NOVEMBER 2023

OAK RIDGE NATIONAL LABORATORY REPORTS EXECUTIVE SUMMARY

Technology Options for Low Environmental Impact Air-Conditioning and Refrigeration Systems

Assessment of the Performance of Hydrofluoroolefins, Hydrochlorofluoroolefins, and Halogen-Free Foam Blowing Agents in Cellular Plastic Foams

OVERVIEW

Faced with increasing concerns about global warming, **Oak Ridge National Laboratory (ORNL)**, a federally funded research and development center sponsored by the U.S. Department of Energy, has assessed the role HFO technology plays in offering low global warming potential (low-GWP) alternatives for use in important commercial applications, including appliances, residential air conditioning, supermarket refrigeration systems, and spray foam insulation.

Published in August 2023 and October 2023, the two ORNL assessments take a data-driven approach to comparing and contrasting the energy efficiencies of alternative solutions. **The results confirm HFOs represent greater energy efficiency (when compared to CO_2 and propane/hydrocarbons) and less flammability (when compared to propane/hydrocarbons),** both of which represent industrially produced alternatives.

REPORT #1: LOW ENVIRONMENTAL IMPACT OPTIONS FOR AIR CONDITIONING & REFRIGERATION

In the study, "Technology Options for Low Environmental Impact Air-Conditioning and Refrigeration Systems,"[1] ORNL evaluated options for two main applications – residential air conditioning and commercial supermarket refrigeration – to explore whether innovative technologies such as HFOs can serve as long-term and sustainable replacements for legacy refrigerants.

ORNL STUDIED HFOs COMPARED TO BOTH PROPANE AND CO_2 IN APPLICATIONS ACROSS THE GLOBE

Application	System Type	Refrigerants	Climate
Air-Conditioning	US Residential AC	HFO/HFC: R455A, R454C[2]	• Phoenix (Warm) • Atlanta (Average) • Chicago (Cold)
	Rest of the World Residential AC (Multi Split AC)	HFO/HFC: R455A, R454C NIK: Propane	• Delhi (Warm) • Sao Paulo (Warm) • Shanghai (Average) • Rome (Average) • Frankfurt (Cold)
Commercial Refrigeration	Supermarket Refrigeration System	HFO/HFC: R455A, R454C NIK: Propane, CO_2	• Phoenix (Warm) • Shanghai (Average) • Atlanta (Average) • Rome (Average) • Frankfurt (Cold) • Chicago (Cold) • Oslo (Cold)

[1] https://info.ornl.gov/sites/publications/Files/Pub200582.pdf

[2] R455A and R454C are low-GWP HFO blend refrigerants, containing more than 75% HFO (1234yf)

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In its findings, ORNL outlined key issues with alternative industrial refrigerants, including:

- "Propane is a **highly flammable** refrigerant." (P. 6)
- "The **reliability of CO_2 systems** has historically been an issue. They are typically **prone to leaks** and very sensitive to charge levels." (P. 26)
- "The handling of **very high-pressure** CO_2 will require highly skilled technicians and operators." (P. 25)
- "Owing to its lower critical temperature, CO_2 **has an inherently lower thermodynamic efficiency."**[3] (P. 25)

ORNL FOUND THAT HFOs ARE SAFE FOR INTENDED USE

ORNL emphasized the findings from past reports by WMO (2022) and the UNEP EEAP (2022), which show increased confidence that **TFA produced from the breakdown of new low-GWP refrigerants will not harm the environment.**

It also highlighted that global safety standards, including IEC 60335-240, ISO 5149, and EN378, allow the safe use of HFOs for the stationary air-conditioning and refrigeration industries.

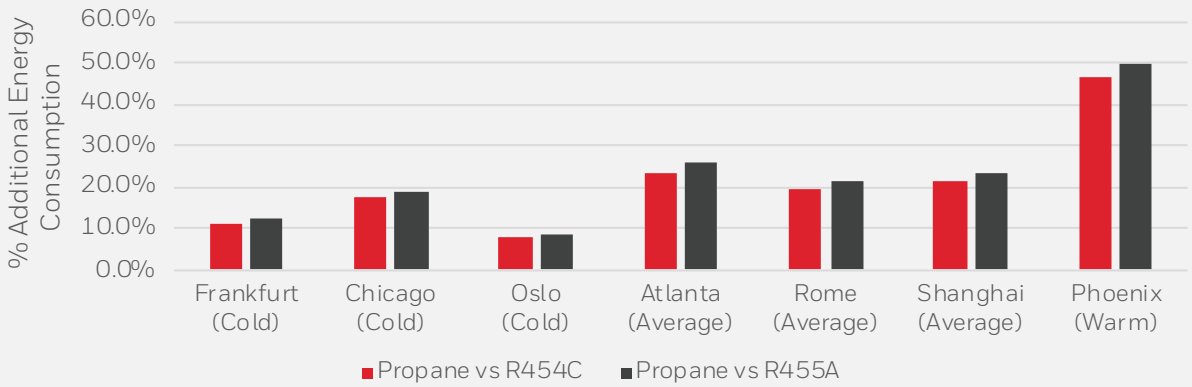
ORNL FOUND THAT HFOs ARE LOW EMISSION AND ENERGY EFFICIENT ALTERNATIVES

Researchers found that HFO mixtures **can reduce the total lifetime emissions from 2.5% to 3.8%.** If HFO blends were 100% adopted to replace refrigerants in air conditioning, the best-case scenario can r**educe total lifetime greenhouse gas (GHG) emissions by 12.4%** while maintaining the current energy consumption.

In addition, ORNL has shown that **HFO-based blends require the lowest overall energy usage** in all cities studied for commercial refrigeration.

KEY REPORT FINDING: CO_2 SYSTEMS WILL CONSUME 8% TO 50% HIGHER ENERGY VS. HFO SOLUTIONS OVER THE LIFETIME OF THE SYSTEM (15 YEARS) IN COMMERCIAL REFRIGERATION.

Commercial Refrigeration Energy Consumption for 15 years (HFO Solutions vs. CO_2)



[3] In thermodynamics, efficiency is one of the most frequently used terms to indicate how well energy is converted into useful work. Generally it is defined as the ratio of desired output to required input

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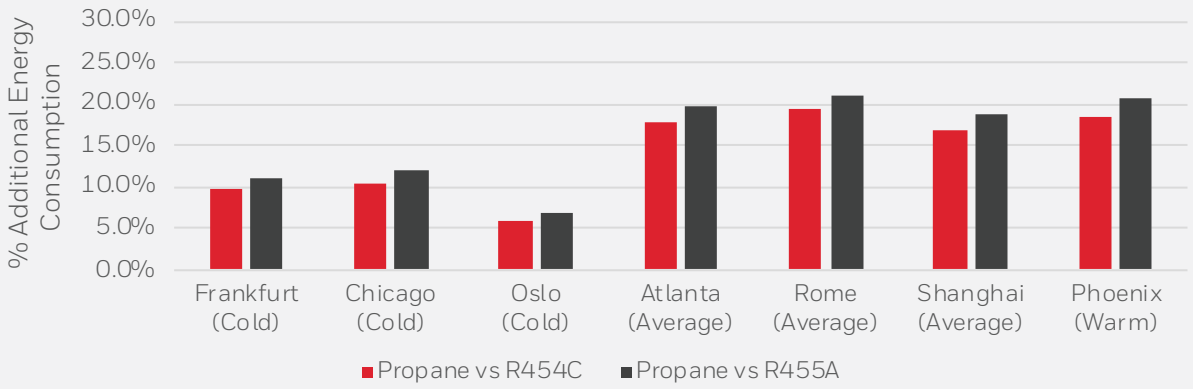
KEY REPORT FINDING: PROPANE SYSTEMS WILL CONSUME 5% TO 21% HIGHER ENERGY VS. HFO SOLUTIONS OVER THE LIFETIME OF THE SYSTEM (15 YEARS) IN COMMERCIAL REFRIGERATION.

Commercial Refrigeration Energy Consumption for 15 years (HFO Solutions vs. Propane)



REPORT #2: ASSESSMENT OF PERFORMANCE FOR SPRAY FOAM INSULATION ALTERNATIVES

In the study "Assessment of the Performance of Hydrofluoroolefins, Hydrochlorofluoroolefins, and Halogen-Free Foam Blowing Agents in Cellular Plastic Foams,"[4] ORNL conducted an extensive literature review to evaluate the publicly available data on HFOs to assess their viability and performance in spray foams, boardstocks, appliances, and panels compared to available alternatives like hydrocarbons, methylal, and CO_2. Researchers evaluated the performance attributes of HFO blowing agents to evaluate energy efficiency, as well as safety attributes to identify HFOs' flammability characteristics, ultimately concluding **HFOs can effectively replace higher GWP solutions, such as HFCs, to reduce emissions and mitigate the use of flammable and explosive materials in high-density, urban areas.**

The report confirmed that HFO technology is widely used across these applications for commercial and domestic use, with ORNL citing that HFO-based blowing agents are non-ODP, low-GWP, and **"have good thermal insulation and physical properties, which are quite important to comply with the energy efficiency standards mandated for these applications."** (P. 48)

Further findings across individual applications include:

- **High-pressure spray foam:** Low-GWP HFO-based high-pressure spray foams "provide the desired characteristics of current HFCs", including suitable boiling point, low vapor conductivity and nonflammability." (P. 3)
- **Low-pressure spray foam:** Low-GWP HFO-based low-pressure spray foams are "non-flammable, exhibit adequate compressive strength and are **compatible with spray foam processing equipment."** (P. 16)
- **Boardstock:** "HFO blowing agents are adequate alternatives for PU/PIR foam board applications as they are non-flammable and possess excellent insulation and physical properties." (P. 24)
- **Panels:** "Non-flammable HCFOs are practical when setting up manufacturing plants as they do not require safety mitigation." (P. 37)
- **Appliances (Domestic and Commercial):** "Foams produced with [HFO and HFO blend] blowing agents have good thermal insulation and physical properties, which are quite important to comply with the energy efficiency standards mandated for these applications." (P. 48)

[4] https://info.ornl.gov/sites/publications/Files/Pub200858.pdf

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SUMMARY OF ALTERNATIVE BLOWING AGENTS USED IN COMMERCIAL APPLIANCES (P. 48)

Criteria	HFOs	Hydro-carbons	Methyl Formate	Methylal	CO_2 (water)	CO^2	TDCE
Commercially adopted	Yes	Yes	Yes	Yes	Yes	No	No
Blowing agent flammability	Non-flammable	Flammable	Flammable	Flammable	Non-flammable	Non-flammable	Flammable
Foam thermal insulation performance	Excellent	Good	Fair	Fair	Poor	Unknown	Unknown
Foam physical properties	Excellent	Excellent	Fair	Fair	Good	Unknown	Unknown
Compatibility with foam processing equipment	Yes	Yes	Yes	Yes	Yes	No	Yes
Economically viable	Yes	Yes	Yes	Yes	Yes	Unknown	Yes
Environmental considerations	None	VOC by EPA	None	VOC by EPA	None	None	VOC by EPA
Safety considerations	None	Flammable	Flammable	Flammable	None	HP cylinders required	Flammmable, toxicity issues
Overall suitability as a blowing agent in this application	Suitable	Suitable	Suitable	Suitable	Suitable where low lambda is not critical	Suitable where low lambda is not critical	Suitable, but only as an additive

ABOUT OAK RIDGE NATIONAL LABORATORY (ORNL)

Oak Ridge National Laboratory is the world's premier research institution. Established in 1943 as part of the U.S. Department of Energy's Manhattan Project to address the United States' most urgent R&D needs, ORNL has a legacy of discovery and innovation to realize solutions in energy and national security, as well as provide economic benefit to the nation.

Honeywell Advanced Materials
115 Tabor Road
Morris Plains, NJ 07950
honeywell.com/hfofacts

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