SAE CRP1234

Industry Evaluation of low global warming potential refrigerant HFO1234yf

HFO1234yf

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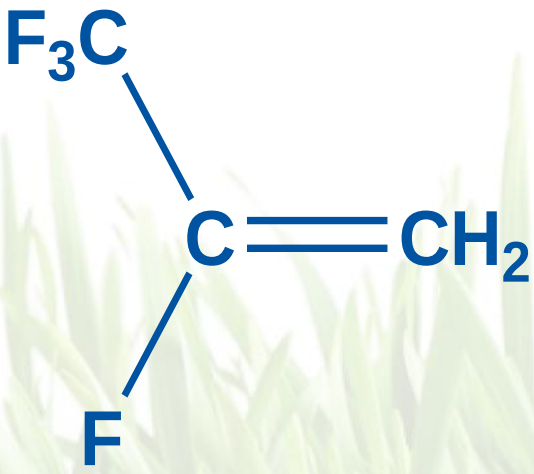


Europe MAC Directive EU2006/40/EC

- **In 2006, the European Commission ordered the phase-out of the refrigerant R-134a in mobile air conditioning (MAC) systems for vehicles sold in Europe.**
  - **The EC mandated that autos and light trucks use refrigerants with a global-warming potential (GWP) not higher than 150.**
  - **The use of R-134a, hydrofluorocarbon (HFC) refrigerant, will be banned in all new type vehicles starting in 2011, and in all cars by 2017.**
- **Because of the long lead times in car design, global automakers who sell in Europe are currently evaluating alternative refrigerants.**

HFO1234yf Cooperative Research

- In 2007, global automobile manufacturers and suppliers along with industry experts and independent test laboratories initiated the SAE Cooperative Research Programs CRP 1234-1 and CRP1234-2 to investigate the safety and performance of HFO1234yf for use in Mobile Air Conditioning.

- The Cooperative Research Program (CRP) was sponsored by major automobile manufacturers including: Chrysler, Fiat, Ford, General Motors, Jaguar, Land Rover, Hyundai, PSA, Renault, and Toyota.

1234 OEM Group

These OEMs account for approximately 70 percent of all new vehicle sales in the European Union and worldwide.

Brands represented

HFO1234yf Cooperative Research

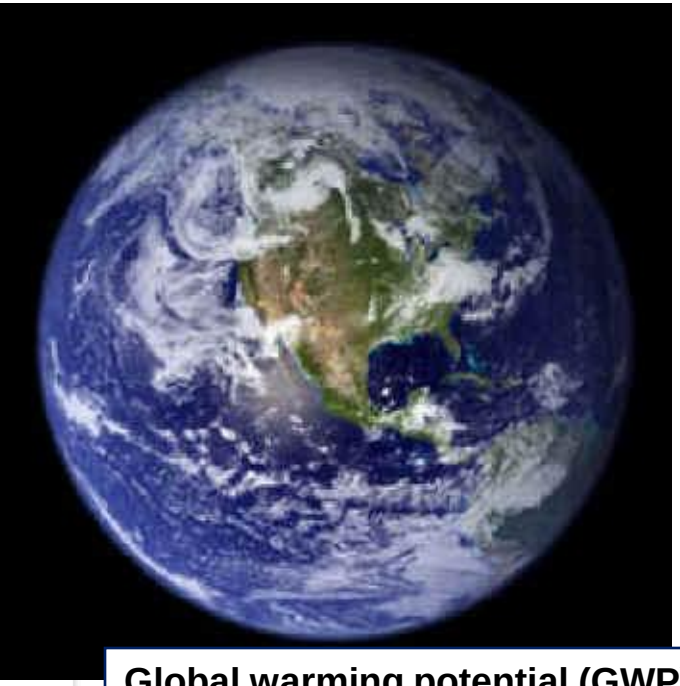
The Cooperative Research Programs Investigated and confirmed the new refrigerant for:

- Safety and risk assessment
- Air-conditioning system performance
- Material compatibility

HFO1234yf is safe to use in automobiles designed for use with HFO1234yf as verified through extensive third-party testing.

HFO1234yf

A Global Mobile Air Conditioning Refrigerant Solution



Refrigerant	Atmospheric Lifetime	GWP
R134a	13 years	1430
HFO1234yf	11 days	4
R744	100 years	1

Global warming potential (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by definition 1). GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram of a greenhouse gas to that from emission of one kilogram of carbon dioxide over a period of time (usually 100 years).

HFO1234yf:

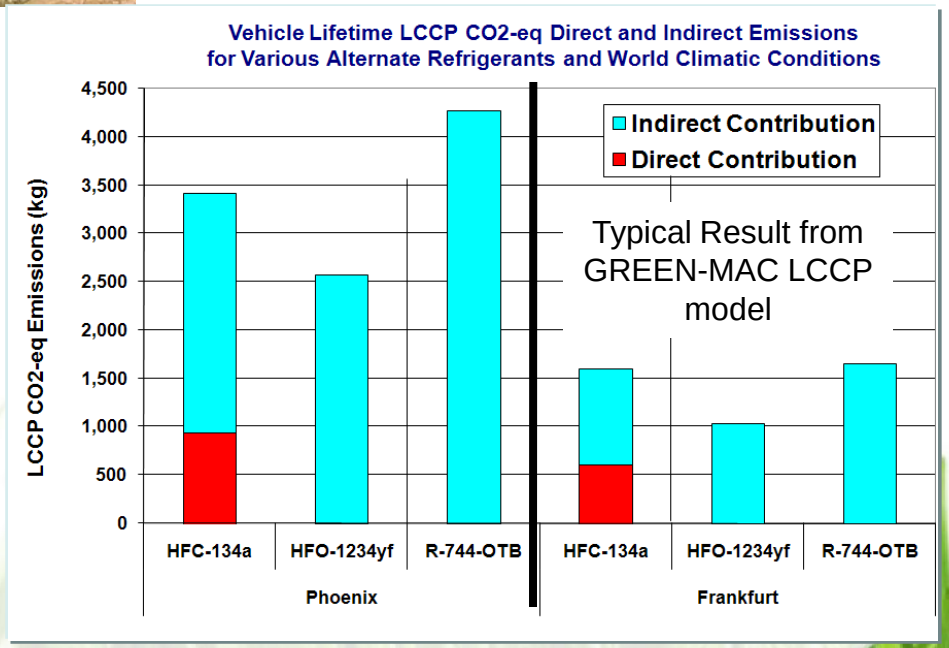
- Global Warming Potential well below the EU regulations of 150.
- Low atmospheric lifetime
- Highly energy-efficient refrigerant, meaning autos with HFO1234yf use less fuel and have fewer emissions than HFC134a.

Green House Gas (GHG) Emission from Refrigerant Use

Air conditioning systems derive their power to run from the car's engine, so their efficiency impacts the greenhouse tail pipe exhaust gas emission of the vehicle.

Direct emissions:
The greenhouse gas emissions resulting from the direct emission of the refrigerant.

Indirect emissions:
The greenhouse gas emissions (CO_2) resulting from the power needed to run the air conditioning system. The majority of total GHG emissions come from this, especially for low GWP fluids.



In developing a low-GWP solution, one must look at the GHG impact of the refrigerant and its efficiency with an eye on <u>total</u> greenhouse gas emissions

GREEN-MAC-LCCP©

- **50 world experts have agreed an LCCP Model:**
  - Experts from Industry, Governmental and Non-Governmental Organizations, National Laboratories, and Academia
  - Transparent assumptions, calculations, and results

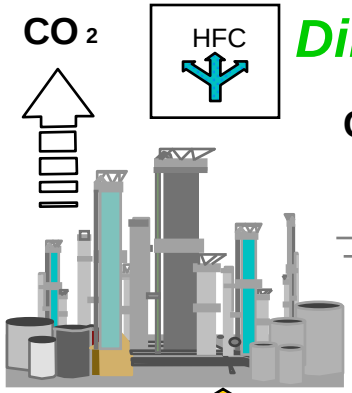
- **Globally peer reviewed** and accepted worldwide as the most credible method of comparing the Life Cycle GHG emissions of alternative refrigerants

- Hosted on the US EPA's website: http://www.epa.gov/cppd/mac/

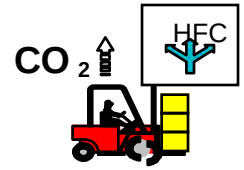
- SAE has developed standard SAE J2766 addressing MAC system Life Cycle Analysis

Life Cycle Climate Performance (LCCP)

Refrigerant MANUFACTURING

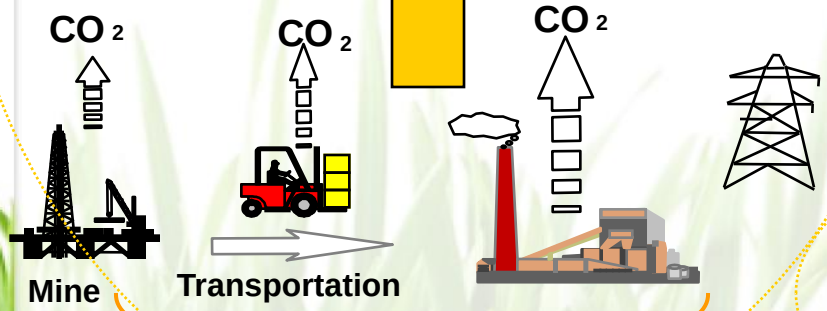


Direct Emissions



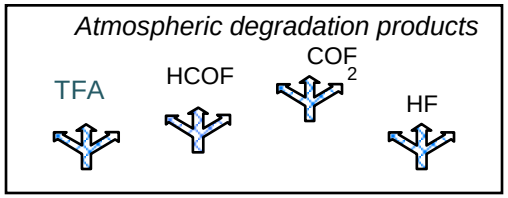
Transportation

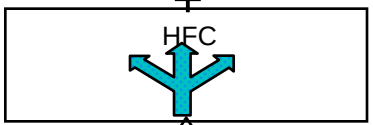
Indirect Emissions



Raw Materials

Refrigerant USE

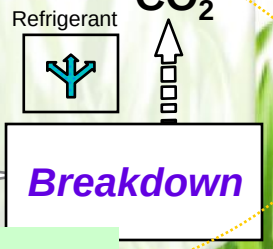




CO2

End-use of chemicals

Recycling



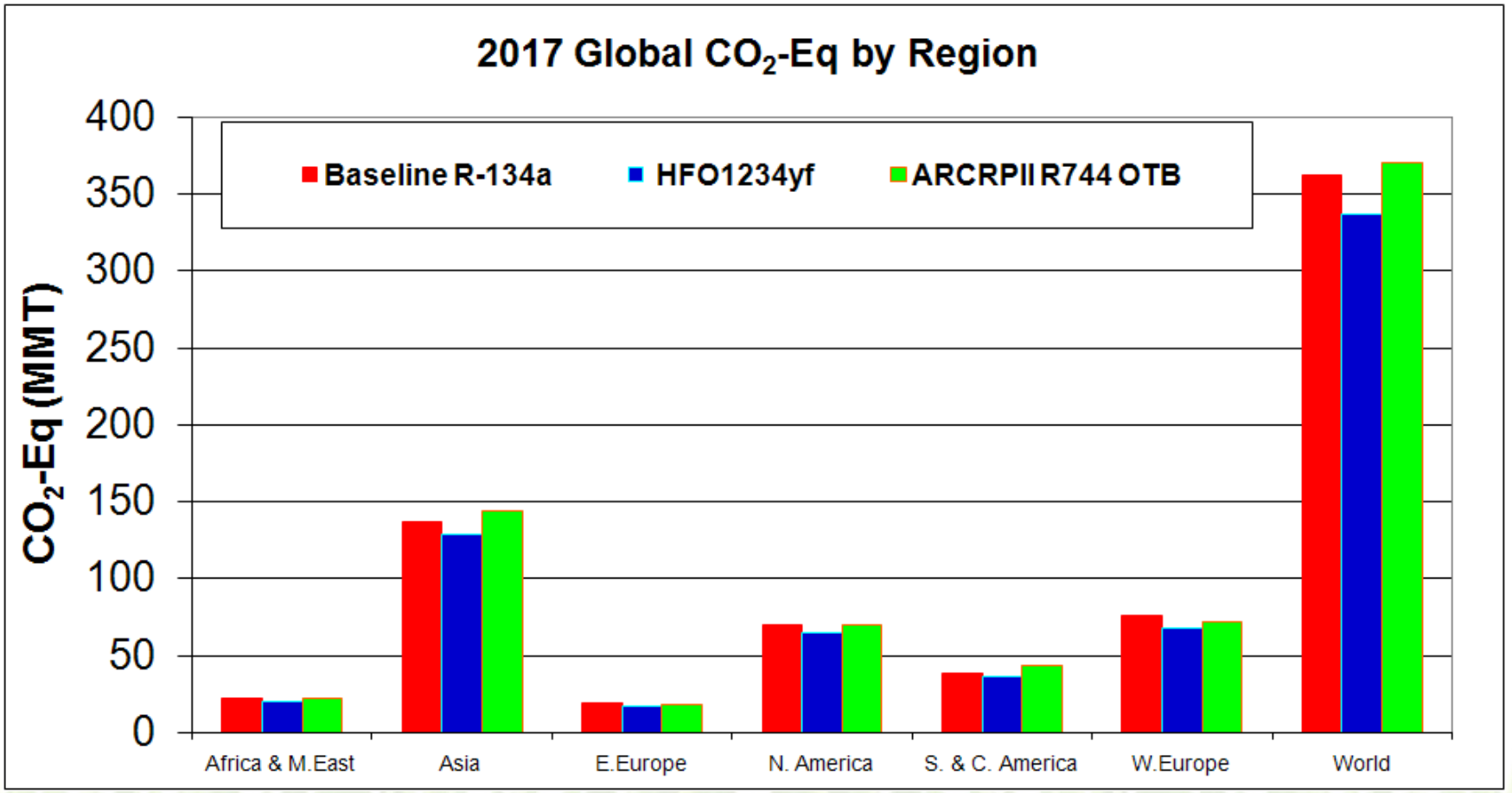
Refrigerant End-of-Life

GREEN-MAC-LCCP©

Direct Emissions	Indirect Emissions
Regular Emissions	Energy Consumption of AC System and Engine Cooling Fan
Irregular Emissions	Energy Consumption to Make Components
Service Emissions	Energy Consumption to Make Refrigerant
End-of-Life Emissions	Energy to Transport Each Component
Leakage from Refrigerant Production and Transportation	Energy for the End-of-Life Recycling and Recovery

HFO1234yf

Superior Environmental Performance in all Climates



The data above is based on bench data from CRP1234-1 and earlier research on R744 in the Alternate Refrigerant CRP conducted in 2003.
Life Cycle Analysis is done per the latest GREEN-MAC-LCCP© model described in SAE J2766.
The results assume the use R134a for vehicles in the fleet prior to 2011 and all new vehicles produced after 2011 have the new refrigerant.
[ARCRPII =the second phase of the Alternate Refrigerant CRP. OTB=Orifice with a Bypass for expansion device.]

HFO1234yf and Safe use in Cars

Extensive Toxicity Testing at Leading Labs

- Independent, global testing laboratories have conducted comprehensive toxicity tests on HFO1234yf and based on these tests it is concluded that HFO1234yf is safe for use in mobile air conditioning.

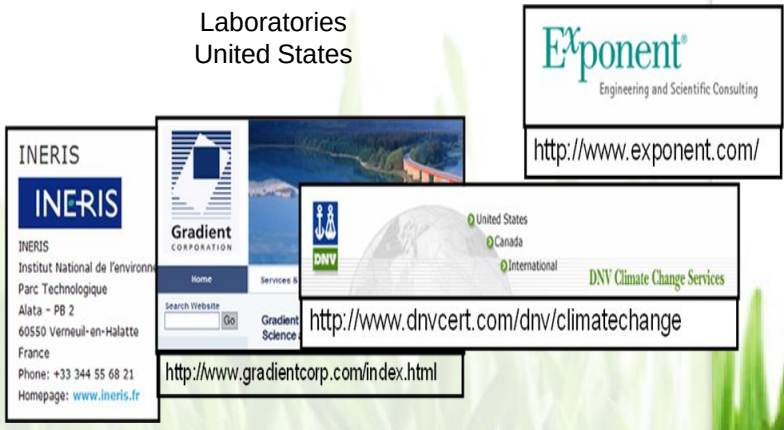
WIL Research Laboratories
The United States

TNO Pharma
The Netherlands

Flammability Testing at Leading Labs

- In the event of a car fire, HFO1234yf -- like other materials found in an automobiles such as plastic parts -- will burn and release hazardous materials. However, there have been no documented cases where combustion of automotive refrigerants has resulted in injury or death.
- Flammability testing at Ineris and Exponent labs have not indicated flammability risks either in the passenger compartment or engine compartment.

Underwriters
Laboratories
United States



HFO1234yf toxicology has been thoroughly evaluated by experts from around the world and is judged to be safe for use in mobile air conditioning systems

Hydrogen Fluoride Formation

- Hydrogen fluoride (HF) can be formed when fluorine containing refrigerants are exposed to an open flame
- Risk assessments have concluded there is an extremely low probability of a fire associated with HFO-1234yf during an accidental release. Therefore, there is an extremely low probability of HF formation.
- In the unlikely event of an accidental refrigerant release, where HFO-1234yf or HFC-134a are exposed to a flame (such as a butane lighter), experimental tests have confirmed the amount of HF formed is extremely low and similar for HFO-1234yf and HFC-134a.
- There have been no known published medical reports of any documented injuries attributed to HF formed during accidental release of HFC-134a. HFC-134a has been used for more than 16 years in the automotive industry.

SAE International

CRP1234-2 Material Compatibility Summary

Table 1a – Overall Project Summary – Material Compatibility and Permeation*

Material	Compatibility			Permeation	Permeation
	Oil A HFO1234yf	Oil-B HFO1234yf	Oil-C R134a	HFO1234yf	R134a
eals					
PDM-1					
PDM-2					
PDM-3					
PDM-4					
NBR-1					
NBR-2					
NBR-3					
R-1					
ormal Temp. Hoses					
R-1					
IIR-1					
R-2					
IIR-2					
A-1					
A-2					
igh Temp. Hoses					
R-3					
R-4					
R-1					
A-3					
A-4					
A-5					
hermo-plastics					
PS-1					
PS-2					
EI-1					

Table 1b – Overall Project Summary –Oils*

Oil	Thermal Stability		Miscibility		Daniel Plots	
	R134a	HFO-1234yf	R134a	HFO-1234yf	R134a	HFO-1234yf
Oil-A						
Oil-B						
Oil-C						
Oil-D						

*Green color indicates no issues were noted, Yellow color indicates improvements are suggested, no color indicates materials were not tested

No significant issues with materials are found.

*Green color indicates no issues were noted, Yellow color indicates improvements are suggested, no color indicates materials were not tested.

HFO1234yf Alternative Conclusion

- Thorough International testing, including independent, third-party, documented tests by the SAE International -- Engineers and automakers using real-world conditions have demonstrated that HFO1234yf is safe to use in mobile air conditioning.

SAE HFO1234yf Standards

Members from both the CRP1234-1 and 2 groups, together with the SAE ICCC [Interior Climate Control Committee] have developed nine new or revised SAE standards to assure that this refrigerant is applied to mobile air conditioning systems in a safe manner. Furthermore, many of the members of this team as well as the

SAE ICCC are working with the ISO Technical Committee 22, Working Group 14 to develop a new ISO standard for mobile air conditioning safety.

HFO1234yf SAE Standards	
Safety Standards for Motor Vehicle Refrigerant Vapor Compression Systems	J639
Service Standards for Mobile Air Conditioning Systems	J2770
Measurement of Passenger Compartment Refrigerant Concentrations under A/C system refrigerant leakage conditions	J2772
Refrigerant Guidelines for Safety and Risk Analysis for use in Mobile Air Conditioning Systems	J2773
Evaporator Design Certification for OEM and service replacement	J2842
Refrigerant Recovery- Recycle-Charging Equipment for Mobile Automotive Air Conditioning Systems	J2843
Refrigerant Purity and Container Requirements for Refrigerant Used in Mobile Air-Conditioning Systems	J2844
Technician Certification for Servicing and Refrigerant Containment of A/C Systems	J2845
Refrigerant Recovery Only Equipment for Mobile Automotive Air Conditioning Systems	J2851

R744 Alternative

Carbon dioxide (R744) has been put forward as alternative to meet EU regulations.

- Lifecycle climate analyses indicate that R744 based solutions will produce 10-15% more total CO_2 equivalent emissions than a HFO1234yf solution.
- R744 AC system performs poorly in hot climates
- Requires all new components in the MAC system
- Adoption rate will be slower due to complexity

CO2 Potential Health Effects

Concentration of CO2 (%)	Time	Adverse Effects	References
17-30	0-60 seconds	Loss of controlled activity, unconsciousness, death	OSHA 1989; CCOHS 1990, Dalgaard et al. 1972; CATAMA 1953, cited in USEPA 2000; Lambertsen 1971
> 10-15	1-3 minutes	Dizziness, drowsiness, muscle twitching, unconsciousness	Wong 1992; CATAMA 1953; Sechzer et al. 1960, cited in USEPA 2000
7-10	1.5-60 minutes	Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing	Wong 1992; Sechzer et al. 1960 and OSHA 1989, cited in USEPA 2000
7.5	5 minutes	Significant performance decrement	Sayers 1987
6	Several hours	Tremors	Schulte 1964, cited in Wong 1992
6	<16 minutes	Headache, dyspnea	White et al.1952, cited in Wong 1992
6	1-2 minutes	Hearing and visual disturbances	Gellhorn 1936, cited in Wong 1992
5	N.S.	Significant degradation in pilot performance during landing; unacceptable increase in touch down sink rates	Wamsley et al. 1975, cited in Wong 1992
4-5	4 hours	Drop in body temperature (one degree); no deficit in performance on Army Intelligence Test	Brown 1930, cited in Wong 1992
4-5	A few minutes	Headache, dizziness, increased blood pressure, uncomfortable dyspnea	Schulte 1964, Schneider and Truesdale 1922, Patterson et al. 1955, cited in USEPA 2000
3	1 hour	Mild headache, sweating, dyspnea at rest	Schulte 1964, cited in USEPA 2000
2	Several hours	Headache, dyspnea upon mild exertion	Schulte 1964, cited in Wong 1992

http://www.epa.gov/Ozone/snap/fire/co2/co2report.pdf.

HFO1234yf vs R744 Summary

	HFO1234yf	R744
Environmental Impact	Lower total greenhouse gas emissions than either 134a or CO_2	10-15% more total global warming emissions than HFO1234yf
Atmospheric Lifetime	11 days	> 100 years
Drop-in Solution?	Near drop-in solution	New system design required
Ability to Cool Auto Interior	Superior performance in all climates	Less effective/efficient in hot climates – where air conditioning is used more
Safety	Safe for use in automotive air conditioning applications with proper mitigation	Safe for use in automotive air conditioning applications with proper mitigation

Conditions for Safe Use

- HFO1234yf
  - Concentration must be less than 6.2% [LFL] in all areas of the interior
  - Ignition sources of high energy content should be avoided [300V systems may be a concern]
    - Both ignition sources and concentration are required for there to be a concern
  - EPA recommended that for safe use for R152a, concentration shall not exceed LFL for more than 15 seconds
    - A similar requirement is expected for HFO1234yf
  - Plumbing Underhood must be routed to avoid impingement on hot surfaces or shielded [similar to other flammable fluids criteria]
- R744
  - Concentration may not exceed 3% for more than 15 minutes according to EPA proposed guideline for safe use.
    - Odorant does not help to meet this requirement
  - Normal occupant breathing in the vehicle may cause elevated CO2 levels [1-2%] when MAC is in RECIRC or off mode
    - Decreasing allowable R744 refrigerant leakage amount
  - Leakage rates will be higher with the same diameter leak due to higher pressures [Est. 21g/s vs.. 12g/s for HFO1234yf for 6.5mm hole]
    - Same mass displaces more volume

Risk Assessments

- **Risk Assessments Completed**
  - Independent Assessments
    - SAE Cooperative Research Project
    - JAMA/JAPIA Assessment
    - Fiat/Renault/PSA Assessment
  - Risk is less with HFO1234yf as compared to R744

http://www.dnvcert.com/dnv/climatechange

http://www.gradientcorp.com/index.html

Overall Conclusions

- HFO1234yf safety mitigation strategies can be developed.
  - Risk is lower because you need 6.2% [vs 3%] concentration and also an ignition source of sufficient energy must be present
  - Should HF be formed in unlikely event of fire, it is the same risk that currently exists today. (In use over 16 years in millions of A/C systems)
- Need to develop additional risk mitigation strategies for R744
  - Risk is higher because threshold is lower [3% time weighted average over 15 minutes]
    - Risk mitigation strategy needs to mitigate risk by not exceeding threshold
    - Background passenger cabin concentration due to respiration makes mitigation difficult