The Transition from HFC-134a to a Low-GWP Refrigerant in Mobile Air Conditioners

HFO-1234yf

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Overview of the Transition to Low-GWP Refrigerant

- The industry shift to a new, low-GWP refrigerant for vehicle air conditioners is well underway
- The new chemical, HFO-1234yf, has a GWP of only 4, versus over 1,400 for the current refrigerant (R-134a)
- The switch will eliminate about 4% of automobile greenhouse gases
- Although development work continues on other possible future alternatives, HFO-1234yf will remain the only viable low-GWP vehicle air conditioner refrigerant for many years

Alternative Refrigerants Evaluated

- Recognizing long term environmental needs, the auto industry began to look for new, low-GWP air conditioner refrigerants in approximately 2001

- GM next generation refrigerant goals
  - One future GM refrigerant globally
  - Compliant to global regulations
  - Best customer balanced value
  - Enduring long term solution

- Many new refrigerant technologies were evaluated through SAE Cooperative Research Programs and independent evaluations
  - R-744 (CO_2) high pressure system
  - Multiple new chemicals proposed by the chemical industry
  - Several refrigerants via secondary loop
  - HFO-1234yf

- Timing became driven by the European Union MAC Directive, requiring mobile air conditioner refrigerants with a GWP below 150 on new vehicle types introduced in 2011 CY

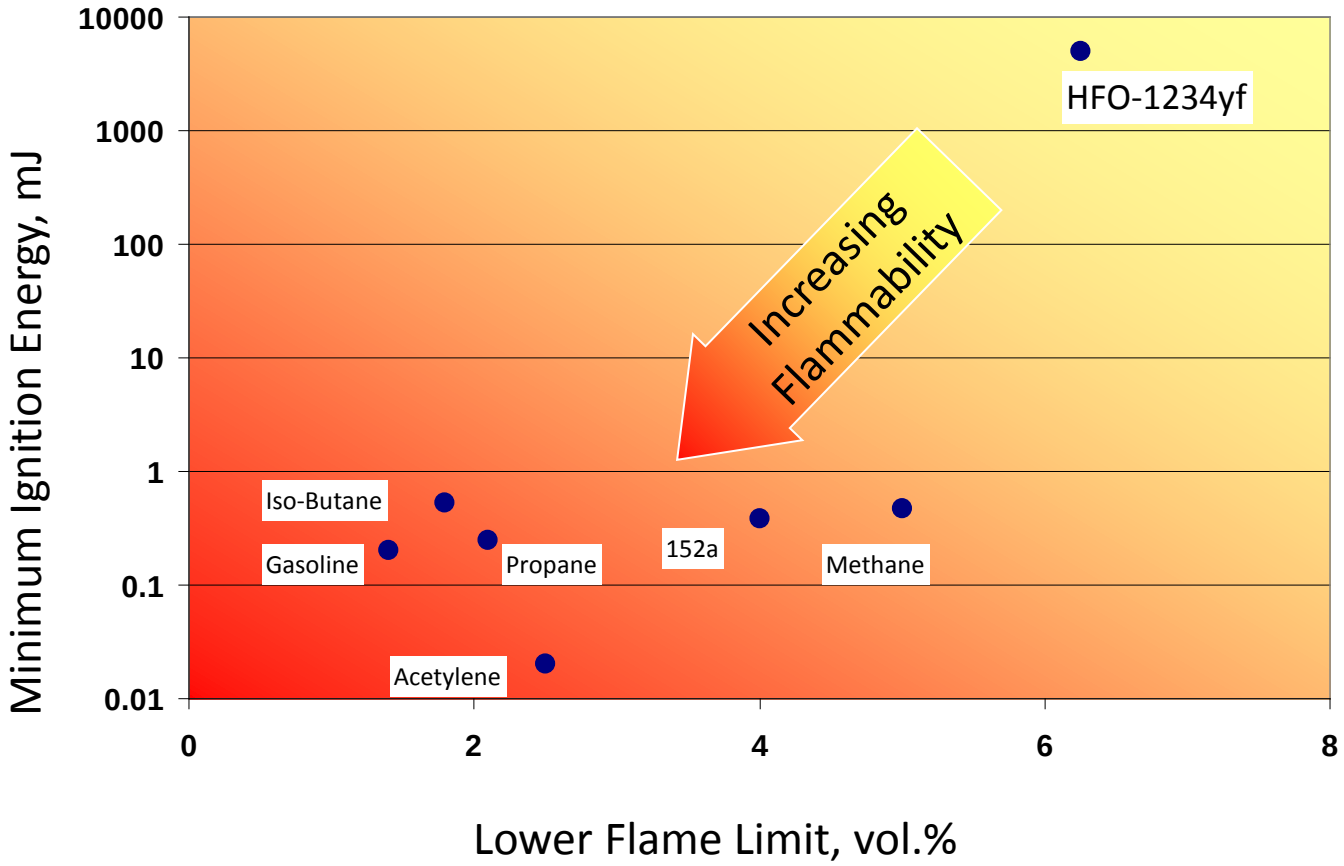
SAE CRP 1234 2008 Conclusions

- In 2007, the SAE CRP 1234 program was launched to investigate the safety and performance of HFO-1234yf
  - CRP sponsors initially included eight major automobile manufacturers: Fiat, Ford, Chrysler, General Motors, PSA, Renault, Hyundai and Toyota
  - Additional OEMs and Tier 1 suppliers participated in later CRP 1234 phases
- In November 2008, SAE CRP 1234yf concluded that the HFO-1234yf offers superior environmental performance and is acceptable for commercial use in future vehicles that are designed to use the new refrigerant
  - Risks for HFO-1234yf are comparable to the current refrigerant (R-134a) and far below risks calculated for other SNAP-approved vehicle refrigerants after reviewing flammability, toxicology and other factors
  - There are no significant environmental side effects or other issues
  - HFO-1234yf has the lowest life cycle CO2-equivalent emissions (LCCP) of all the low-GWP alternatives
- To meet the 2011 timing of the European regulation, and following development difficulties with R-744, GM made a decision in late 2008 to implement HFO-1234yf

HFO-1234yf Flammability Properties

Flammability is evaluated by ‘Chance of Flame occurring’ and ‘Effect of Flame occurring’

- Chance of Flame occurring -> Lower Flame Limit, Minimum Ignition Energy

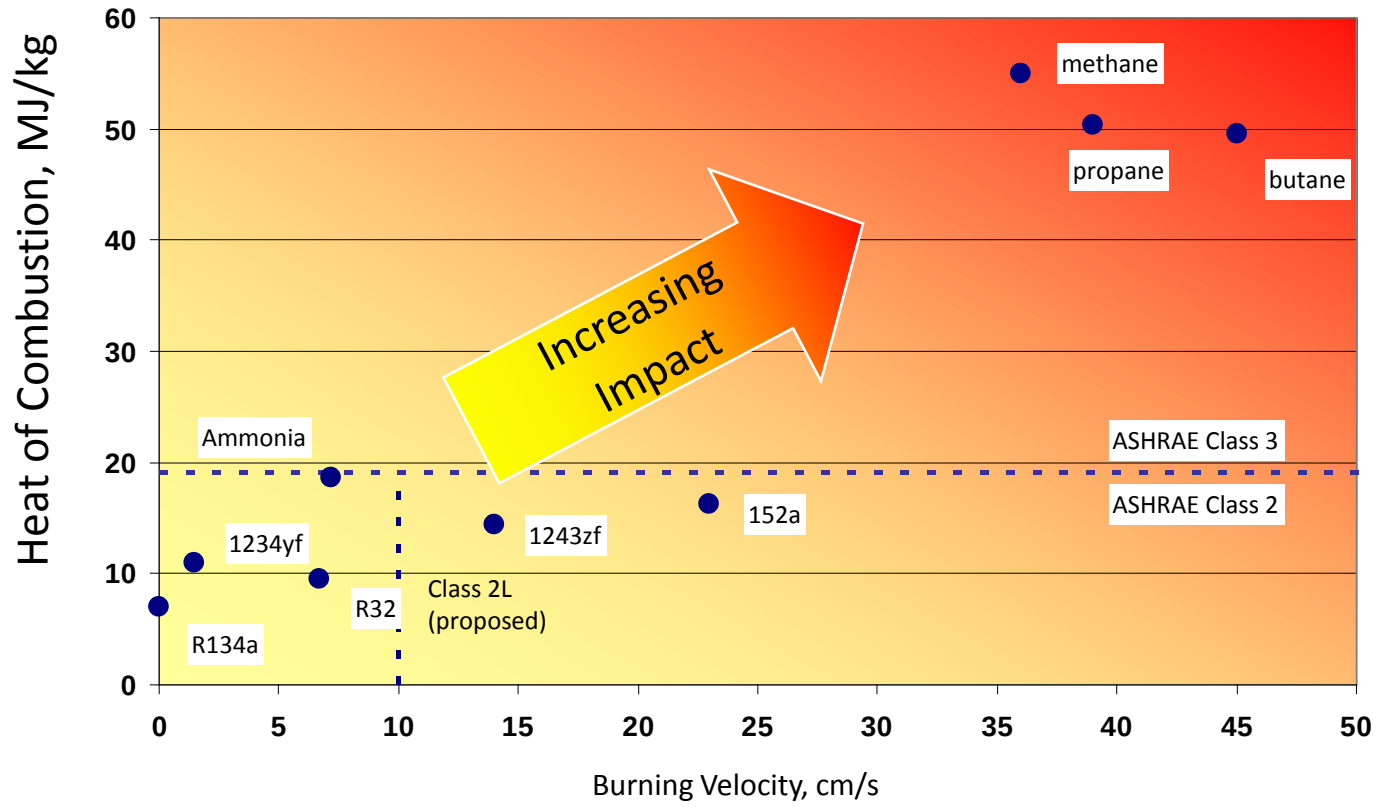


Difficult to ignite HFO-1234yf due to high Minimum Ignition Energy

HFO-1234yf Combustion Energy

Flammability is evaluated by ‘Chance of Flame occurring’ and ‘Effect of Flame occurring’

- Effect of Flame occurring -> Burning Velocity, Heat of Combustion



* Burning Velocity of 1234yf has been measured at AIST. (Advanced Industrial Science and Technology / Japan)

Even if ignited, HFO-1234yf burns only weakly, would have limited effect

Low-GWP Refrigerants Approved by EPA SNAP

- Using information developed through these SAE Cooperative Research Programs, chemical suppliers, OEMs, and other sources, EPA has approved through its SNAP program three main low-GWP candidates for use as air conditioner refrigerants in new light-duty vehicles

		Key SNAP “use conditions”
R-152a	GWP=124	Avoid occupant exposure to concentrations of R–152a above 3.7% in the passenger cabin free space for more than 15 seconds
R-744	GWP=1	CO2 concentrations can not exceed: 1) the short term exposure level (STEL) of 3% averaged over 15 minutes in the passenger free space; and the ceiling limit of 4% in the passenger breathing zone
R-1234yf	GWP=4	Conduct Failure Mode and Effect Analysis (FMEA) as provided in SAE J1739

- R-123yf can be implemented using sound engineering practices that are already standard within the industry, and with minimal changes to the air conditioner components, service procedures, etc.

Implementation Delays

- Construction of production capacity for HFO-1234yf was delayed and is still a constraint
  - Honeywell and DuPont are currently the only HFO-1234yf suppliers
  - Honeywell and DuPont claim intellectual property rights over the use of HFO-1234yf in vehicle air conditioners, although this is under dispute
  - HFO-1234yf refrigerant prices have been higher than expected

- Due to insufficient HFO-1234yf production capacity, the European Union delayed its MAC Directive from January 2011 until January 2013
  - All new vehicles in the EU are still supposed to use low-GWP refrigerant in 2017 CY

- In September 2012, Daimler claimed that recent testing had discovered unexpected risks in HFO-1234yf
  - Daimler conducted a voluntary recall of the relatively small number of vehicles it had already sold in North America and Europe with HFO-1234yf, converting them to R-134a
  - Daimler stated that it would continue to use R-134a
  - The German Automobile Manufacturers Association (VDA) restarted development activity for R-744 systems

- The industry quickly initiated another safety evaluation of HFO-1234yf in response to the Daimler claims (SAE CRP 1234 Phase 4), while regulatory agencies also launched new evaluations

Daimler Press Release – Sept 25, 2012

New findings concerning the risks of the new R1234yf refrigerant: Mercedes-Benz wishes to continue using the tried-and-tested R134a refrigerant in passenger cars

Sindelfingen, Sep 25, 2012

Text

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Sindelfingen. [illegible] investigation [illegible] recognised R[illegible] used worldwi[illegible] This was dete[illegible] international [illegible]

Despite multip[illegible] additional test[illegible] house which goes above and beyond the legally prescribed requirements.

In the new real-life test scenario, the refrigerant is dynamically dispersed at high pressure near to hot components of the test vehicle's exhaust system. This corresponds to a serious head-on collision in which the refrigerant line is severed and the reproducible results demonstrate that refrigerant which is otherwise difficult to ignite under laboratory conditions can indeed prove to be flammable in a hot engine compartment. Similar tests of the current R134a refrigerant did not result in ignition.

Due to the new findings of this study and the high safety demands at Mercedes-Benz, this chemical will not be used in its products. The company therefore wishes to continue to use the proven and safe R134a refrigerant in its vehicles.

Daimler has already informed the relevant authorities of these facts and will also make the results of this investigation available to all relevant associations as well as to other vehicle manufacturers.

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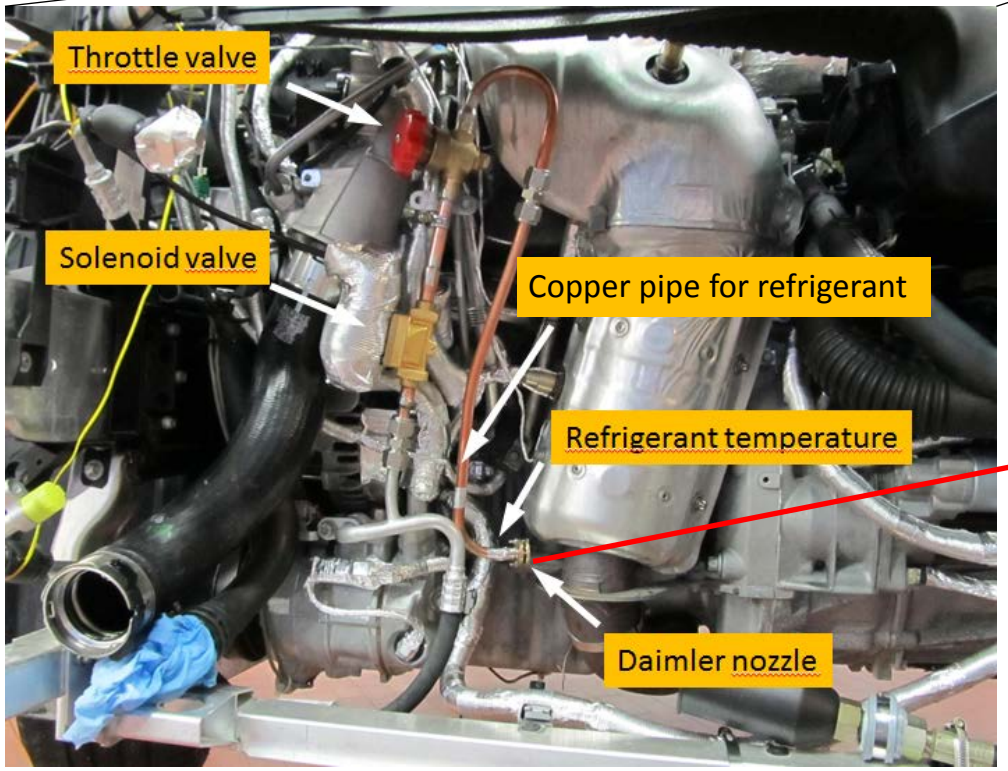
Daimler claimed they assessed

1) **Real-life scenario**
2) **Serious head-on collision**
3) **Flammability of refrigerant**

Daimler Test Setup

B-Class vehicle, with R-1234yf, used for evaluation

1. Pre-conditioned to max temp on exhaust surface
2. Release R-1234yf underhood
3. Observe ignition



Front-end of vehicle with fascia removed

Refrigerant Nozzle

Numerous parts (throttling valve, copper tube, nozzle) added to vehicle

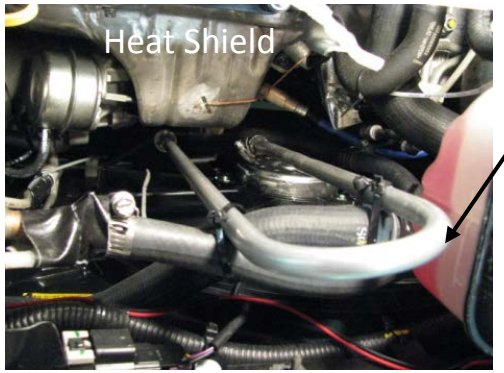
General Motors Response

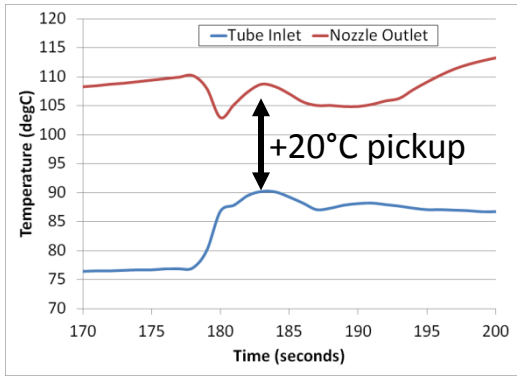
- In response to the Daimler actions, General Motors initiated hundreds of additional safety tests to confirm the safety of HFO-1234yf
  - Recreated the Daimler release tests
  - Conducted actual crash tests on GM vehicle platforms using HFO-1234yf
  - Updated Fault Tree Analysis to incorporate all the latest information on real world impacts

- Other OEMs conducted similar tests and analyses, and this information was shared within the SAE CRP 1234 Phase 4 to provide data for the updated SAE Fault Tree Analysis

Unrealistic vehicle modifications made to create ignition

1) **Added Hardware:** Daimler Nozzle + 'candy cane', throttling valve





Gap width tuned to slow gas velocity & atomize oil

Long metal tube added near exhaust to pre-heat refrigerant

Function: Precondition refrigerant/oil to create ideal conditions for ignition

2) **Overrode Fan Control:** Disable production-intent vehicle control to force cooling fan off

Function: Eliminate vehicle's ability to disperse refrigerant away from exhaust

Note: vehicle control always commands fan to operate at these conditions

3) **Extreme Precondition:** 10% grade, control gear to maintain redline, repeated WOT

Function: Artificially increase exhaust surface temperature to extreme levels

No ignitions when exhaust surface temperature < 800C

Note: vehicle overheated at end of each test – indicating test method exceeds capability of vehicle

4) **Undercharge A/C System:** Used 50% of specified amount

Function: Create idealized mixture of refrigerant/oil to encourage ignition

5) **Ignition Tuning:** Increase gap width, throttle down release valve, varied release height

Function: Optimize fluid dynamics of release to promote ignition of refrigerant

Significant modifications to vehicle hardware and controls necessary to create ignition

SAE CRP 1234-4 Key Findings

- Testing and Fault Tree Analysis conclusively demonstrate that R-1234yf can be used safely as an automotive refrigerant
- Conclusions of the initial SAE risk assessment are still valid:
  - The risk of passenger exposure to a vehicle fire based on the use of R-1234yf is very low ($3x10^{-12}$)
  - Risks are very small compared to risks of vehicle fire from all causes and well below risks commonly viewed as acceptable by the public
- The risk assessment is a highly conservative analysis based mostly on data and less on expert opinion
- Complete agreement of the 10 OEMs involved: Chrysler/Fiat, Ford, General Motors, Honda, Hyundai, Jaguar Land Rover, Mazda, PSA, Renault and Toyota
- The German Federal Motor Transport Authority (KBA) found no “serious threat within the meaning of the Product Safety Act”
  - The EU Joint Research Centre is also studying the issue

General Motors HFO-1234yf Roll-Out

North America

- In May 2012, the Cadillac XTS was introduced in North America using HFO-1234yf
- The Cadillac ATS was scheduled to be introduced in 2012 with HFO-1234yf, but at the last minute it was switched to R-134a due to a compressor noise issue
- In June 2013, the Chevrolet Spark Battery Electric Vehicle was introduced in North America with HFO-1234yf

Europe

- The Chevrolet Malibu was introduced with HFO-1234yf in Europe in mid-2012
- The Chevrolet Trax and Opel Mokka adopted HFO-1234yf in Europe in January 2013

Total

- Over 100,000 GM HFO-1234yf vehicles are already on the roads globally
- An even larger combined number of vehicles is on the roads in Europe with HFO-1234yf from other OEMs such as Hyundai, Subaru, Ford, BMW

Future R-1234yf Challenges

- Production capacity for R-1234yf remains insufficient
  - EU regulations call for low-GWP refrigerant in all new vehicles in 2017 CY
  - The U.S. EPA greenhouse gas regulation set standards based on a presumed across-the-board conversion between 2017 and 2022
  - Other nations may regulate refrigerants
- Vehicle service sector capability
- Safety questions may persist
  - Creates uncertainty for regulation as well as customer acceptance
- Competitive technologies may divert attention

Despite these challenges:

- On-time implementation of HFO-1234yf is essential for compliance with U.S. and EU greenhouse gas regulations
- The U.S. incentives to implement a low GWP MAC refrigerant are working faster than modeled by EPA for the 2017-2025 regulation