The Refrigerant Column, March 2025

Comparing the Performance of Pure Low-GWP Refrigerants

By Björn Palm

We have often discussed the EU F-gas regulation, as well as the fact that nearly all synthetic refrigerants belong to the group of **PFAS substances**. This means that in the future, almost all applications will rely on **natural refrigerants**. Europe is leading this transition, but several U.S. projects are also exploring how to minimize risks associated with flammable refrigerants.

The chemical industry has long argued that a switch to natural refrigerants would reduce system energy efficiency. In reality, both **hydrocarbons and ammonia** are excellent refrigerants, often equal to or better than synthetics. Many experimental and theoretical studies confirm this, thanks to their favorable **thermodynamic and transport properties**.

Some of the world's leading refrigerant researchers work at **NIST (U.S. National Institute of Standards and Technology)**, the organization behind **Refprop**, the program used worldwide for refrigerant property data. In a *Nature* article [1], NIST researchers presented theoretical comparisons of refrigerant performance in a small AC system. Here are some of their findings.

Screening for Candidates

In earlier studies, the team began with more than **60 million molecules**. They applied several filters:

- Molecules with more than 18 atoms were removed.
- Molecules containing "unusual" atoms (anything other than C, H, F, Cl, Br, O, N, or S) were excluded.
- Substances with **GWP above 1000** or **critical temperatures outside 47–147°C** were also removed.

This left **138 candidates**. Some were already known to be unstable or toxic and could also have been excluded.

Performance Simulations

The researchers then simulated performance for all remaining refrigerants, plus eight common ones (such as R410A) that had been excluded earlier due to high GWP. They modeled three different refrigeration cycles (Fig. 1), assuming **evaporation at +10°C** and **condensation at +40°C**—a typical AC scenario.

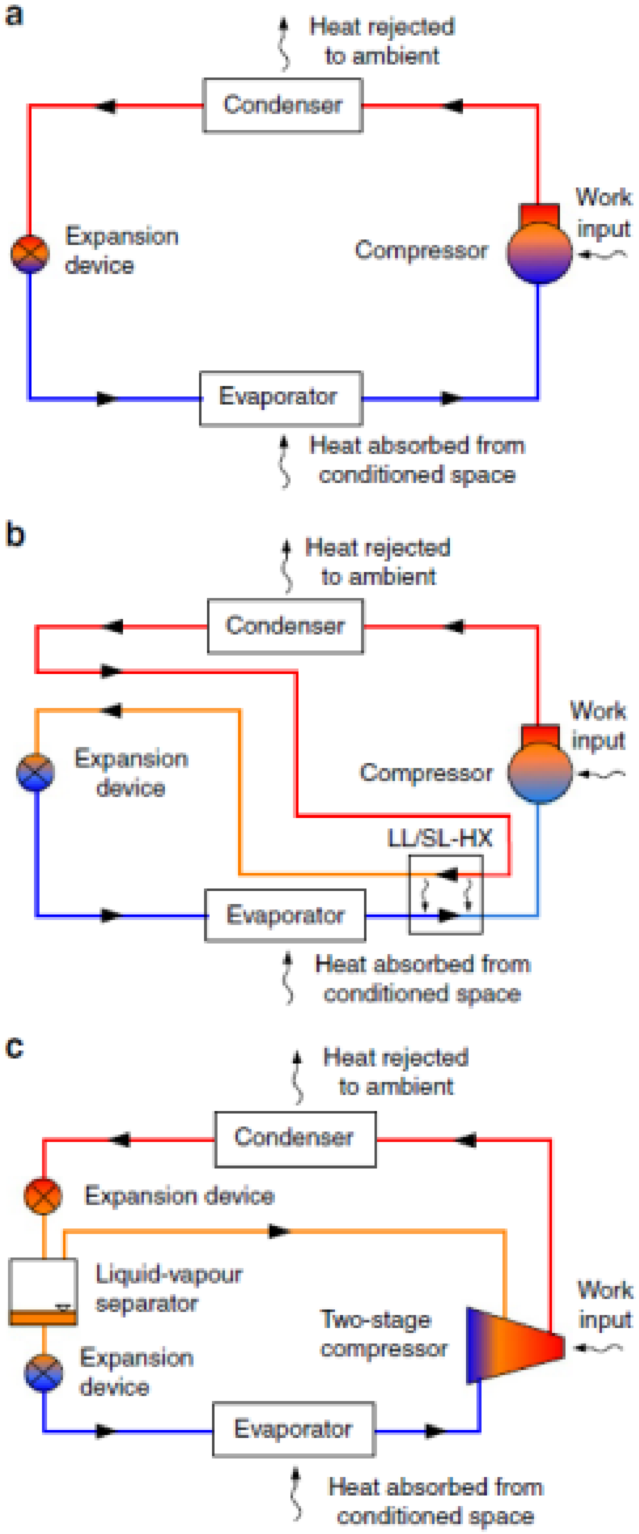

Figure 1. The three cycle types analyzed.

Results for the simple cycle (Fig. 2) were plotted as:

- **Vertical axis:** COP of an idealized process (isentropic compression, no pressure drop) relative to the Carnot COP.
- **Horizontal axis:** Volumetric cooling capacity, i.e., cooling output per m³ of refrigerant entering the compressor.

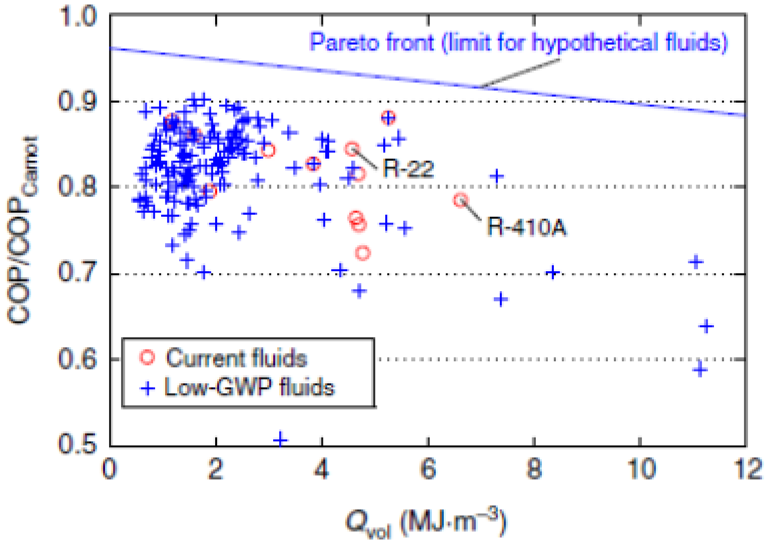

Figure 2. Performance of the simple cycle for various refrigerants.

Ideally, a refrigerant should be in the top-right corner—high COP and high volumetric capacity. The analysis showed a clear trade-off: **one can maximize either COP or volumetric capacity, but not both**. Higher volumetric capacity generally requires higher pressures, meaning **high-pressure refrigerants** appear on the right side of the diagram.

Based on these results, along with stability and toxicity criteria, the researchers selected **27 low-GWP refrigerants** for closer study. Most were already known, but a few were new to refrigerant discussions. For the comparison, **air-to-air heat exchangers** were optimized for heat transfer versus pressure drop, with the same surface area on the evaporator side for all refrigerants. Compressor efficiency was adapted to refrigerant properties, averaging 70%.

Key Findings

For the simple cycle (Fig. 3), using R410A as reference:

- **Ammonia** achieved the highest COP—**5.5% better than R410A**.
- **Propan (R290), propen (R1270), and cyclopropan (RC270)** all outperformed R410A in COP.
- **R32** (though synthetic) ranked second after ammonia. Thanks to its high pressure, it also had the **highest volumetric cooling capacity** among the well-known refrigerants.

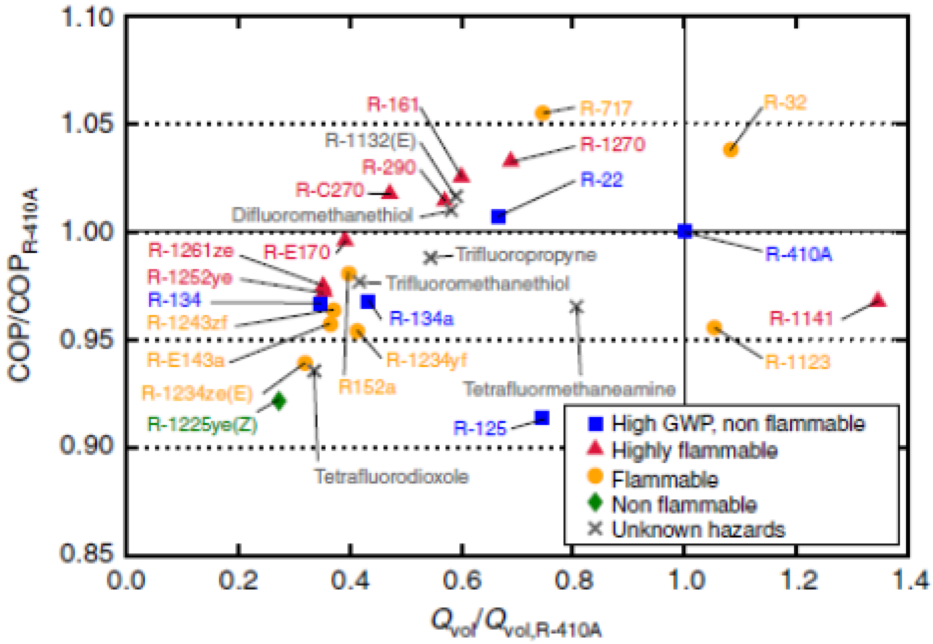

Figure 3. Results for the 27 best refrigerants in the simple cycle.

When an **internal heat exchanger** was added (cycle b in Fig. 1), results shifted (Fig. 4). Simple molecules like ammonia and R32 lost some advantage, while more complex molecules gained. **Propen (R1270) and propane (R290)** emerged as top performers in this case.

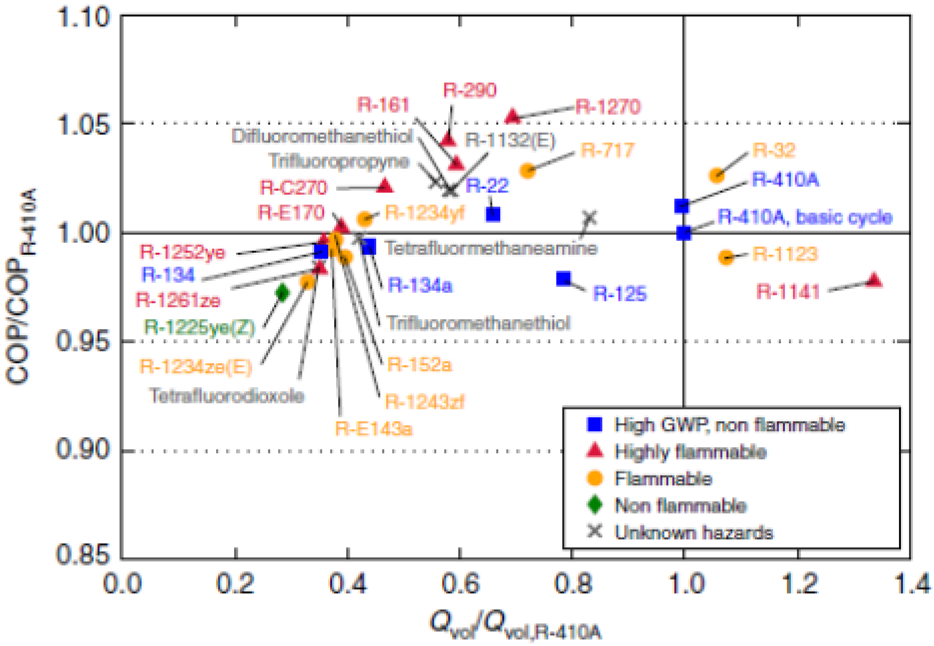

Figure 4. Results with an internal heat exchanger.

With an **economizer cycle** (cycle c in Fig. 1), COP increased for all refrigerants. Ammonia again had the highest COP, closely followed by propen and R32.

Overall, however, the differences in COP across all refrigerants were relatively small—**within about ±5% compared to R410A**, regardless of the cycle.

Safety Considerations

Among the low-GWP candidates, **all but one are flammable**. The exception is **R1225ye(Z)**, a low-pressure refrigerant that is, however, toxic at relatively low concentrations with prolonged exposure.

Conclusion

The study focused on a **small air-conditioning unit** using air as both heat source and sink. Results may vary for other applications or temperature levels, but the authors conclude that the general findings also apply to small refrigeration systems and heat pumps.

The bottom line: **natural refrigerants such as ammonia, propane, and propylene perform at least as well as synthetics**—often better. The argument that efficiency must be sacrificed when switching to natural options does not hold up under careful analysis.

Source:
Mark O. McLinden, J. Steven Brown, Riccardo Brignoli, Andrei F. Kazakov & Piotr A. Domanski, 2016. *Limited options for low-global-warming-potential refrigerants*. *Nature Communications* 8:14476. DOI: 10.1038/ncomms14476.
https://www.nature.com/articles/ncomms14476
