Abstract

The Kigali Amendment to the Montreal Protocol and Japan's Act on Rational Use and Appropriate Management of Fluorocarbons call for an accelerated transition to next-generation refrigerants with low global warming potential (GWP). However, many low-GWP refrigerants are flammable, and their safe handling involves significant technical and social costs. To address these challenges, Japan aims to develop refrigerants that combine sufficiently low GWP, low flammability (A2L classification), and high energy efficiency.
Supported by the New Energy and Industrial Technology Development Organization (NEDO), a national R&D program entitled Development of Refrigeration and Air-Conditioning Technologies for Practical Use of Next-Generation Low-GWP Refrigerants (JPNP23001) was launched in 2023. This five-year project involves collaboration among universities, national laboratories, and industry partners. The program integrates four parallel research themes: (1) screening and characterization of low-GWP refrigerant blends, (2) evaluation and mitigation of chemical instability and self-decomposition risks, (3) development of key components and materials to maintain high system performance, and (4) establishment of performance evaluation methods and safety standards.
Through these activities, the project aims to accelerate the safe commercialization and international standardization of low-GWP refrigerants for air-conditioning and refrigeration systems, contributing to global decarbonization efforts and the sustainable growth of the HVAC industry.

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Keywords: Low-GWP refrigerant; National Project; HFO refrigerants

1. Introduction

Hydrofluorocarbons (HFCs), developed as replacements for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) to eliminate ozone-depletion risks, are now widely used as refrigerants in air-conditioning and refrigeration systems and as foaming agents. However, as this transition has progressed, both the consumption and emissions of HFCs have continued to rise. Although HFCs were identified as greenhouse gases subject to control under the Paris Agreement, their long atmospheric lifetimes and high global warming potential (GWP) have led to significant environmental concerns.

To address this issue, at the 28th Meeting of the Parties to the Montreal Protocol (MOP28) held in Kigali, Rwanda in October 2016, the Kigali Amendment, which mandates that developed countries reduce HFC production and consumption by 85% from the 2011-2013 average by 2036, was adopted. This ambitious goal cannot be achieved if the use of existing high-GWP refrigerants continues. Consequently, there is an urgent need to develop refrigerants that exhibit minimal global warming impact while remaining compatible with existing refrigeration and air-conditioning technologies—in other words, "next-generation refrigerants."

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Beyond national efforts, several large-scale international programs have been established to accelerate the transition to low-GWP refrigerants. For instance, the Air-Conditioning, Heating, and Refrigeration Institute's (AHRI) Low-GWP Alternative Refrigerants Evaluation Program (AREP) has included extensive compressor and system drop-in testing across major equipment categories in North America, providing key benchmarks for candidate fluid selection and industry readiness [1]. Meanwhile, under the IEA Heat Pumping Technologies Technology Collaboration Programme (HPT TCP), Annex 54: Heat Pump Systems with Low-GWP Refrigerants has brought together multiple countries to review the state of the art in low-GWP heat pump systems, optimize system design, and evaluate the life-cycle climate performance of heat pumps using low-GWP working fluids [2]. These international initiatives provide valuable frameworks and design guidance for the global development of next-generation low-GWP refrigerant systems.

In Japan, HFCs account for more than 90% of non-CO_2 greenhouse gas emissions. Fig. 1 shows the emission trends of the four major fluorinated greenhouse gases—HFCs, perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)—in Japan [3]. While emissions of PFCs, SF_6, and NF_3 have declined substantially in recent years, HFC emissions remain high. Approximately 83% of HFC emissions originate from refrigeration and air-conditioning equipment, and only about 13% of the refrigerant charged into such systems is recovered at the end of use. Given the difficulty of recovery and recycling, reducing the GWP of working fluids is an essential mitigation measure. However, candidate next-generation refrigerants face major technological challenges if they are to achieve performance comparable to existing HFC-based systems and are often hindered by flammability or chemical instability.

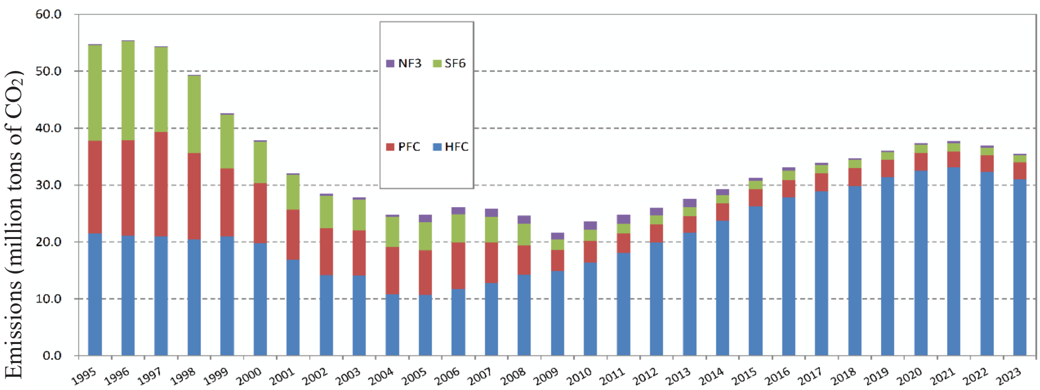


Fig. 1. Annual emissions of four greenhouse gases (HFC, PFC, SF6, NF3) in Japan

In response to this situation, the New Energy and Industrial Technology Development Organization (NEDO), supported by the Ministry of Economy, Trade and Industry, launched a five-year national R&D program in fiscal year 2023 entitled Development of Refrigeration and Air-Conditioning Technologies for Practical Use of Next-Generation Low-GWP Refrigerants. The program aims to clarify the thermophysical properties of promising refrigerants, establish reliable evaluation methods for their flammability and thermal stability, and formulate domestic and international safety standards. Through these activities, it seeks to lay the scientific and technical foundation for energy-efficient air-conditioning and refrigeration systems using next-generation refrigerants for both commercial and residential applications.

Developing environmentally friendly refrigerants for room and packaged air conditioners is particularly important, since the currently dominant refrigerant, R-32, with a GWP of approximately 675, will not satisfy the long-term Kigali reduction targets. Therefore, this project focuses on developing refrigerants capable of replacing R-32 and R-404A while meeting multiple constraints: GWP < 150, low flammability (A2L class), system performance equivalent to that of existing equipment, and excellent chemical stability. These efforts are expected to accelerate the global transition to low-GWP technologies in the air-conditioning industry. This paper outlines the structure and research framework of the NEDO project launched in 2023 to address these challenges.

2. Refrigerants under development in the NEDO project

Refrigerants with low global warming potential and high safety have long been sought as promising candidates for next-generation refrigerants, but none have been put to practical use. Therefore, the NEDO project focuses on R-1132(E) and HFO-1123, both of which are obtained by replacing hydrogen atoms in ethylene with fluorine. The properties of these substances are shown in Table 1. These compounds belong to the family of hydrofluoroolefins (HFOs) characterized by a carbon–carbon double bond. However, such unsaturated fluorinated compounds are known to exhibit a tendency for self-decomposition under high-temperature and high-pressure conditions, which has so far prevented their practical application due to potential safety risks.

The self-decomposition of these refrigerants can occur even in an oxygen-free environment, as illustrated in Eq. (1) and (2).

For HFO-1123: $2CF_2 = CHF \rightarrow CF_4 + 3C + 2HF$ (1)

For R-1132(E): $CHF = CHF \rightarrow 2C + 2HF$ (2)

These reactions are strongly exothermic and can proceed even in the absence of oxygen, producing carbon and hydrogen fluoride as byproducts under high-temperature, high-pressure conditions.

Table 1. Thermodynamic properties of low-GWP refrigerants

Refrigerant	HFO-1123	R-1132(E)
Formula	$CHF=CF_2$	trans-CHF=CHF
Critical Temperature [°C]	58.6	75.7
Critical Pressure [MPa]	4.54	5.17
Boiling Point [°C]	-59.1	-52.6
Lower Flammability Limit [vol%]	6.3	4.4
Burning Velocity [cm・s-1]	6.5	30.5
Safety Class	-	A2

Fig. 2 shows a conceptual diagram of self-decomposition pathways of HFOs. The diagram illustrates the two principal modes of self-decomposition: disproportionation occurring at moderate temperatures, and thermal dissociation occurring under high-temperature or discharge conditions. The boundary line represents the transition from disproportionation to complete thermal decomposition. In the event of a malfunction inside the compressor, the HFO refrigerant may become hot and pressurized, potentially leading to an electrical short and discharge that could trigger self-decomposition. The reaction reaches temperatures exceeding 1000°C, causing thermal dissociation.

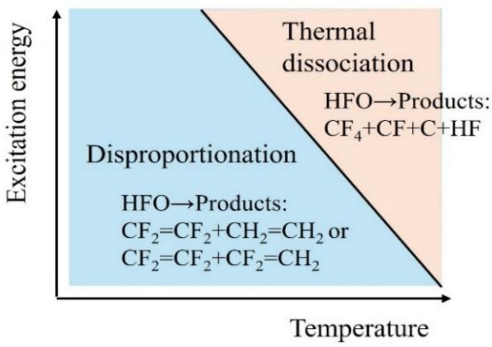
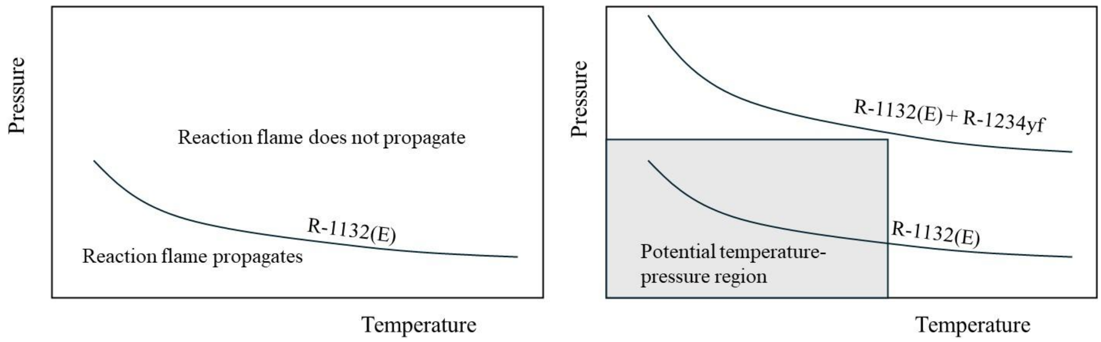


Fig. 2. Self-decomposition pathways of HFOs

Because the reaction is highly exothermic, any ignition within a compressor could promote flame propagation, possibly leading to catastrophic failures such as casing rupture. To suppress this phenomenon, an inert or stabilizing component must be blended with the refrigerant to absorb or neutralize reactive intermediates. Among the potential inhibitors investigated, R-1234yf and R-32 have been identified as promising candidates, provided that the resulting mixtures also satisfy the above criteria.

Fig. 3(a) illustrates a schematic pressure–temperature diagram showing the boundary conditions under which the self-decomposition reaction of R-1132(E) propagates. As temperature and pressure increase, the decomposition flame can propagate more readily. Above the boundary line, the reaction becomes self-sustaining and poses a potential hazard, whereas below this line, propagation is suppressed and the refrigerant remains stable. Fig. 3(b) shows, in gray shading, the typical operating pressure and temperature range encountered in refrigeration and air-conditioning systems. The stability boundary of pure R-1132(E) lies within this region, suggesting that auto-decomposition may occur under certain high-temperature, high-pressure conditions during equipment operation. When R-1234yf is added as a reaction inhibitor, the boundary shifts toward higher temperatures and pressures, thereby expanding the safe operating range. If the stability boundary of the R-1132(E)/R-1234yf mixture lies completely outside the gray-shaded region, the refrigerant can be considered thermally stable under normal system conditions.

The thermophysical and environmental properties of internationally registered R-1132(E)-based mixtures are summarized in Table 2 [4]. R-474 represents mixtures of R-1132(E) with R-1234yf, whereas R-479 additionally includes R-32. The inclusion of R-32 enhances system performance but increases the global warming potential.



(a) R-1132(E) (b) R-1132(E) / R-1234yf

Fig. 3. Propagation boundary of the self-decomposition flame for the R-1132(E)/R-1234yf mixture

Table 2. Thermophysical and environmental properties of R-1132(E) mixtures

Refrigerant		R-474A	R-474B	R-479A	R-479B
Composition	R-1132(E) [mass%]	23	31.5	28	23
	R-1234yf [mass%]	77	68.5	50.5	33
	R-32 [mass%]	-	-	21.5	44
Physical Property	Boiling Point [°C]	-43.4	-45.8	-50.5	-51.9
	Critical Temp. [°C]	87.8	85.2	80.5	78.1
	Critical Pres. [MPa]	4.05	4.22	4.81	5.23
GWP(AR4)		< 1	< 1	147	299
Safety Class		A2L	A2L	A2L	A2L

3. Basic performance of low-GWP refrigerant mixtures

Because non-azeotropic refrigerant mixtures exhibit temperature glide, cycle performance may be reduced compared with that of pure refrigerants. Therefore, the thermodynamic performance was calculated using REFPROP Version 10. The calculation conditions are as follows. The representative temperature of the evaporator is 5°C, and the pressure is assumed to be isobaric, with a superheat of 5°C. To account for heat-exchanger performance degradation due to temperature glide, the evaporator pressure is defined as $P_e = (1 - \alpha) P_b + \alpha P_d$ where P_b and P_d are the bubble-point and dew-point pressures at 5°C.

The representative condenser temperature is 40°C, the pressure is assumed to be isobaric, and the subcooling is set to 5°C. The condenser pressure is defined as $P_c = \beta P_b + (1 - \beta) P_d$. The adiabatic efficiency of the compression process is assumed to be 0.75.

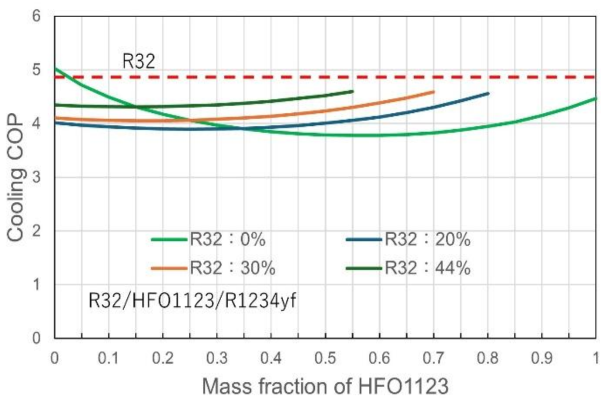


Fig.4. Cooling COP of R-32/1123/1234yf mixture

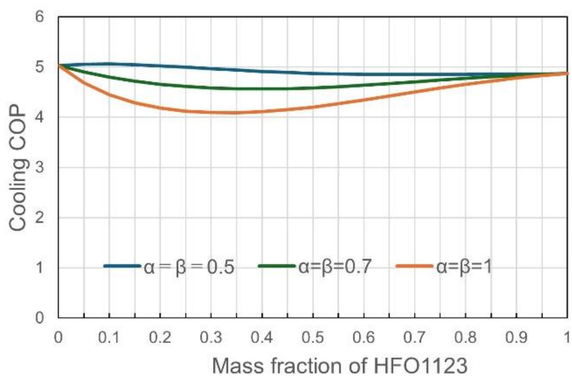


Fig.5. Effect of pressure on cooling COP of HFO-1123/1234yf mixture

Setting $\alpha = \beta = 0.5$ neglects the heat-exchanger performance degradation due to temperature glide, whereas setting $\alpha = \beta = 1$ represents the maximum degradation. Fig. 4 shows the cooling COP of the HFO-1123/1234yf/32 system assuming $\alpha = \beta = 1$. Since the GWP is governed by the R-32 concentration, the R-32 mass fraction is fixed at 0, 20, 30, or 44 %. At 0% R-32, the COP of the binary HFO-1123/1234yf mixture is significantly lower than that of pure refrigerants, and this reduction is mitigated by adding R-32. Fig. 5 shows the simulated improvement in heat-exchanger performance for the HFO-1123/1234yf system as α and β are reduced from 1 to 0.5. The COP increases significantly owing to the improved heat-exchanger performance.

4. Overview of the NEDO project

Fig. 6 presents a conceptual diagram showing the relationship between system performance and mixture composition for R-1132(E)-based refrigerants. The qualitative trend shown in Fig. 6 is derived from the thermodynamic performance calculations presented in Section 3, particularly the COP dependence on refrigerant composition and temperature glide effects. The horizontal axis represents the mixing ratio of R-1234yf and R-1132(E). Although blending R-32 can partially recover performance, the overall efficiency remains lower than that of pure R-32. To achieve system performance equivalent to current R-32-based equipment, improvements in component technologies, particularly heat exchangers and compressors, are required.

The NEDO project is organized into four research and development groups, each addressing specific technical challenges associated with R-1132(E) and HFO-1123 mixtures and promoting their safe deployment internationally. The main research areas are as follows:

- To measure the thermophysical properties of refrigerant mixtures and enable highly accurate thermodynamic calculations using property databases such as REFPROP.
- To clarify the conditions under which self-decomposition reactions occur in low-GWP refrigerants and develop suppression methods.
- To develop key component technologies that maintain high system performance when using low-GWP refrigerant mixtures.
- To establish system-level performance evaluation and Life Cycle Climate Performance (LCCP) assessment methods.

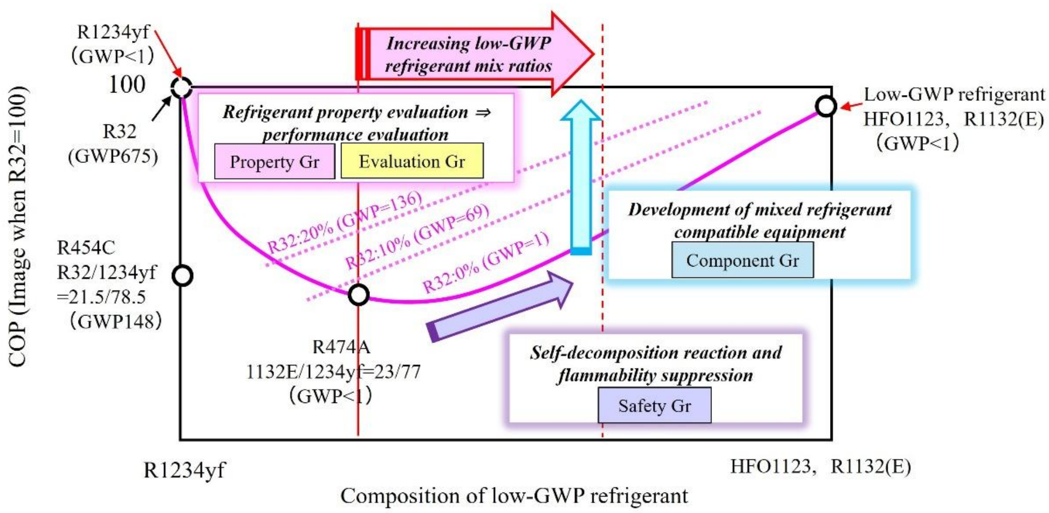


Fig. 6. Conceptual relationship between refrigerant composition and system performance

4.1. Group for Refrigerant Property Evaluation

The Group for Refrigerant Property Evaluation, comprising Kyushu University, Kyushu Sangyo University, Nagasaki University, the National Institute of Advanced Industrial Science and Technology (AIST), and AIZOTH Inc., measures the thermophysical properties of candidate refrigerants, formulates equations of state, and provides verified data for implementation in NIST's REFPROP database. In addition to determining flammability limits and burning velocities, the group investigates mixing rules that describe the behavior of refrigerant blends. By evaluating the overall environmental impact throughout the life cycle, the group identifies and refines promising compositions for next-generation refrigerants.

4.2. Group for Equipment Component Technologies

The Group for Equipment Component Technologies includes Saga University, Kobe University, Tokyo University of Marine Science and Technology, UACJ Corporation, Shizuoka University, Osaka Electro-Communication University, and Advanced Composite Corporation. The group develops technology to suppress heat transfer deterioration of mixed refrigerants and high-performance heat exchangers. They are clarifying the refrigerant dissolution behavior in compressors and developing lightweight composite materials suitable for compressor parts.

4.3. Group for Safety Evaluation

The Group for Safety Evaluation, comprising the Central Research Institute of Electric Power Industry, Suwa University of Science, AGC Inc., and Daikin Industries, aims to incorporate stability-assessment methods into international safety standards such as ISO 817. The group investigates testing procedures for self-decomposition reactions and conducts risk assessments of actual air-conditioning and refrigeration systems, including the possibility of dielectric discharges under high-temperature and high-pressure compressor conditions. The outcomes will support the establishment of reliable safety criteria for next-generation refrigerants.

4.4. Group for System Performance Evaluation

The Group for System Performance Evaluation, made up of Waseda University and the University of Electro-Communications, develops a comprehensive simulation platform to predict system performance using various low-GWP refrigerants. This simulator enables LCCP analysis of newly proposed refrigerant compositions and helps identify the most promising candidates for practical implementation.

5. Conclusions and future developments

To achieve the HFC reduction targets set by the Kigali Amendment to the Montreal Protocol (adopted at MOP28) and the emission reduction goals of the Paris Agreement, NEDO is implementing research and development programs in alignment with both domestic and international policy trends.

The GWP level required for next-generation refrigerants in air-conditioning applications by 2034 will largely depend on future progress in the recovery and recycling of refrigerants from discarded equipment. Accordingly, this program is developing refrigerants with ultra-low (GWP < 10) and low (GWP < 150) values to flexibly meet these evolving societal and regulatory needs.

The current five-year program will conclude in March 2028, after which samples of the developed low-GWP refrigerants will be distributed to equipment manufacturers. Subsequent stages will involve the design of mass-production systems and the development of manufacturing technologies. If these refrigerants are internationally recognized as next-generation alternatives, large-scale production is expected to commence around 2030, leading to the widespread adoption of air-conditioning systems using these new refrigerants.

Through these initiatives, NEDO aims to accelerate the global transition toward safer, more energy-efficient, and lower-GWP refrigerants, thereby contributing to the realization of a sustainable, decarbonized society.

References

[1] Air-Conditioning, Heating, and Refrigeration Institute (AHRI). *Low-GWP Alternative Refrigerants Evaluation Program (AREP): Final Report.* AHRI, Arlington, VA, USA, 2019.

[2] IEA Heat Pumping Technologies Technology Collaboration Programme (HPT TCP). *Annex 54: Heat Pump Systems with Low-GWP Refrigerants — Annual Report 2021.* Heat Pump Centre, Sweden, 2022.

[3] Ministry of Economy, Trade and Industry (METI). *19th Industrial Structure Council, Manufacturing Industry Committee, Subcommittee on Chemical Substance Policy, Working Group on Fluorocarbon Countermeasures – Meeting Materials.* March 22, 2024. (in Japanese)

[4] Information provided by Daikin Industries.