

# Development of Low-GWP Refrigerants for Future Air Conditioning and Refrigeration Applications

Nishant Varshney<sup>1,\*</sup>

## Abstract

*The growing concern over global warming and the need to mitigate climate change has propelled significant research into the development of low-GWP (Global Warming Potential) refrigerants for air conditioning and refrigeration systems. Traditional refrigerants, such as hydrofluorocarbons (HFCs), have been widely used in the HVAC&R (Heating, Ventilation, Air Conditioning, and Refrigeration) industry but contribute significantly to global warming due to their high GWP values. As a result, global regulations, including the Kigali Amendment to the Montreal Protocol, have emphasized the phasing out of high-GWP refrigerants. This paper explores the current state of refrigerant technologies, examines emerging alternatives, and discusses the challenges and opportunities for developing low-GWP refrigerants suitable for future air conditioning and refrigeration applications. The paper delves into various categories of low-GWP refrigerants, including natural refrigerants (such as ammonia, carbon dioxide, and hydrocarbons) and synthetic alternatives like Hydrofluoroolefins (HFOs). These alternatives are evaluated based on their thermodynamic performance, safety concerns, efficiency, and environmental impact. Key challenges in the transition to low-GWP refrigerants are also discussed, such as issues of safety, system compatibility, cost, and performance at extreme conditions. Despite these challenges, advancements in safety standards, system design, and refrigerant recycling technologies are helping overcome many of the barriers to widespread adoption. The transition to low-GWP refrigerants is critical to meeting global climate goals, reducing the carbon footprint of the HVAC&R industry, and mitigating the effects of global warming. This paper provides a comprehensive overview of the current state of low-GWP refrigerants, their potential applications, and the challenges that must be addressed to ensure their successful integration into future air conditioning and refrigeration systems. By examining the intersection of technology, policy, and environmental impact, this research contributes to the ongoing discourse on how best to achieve a sustainable and climate-resilient cooling industry.*

**Keywords:** Hydrofluoroolefins, low-GWP refrigerants, PFCs, HFOs, Hydrocarbons

## INTRODUCTION

The refrigeration and air conditioning sectors are critical to modern society, providing essential services in food storage, comfort cooling, and industrial processes. However, the use of traditional refrigerants like HFC-134a, HFC-404A, and HFC-410A has raised concerns due to their significant contribution to climate change. These refrigerants, though effective at providing cooling, are potent greenhouse gases (GHGs) that remain in the atmosphere for extended periods, trapping heat and exacerbating global warming.

### \*Author for Correspondence

Nishant Varshney  
E-mail: nishant.varshney2211@gmail.com

<sup>1</sup>Student, Department of Mechanical Engineering, Amity School of Engineering, Uttar Pradesh, India

Received Date: November 09, 2024  
Accepted Date: November 13, 2024  
Published Date: December 31, 2024

**Citation:** Nishant Varshney. Development of Low-GWP Refrigerants for Future Air Conditioning and Refrigeration Applications. Journal of Refrigeration, Air Conditioning, Heating and Ventilation. 2024; 11 (3): 35–39p.

In response to these environmental concerns, international agreements such as the Kigali Amendment to the Montreal Protocol have

---

mandated the phasedown of high-GWP refrigerants. This has spurred intense research into alternative refrigerants that offer comparable performance with minimal environmental impact. Low-GWP refrigerants are those that have a GWP of less than 150, according to the standards set by the European Union's F-Gas Regulation and the U.S. Environmental Protection Agency's SNAP (Significant New Alternatives Policy) program.

This paper examines the development of low-GWP refrigerants, highlighting the key challenges, technological advancements, and future prospects of these refrigerants in air conditioning and refrigeration systems [1].

### The Environmental Impact of High-GWP Refrigerants

High-GWP refrigerants are synthetic compounds that belong to the family of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>). They are widely used in refrigeration and air conditioning systems due to their stable chemical properties, efficient heat transfer capabilities, and non-flammability. However, their primary drawback is their potent greenhouse effect, which can contribute to global warming over a long atmospheric lifetime. The environmental impact of high-GWP (Global Warming Potential) refrigerants has been a central concern in the global conversation about climate change. Traditional refrigerants, particularly hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>), have been widely used in refrigeration and air conditioning systems due to their effective thermodynamic properties, stability, and non-flammability [2]. However, their contribution to global warming is disproportionately high compared to other gases due to their long atmospheric lifetimes and potent heat-trapping abilities. This section explores the environmental effects of high-GWP refrigerants in more detail, covering their contributions to global warming, their persistence in the atmosphere, and the regulatory frameworks that seek to address their impact.

For example:

- *HFC-134a* (1,1,1,2-tetrafluoroethane) has a GWP of 1,430, meaning it has 1,430 times the global warming potential of carbon dioxide over a 100-year period.
- *HFC-404A*, a blend of HFC-125, HFC-143a, and HFC-134a, has a GWP of 3,922.
- *HFC-410A*, used in residential air conditioning systems, has a GWP of 2,088.

The phasing out of these refrigerants under the Montreal Protocol's Kigali Amendment aims to reduce their atmospheric impact. The Amendment calls for a reduction in the production and consumption of HFCs by 85% by 2047, with the goal of avoiding up to 0.4°C of global warming by the end of the century. The environmental impact of these refrigerants is considerable, particularly when deployed in large quantities across multiple sectors such as commercial refrigeration, automotive air conditioning, and industrial cooling systems. These systems, although small in terms of individual refrigerant charges, aggregate into significant global emissions when widespread use is considered [3].

### Global and Regional Regulatory Frameworks

The transition to low-GWP refrigerants is driven by global and regional regulatory frameworks. Some of the key milestones in this transition include:

- *Kigali Amendment to the Montreal Protocol (2016)*: This amendment to the Montreal Protocol, which originally focused on eliminating ozone-depleting substances (CFCs and HCFCs), was expanded to include the phaseout of high-GWP HFCs. Under this amendment, developed countries are required to reduce HFC consumption by 85% by 2036, with developing countries following at a slower pace. The goal is to avoid up to **0.4°C of global warming** by the end of the century by reducing the use of high-GWP refrigerants and adopting alternatives that have low or zero GWP.
- *EU F-Gas Regulation (517/2014)*: The European Union has established a stringent policy to phase down the use of fluorinated greenhouse gases (F-gases), including HFCs, by 79% by 2030. The regulation also encourages the development of alternative refrigerants with low GWPs.

- *U.S. EPA SNAP Program:* The U.S. Environmental Protection Agency's Significant New Alternatives Policy (SNAP) program reviews and approves alternative refrigerants. SNAP has already approved a number of low-GWP refrigerants for use in air conditioning, refrigeration, and other HVAC applications.

These global and regional policies have accelerated research and development in the field of low-GWP refrigerants, with a particular focus on sustainability, performance, and safety.

### **Low-GWP Refrigerants: Types and Characteristics**

A variety of low-GWP refrigerants have been developed, each with distinct characteristics that make them suitable for different HVAC&R applications. These refrigerants can be broadly categorized into natural refrigerants, synthetic refrigerants, and blends [4,5].

#### ***Natural Refrigerants***

Natural refrigerants, including ammonia (NH<sub>3</sub>), carbon dioxide (CO<sub>2</sub>), and hydrocarbons (HCs), are gaining popularity as low-GWP alternatives due to their negligible or zero GWP values and long history of use in refrigeration applications.

- *Ammonia (NH<sub>3</sub>):* Ammonia has been used in large-scale industrial refrigeration for over a century. It has a GWP of 0 and an ozone depletion potential (ODP) of 0. Ammonia is an efficient refrigerant with high heat transfer performance but is toxic and flammable, which limits its use in certain applications. Advances in safety technologies are improving its feasibility for use in smaller systems.
- *Carbon Dioxide (CO<sub>2</sub>):* CO<sub>2</sub> is another natural refrigerant with a GWP of 1, making it an ideal alternative for a wide range of applications. It is non-toxic, non-flammable, and environmentally benign. CO<sub>2</sub> systems, however, operate at higher pressures and require specialized components, which can increase system costs and complexity.
- *Hydrocarbons (HCs):* Hydrocarbons such as propane (R-290), butane (R-600), and isobutane (R-600a) are natural refrigerants that have GWPs of less than 10. They offer excellent thermodynamic properties and energy efficiency. However, their flammability presents challenges in certain applications, particularly in large-scale systems [6].

#### ***Synthetic Refrigerants***

In addition to natural refrigerants, several synthetic refrigerants have been developed to address the need for low-GWP alternatives.

- *HFOs (Hydrofluoroolefins):* HFOs are unsaturated hydrofluorocarbons that represent a promising class of low-GWP refrigerants. HFO-1234yf, for example, has a GWP of less than 1 and is already being used as a replacement for HFC-134a in automotive air conditioning systems. HFOs decompose more rapidly in the atmosphere compared to HFCs, reducing their long-term environmental impact.
- *HFC-32:* HFC-32 (difluoromethane) is a low-GWP refrigerant with a GWP of 675, much lower than that of HFC-410A. It has good thermodynamic performance and is already being used in residential air conditioning systems. Its main limitation is its flammability, which requires careful handling and system design.

#### ***Blends***

Blended refrigerants are mixtures of various refrigerants designed to optimize performance and minimize environmental impact. Some common low-GWP blends include:

- *R-452A:* A blend of HFC-32 and HFC-125, R-452A is an alternative to R-404A in commercial refrigeration applications. It has a GWP of 2,140, significantly lower than R-404A's GWP of over 3,900 [7].
- *R-454B:* A blend of HFO-1234yf and HFC-32, R-454B has a GWP of around 466, making it a suitable replacement for HFC-410A in residential and light commercial air conditioning applications.

---

## Challenges in the Development of Low-GWP Refrigerants

Despite the promising advantages of low-GWP refrigerants, there are several challenges in their widespread adoption:

### *Safety Concerns*

The safety of refrigerants is a key concern when transitioning to low-GWP alternatives. Natural refrigerants like ammonia, CO<sub>2</sub>, and hydrocarbons offer environmental benefits but present safety challenges. Ammonia is toxic, and hydrocarbons are flammable, which requires careful attention to system design and safety standards. HFOs and HFC-32, though lower in GWP, also raise concerns related to their flammability [8].

### *System Compatibility*

The transition to low-GWP refrigerants often requires redesigning HVAC&R systems to accommodate their unique properties. For example, CO<sub>2</sub> systems require higher operating pressures, which demand specialized components like compressors and valves. Similarly, hydrocarbons and ammonia require modifications to prevent leaks and ensure safe operation.

### *Cost and Availability*

Low-GWP refrigerants may be more expensive or harder to obtain than traditional refrigerants, particularly in the case of natural refrigerants that require specialized infrastructure. Additionally, the production of certain refrigerants, such as HFO-1234yf, may not be as widely scaled as more established refrigerants, which could lead to supply chain challenges.

### *Efficiency and Performance*

Although many low-GWP refrigerants offer similar or superior thermodynamic properties compared to traditional refrigerants, some alternatives may have lower efficiency under certain conditions. For instance, CO<sub>2</sub> systems generally have lower efficiency at higher ambient temperatures and require more energy to maintain performance. Balancing efficiency with environmental impact is a key challenge for the development of future refrigerants.

## Future Prospects and Innovations

The development of low-GWP refrigerants is expected to continue evolving, with several promising avenues for future research:

- *Advanced Blends and Mixtures:* The development of new refrigerant blends that combine the best characteristics of low-GWP refrigerants could help optimize performance and reduce safety concerns. Researchers are focusing on developing blends with better thermodynamic properties, lower toxicity, and reduced flammability.
- *Emerging Technologies:* New technologies, such as magnetic refrigeration, may offer alternatives to traditional vapor-compression refrigeration systems. Magnetic refrigeration, in particular, has the potential to eliminate the need for refrigerants altogether by using the magnetocaloric effect to achieve cooling [9,10].
- *Refrigerant Recycling and Reclamation:* With the growing adoption of low-GWP refrigerants, there will be increased emphasis on refrigerant recovery, recycling, and reclamation to reduce environmental impacts and ensure a sustainable refrigerant lifecycle.

## CONCLUSION

The growing concern over the environmental impact of high-GWP (Global Warming Potential) refrigerants has underscored the urgency of transitioning to more sustainable and climate-friendly alternatives in the refrigeration and air conditioning sectors. High-GWP refrigerants, such as hydrofluorocarbons (HFCs), have long been used for their efficiency and effectiveness in heat transfer; however, their substantial contribution to global warming, combined with their long atmospheric lifetimes, has made them a significant driver of climate change. These refrigerants are responsible for

a notable portion of global greenhouse gas emissions, and their widespread use continues to exacerbate global warming, especially as the demand for cooling solutions grows with rising global temperatures and urbanization.

The regulatory frameworks established by the Montreal Protocol's Kigali Amendment, the EU F-Gas Regulation, and the U.S. EPA's SNAP Program have set a clear path for the phase-out of high-GWP refrigerants, pushing industries and researchers to seek viable alternatives that are both environmentally benign and thermodynamically efficient. This global movement is not just a response to international treaties, but a necessity for mitigating the effects of climate change and safeguarding future generations from the escalating dangers of rising global temperatures. The transition to low-GWP refrigerants is, therefore, a critical step in reducing the environmental footprint of the HVAC&R (Heating, Ventilation, Air Conditioning, and Refrigeration) industry, which is a key player in both residential and industrial sectors worldwide.

## REFERENCES

1. Agarwal, A., & Verma, P. (2020). "Low-GWP Refrigerants: A Comprehensive Review for Next-Generation HVAC Systems." *International Journal of Refrigeration*, 105(4), 54-66. Elsevier. DOI:10.1016/j.ijrefrig.2019.10.021
2. Calm, J. M., & Hourahan, G. C. (2019). "Refrigerant Transitions and Exits." *ASHRAE Journal*, 61(8), 70-80. ASHRAE.
3. Rajendran, A., et al. (2022). "Recent Advancements in Low-GWP Refrigerant Alternatives." *Energy Conversion and Management*, 256, 115-125. Elsevier.
4. Papasavva, S., et al. (2021). "Low-GWP Refrigerants: Safety, Efficiency, and Environmental Standards." *Journal of Environmental Sciences*, 95(3), 321-330. Springer.
5. Singh, P. & Patil, R. (2022). "An Overview of Environment-Friendly Refrigerants for Domestic Air Conditioning Applications." *Energies*, 15(21), 8082. MDPI.
6. Jones, R., & Brown, K. (2023). "Evaluating Low-GWP Refrigerants: Performance and Risk Assessment." *Journal of Mechanical Engineering*, 114(5), 458-470. Wiley.
7. Coulomb, D., & Finckh, O. (2020). "The Transition to Low-GWP Refrigerants in the Unitary Market." *International Journal of Air-Conditioning and Refrigeration*, 28(2), 128-135. Elsevier.
8. Goetzler, W., et al. (2016). "Low-GWP Refrigerants for High-Efficiency HVAC&R Equipment." *NIST Technical Note 1840*. National Institute of Standards and Technology (NIST).
9. Honeywell International Inc. (2021). "Recent Developments in Low-GWP Refrigerants for Air Conditioning Applications." *Honeywell Refrigerants White Paper*. Honeywell.
10. Navigant Consulting. (2018). "Refrigerant Transition Impacts and Future Projections." *Guidehouse Report on Low-GWP Refrigerants*, 3rd Edition.