ATMO sphere

Accelerating Clean Cooling & Heating

www.atmosphere.cool

Total Thermal Control: Synergizing Cabin Comfort and Battery Life with Natural Refrigerants

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www.atmosphere.cool

25th Ozone Panel, Istanbul

#GoNatRefs

About Us

ATMOsphere is a global, independent, market accelerator with a mission to scale up clean cooling and heating.

Whether you are an investor, an end-user, or a manufacturer, we have developed a comprehensive offering to assist you in transitioning to more sustainable technologies – globally and at scale.

Our Mission: Scaling the Clean Cooling & Heating Economy

A global industry label measuring and recognizing the best-in-class companies

Curated natural refrigerants B2B marketplace with daily news

Defining the future of cooling via exclusive in-person networking & best-practice

Understand the latest market trends, technologies and actors

Our Missions: Scaling the Clean Cooling & Heating Economy

The Coalition for PFAS free Cooling and Heating

Associated Partner

www.pfasfreecoolingheating.eu

Business as usual is not an option

Our Agenda for today:

1. Historical overview of natural refrigerants in MAC
2. The TFA issue
3. The TFA-free solution
4. Market readiness and current trends

Resources

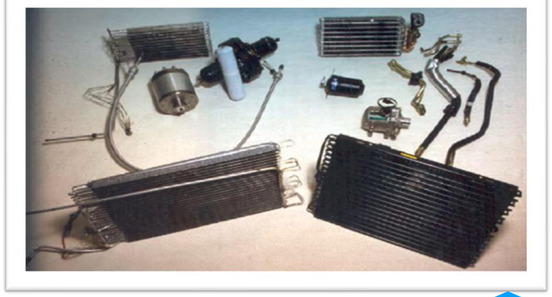
1. Historical overview of natural refrigerants in MAC

It is about more than emission…

25th Ozone Panel, Istanbul

1. Historical overview of natural refrigerants in MAC systems

R744 lab prototype system

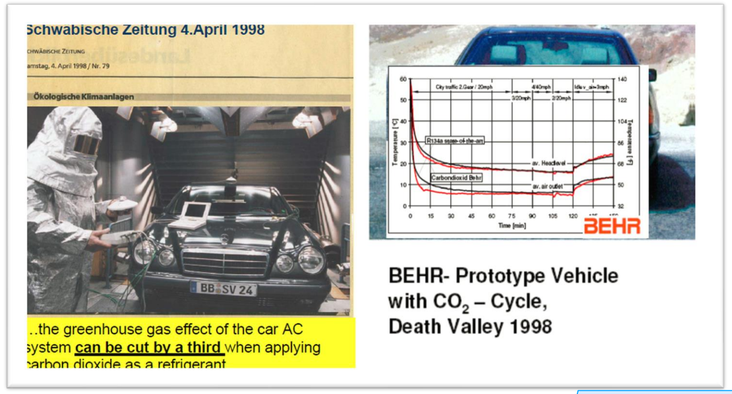


BMW 520 CFC-12 system

1987
The Montreal Protocol Is signed

1989: First CO_2 systems at University labs

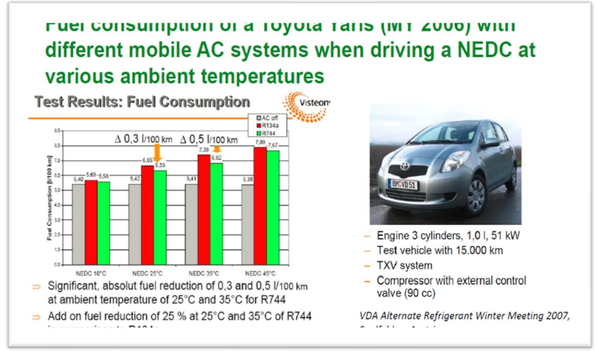
1994
Freon (CFC 12) can no longer be used in cars' AC systems – shift to 134a – zero ODS but GWP 1,430



BEHR- Prototype Vehicle with CO_2 – Cycle, Death Valley 1998

1998: prototypes and first car equipped with CO_2 systems

2002: scientific studies begin to measure 134a emissions from vehicles, linking them to climate change



2006: tests under different conditions show fuel consumption reductions when using a CO_2 AC system

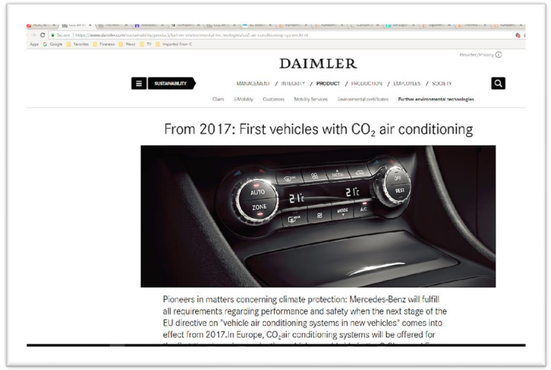
Source: Prof. Stefan Elbel X ATMO MAC Summit 2025

1. Historical overview of natural refrigerants in MAC systems

CO_2 car operated by German UBA between 2009 and 2017, accumulates more than 165,000 km

Source: www.uba.de

1234yf has flammability issues – in 2017 the first mass produced car using a CO_2 system is produced



VW CO2 Heat Pump

Source: www.Volkswagen.de

2006 EU MAC Directive

2008: the Automotive industry moved to adopt 1234yf

2009 – 2019: while some OEMs continue developing CO_2 systems and prototyping R290 systems, all OEMs in the EU, Japan and the US use 1234yf

2019: the Kigali Amendment is signed

2020s: NEV are a game changer because 1234yf does not perform as well as CO_2 systems in low temperature heat pumps

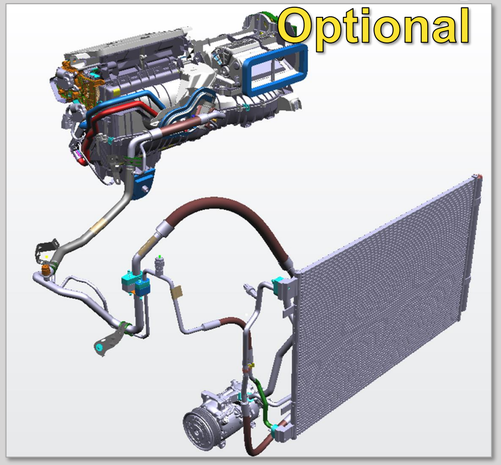
2023: five countries submit the uPFAS to ECHA requesting MAC systems restrict the use of PFAS refrigerants

Source: Prof. Stefan Elbel X ATMO MAC Summit 2025

1. Historical overview of natural refrigerants in MAC systems

Internal combustion Engine

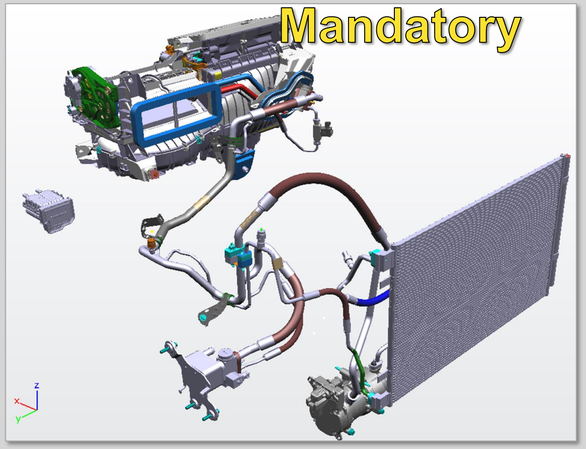
Optional



Cooling / Dehumidification of passenger cabin

xHEV (ICE + electrical

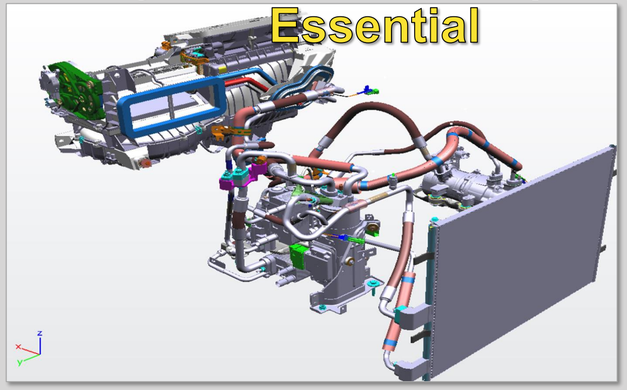
Mandatory



Cooling / Dehumidification of passenger cabin
Cooling of Battery

Battery Electric Vehicles (BEV)

Essential

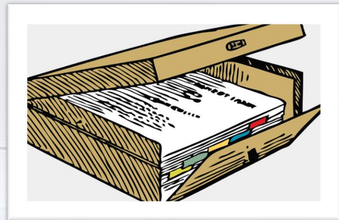


Cooling / Heating of Battery
Cooling / Dehum. / Heating of passenger cabin
Cooling of electronics
Cooling of electric drive motor

A/C Systems were initially designed as a vehicle passenger cabin cooling option and are now heat management systems, essential for the function of BEVs

Source: Bernd Dienhard – Ford Werke Gmbh X ATMO MAC Summit 2025

1. Historical overview of natural refrigerants in MAC systems



Universal PFAS restriction proposal

Restriction on the manufacturing, placing on the market and use of PFAS

Scope: The OECD definition of PFAS, in which TFA is included

Does not include active substances in biocides, pharmaceuticals and plant protection products

Regulate PFAS as a class to avoid the cycle of “regretful substitution”

irreversible environmental accumulation

irreversible environmental exposure

mobile

water solubility

very difficult and extremely costly to remove PFASs when released to the environment

contamination of surface, ground water, drinking water and soil

toxic and/or bioaccumulative substances

January 2023: the proposal is officially submitted to ECHA by the dossier submitters

1. Historical overview of natural refrigerants in MAC systems

Timeline of the uPFAS restriction proposal

Consumer mixtures, cosmetics and ski wax;
Hazards of PFAS (only by RAC);
General approach (only by SEAC)
Metal plating and manufacture of metal products; and
Additional discussion on hazards (only by RAC).
Textiles, upholstery, leather, apparel, carpets (TULAC);
Food contact materials and packaging; and
Petroleum and mining

Application of F gases
Transport
Energy
Medical devices
Lubricants
Electronics and semi conductors
Explosives and military applications
Other

Comitology procedure: the EP and the Council are NOT co-legislator.

March – September 2023: public consultation on the uPFAS

More than 5600 comments received

2024 – 2025:
RAC and SEAC committee analyse and discuss the uPFAS and the comments received. DS updates the proposal after the discussions on each sector are completed

June 2025 SEAC meeting: transport will be discussed as well as medical devices and lubricants.

Q1 2026:
The SEAC opinion is published. There will be a 60 days feedback period.

Q3-4 2026:
The SEAC final opinion is sent the European Commission.

2027 ?:
The European Commission sends the final text to the ECHA MS Committee for approval.

Q1 2030 ? :
The uPFAS enters into force.

1. Historical overview of natural refrigerants in MAC systems

Summary table of current regulation for MAC

		Climate chage		PFAS Regulations
Europe	**Montreal Protocol** UN Multilateral Agreement (01.01.1989) Regulates production and consumption of ozone depleting substances **Kigali Amendment** UN mandate (EiF 2017-2024) Global phase down of HFC production and consumption 80-85% by 2047	**EU MAC Directive** 2006/40/EC (EIF May 17, 2006) Prohibits the use of fluorinated gases with a global warming potential (GWP) higher than 150, Jan 2011 to Jan 2017	✓ **EU F-Gas directive** ✓ EU 517/2014 -> EU 2024/573 ✓ phasing out HFCs by 2050 ✓ Stricter emission prevention ✓ Quota system for HFCs ✓ Certification and training ✓ Reporting and monitoring	**ECHA** Upcoming PFAS restriction for F-Gases (potentially 2028 EiF) - Restricting the use of fluorinated gases due to persistence behavior of the gas and degradation products
USA		**US EPA** AIM act (EIF Jan 01, 2025) ✓ Restriction to substances with a GWP lower than 150 as of: ✓ MY 2025 for light duty vehicles ✓ MY 2028 for medium- and heavy-duty vehicles		**US EPA / State regulations** <u>Passed</u> PFAS Prohibition: Minnesota 2032 Maine 2040 (with SNAP approval) <u>Proposed</u> Refrigerant Prohibition: Ohio 2032 North Carolina (Immediate, if passed)
Asia		**China** (EiF July 1, 2029) prohibit newly applied M1 category vehicle air conditioning systems from using refrigerants with GWP values greater than 150 + Quota system for HCFC & HFC	**Japan** (EiF Apr. 2015) GWP < 150 by 2023	

Source: Bernd Dienhard – Ford Werke Gmbh X ATMO MAC Summit 2025

2.The TFA issue

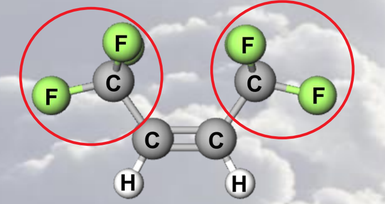
It is about more than emissions…

2. The TFA issue

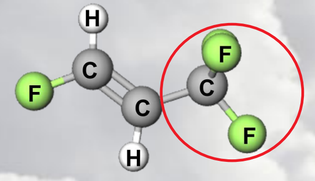
The OECD define PFAS as substances which contain at least one fully fluorinated carbon atom (CF_3 or CF_2) without any hydrogen, chlorine, bromine or iodine atoms attached

PFAS are **persistent**; they are, or they degrade into, substances which are chemically stable and thus remain in the environment for very long periods of time.

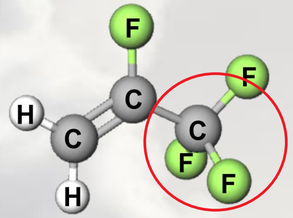
The risk posed by TFA is the subject of intense debate in the scientific community and beyond.



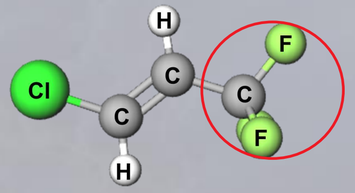
HFO-1336mz(Z)



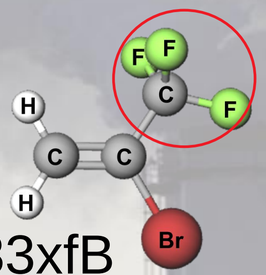
HFO-1234ze(E)



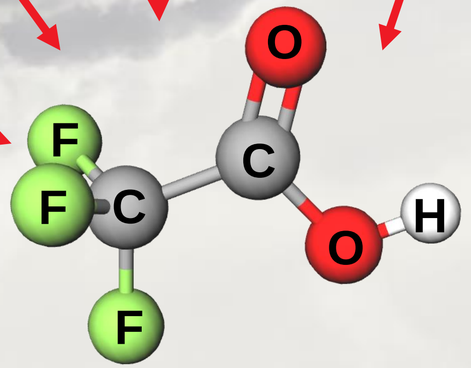
HFO-1234yf



HCFO-1233zd(E)



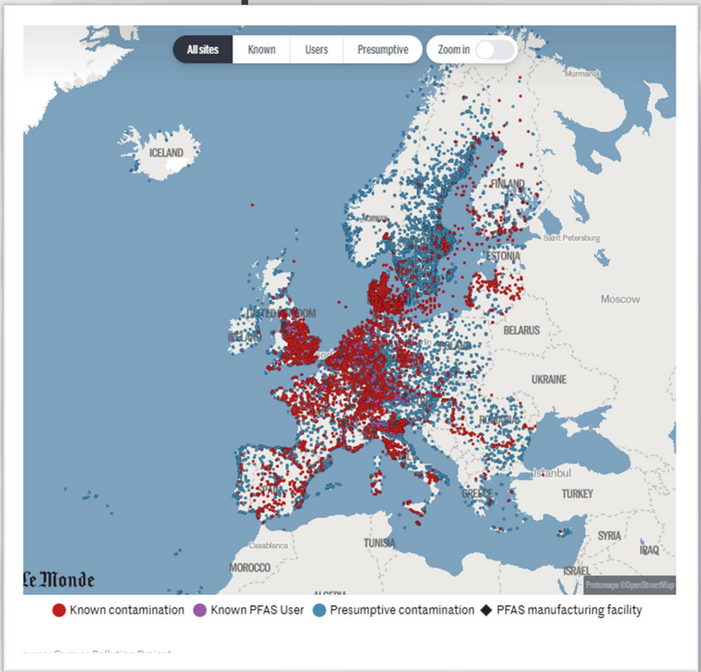
HBFO-1233xfB

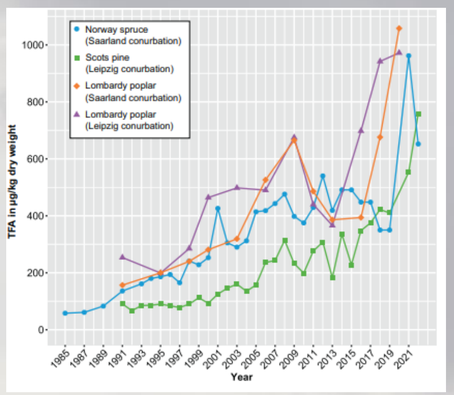


2. The TFA issue

TFA cannot be removed: the only technique could be reverse osmosis, which would only work for water, but it is not feasible, it is expensive, energy intensive, creates problematic residues.

The Forever Pollution Project estimates that the cost to remediate emerging ultra-short chain PFAS like TFA in Europe 100 billion EUR per year.





Concentration of TFA increasing in tree leaves

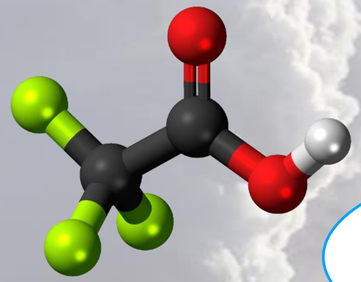
Facts about TFA

It is very persistent; it cannot degrade naturally (UBA) its lifetime is indefinite

It is found in increasing concentrations by several studies, reviewed in Arp and Gredelj et al. 2024

It is found everywhere

most abundant PFAS in environment – in all water bodies, plants, wine, beer, humans



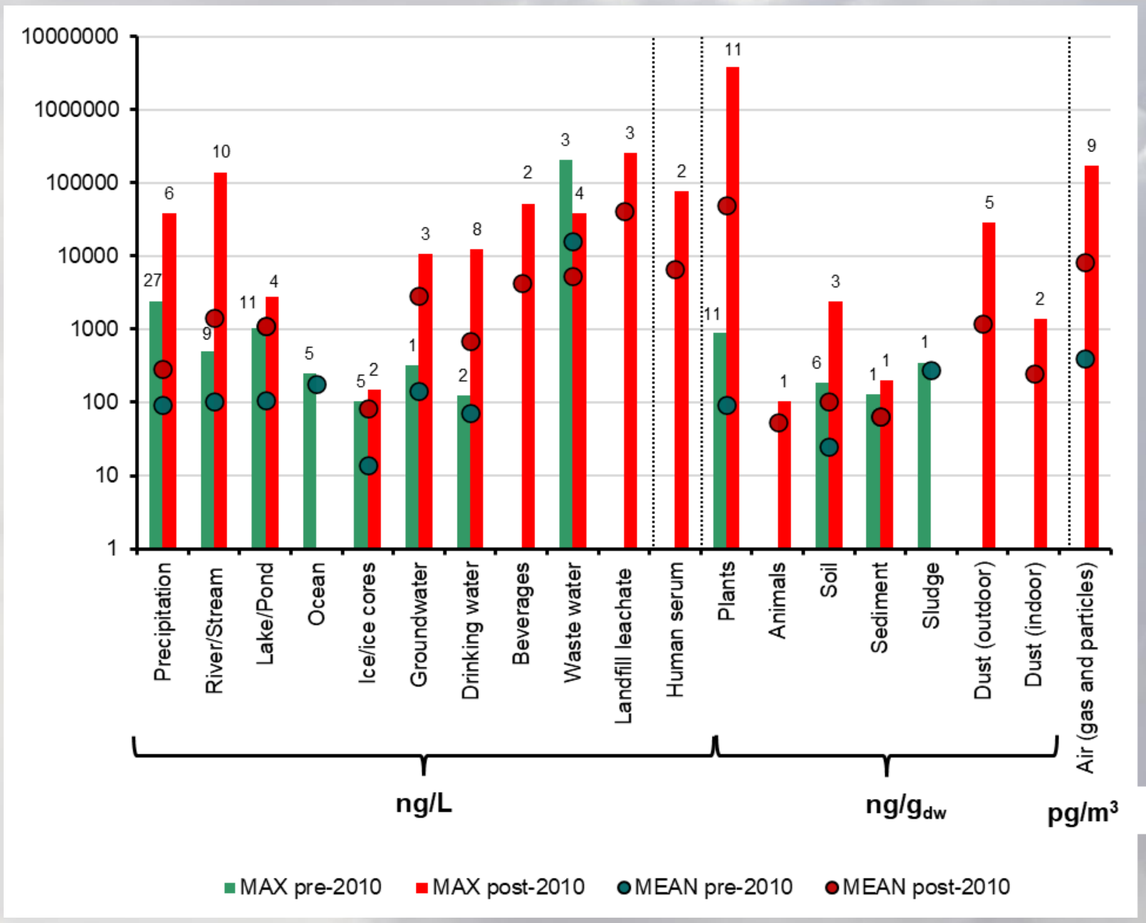
It is a degradation product of F-gases and pesticides

It is very mobile

high water solubility makes it spread rapidly in water cycle

It is a man-made molecule; claims it is a naturally occurring compount have been disproved by Young and Joudan

2. The TFA issue



Duan et al. (2020) Environ Int 134:105295.
Zheng et al. (2023) ES&T 2023, 57, 15782-15793
Arp et al. ES&T 2024, 58, 45, 19925-19935

PAN Europe: Message from the Bottle – The Rapid Rise of TFA Contamination Across the EU

Drinking water (median)[1,2]

- **Germany: 1.5 µg/L**
- **19 countries: 0.23 µg/L**

Tea (median): 2.4 µg/L[2]

Beer (median) 6.1 µg/L[2]

Orange juice (mean 34 µg/L)[3]

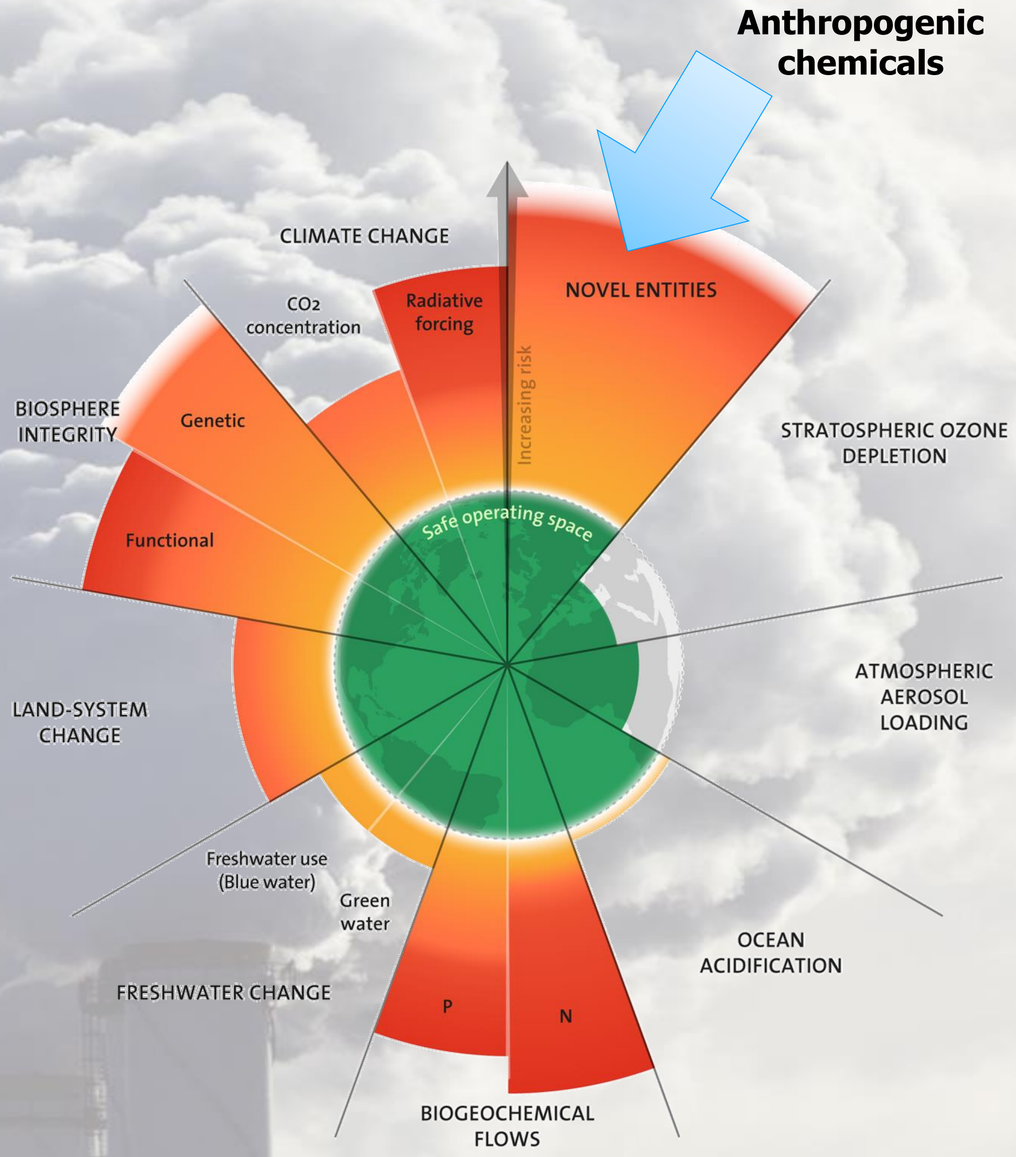
Apple juice (mean 6.2 µg/L)[3]

Neuwald **et al.** *Environmental Science & Technology* **2022** *56* (10), 6380-6390
Scheurer & Nödler. *Food Chemistry*, *351*, 129304.
Van Hees et al. **https://cdnmedia.eurofins.com/european-east/media/uxcnaa2c/eurofins_tfa_tfms_juice_24_final.pdf**

2. The TFA issue

As defined by Arp and Gredelj et al. 2024:
increasing accumulation of TFA meets the 3 conditions of a planetary boundary threat for novel entities*

- **pollution has a disruptive effect on a vital earth system process of which we are ignorant; (impacts already measurable at hotspots; we remain ignorant of the impacts from life-long intergenerational exposure)**
- **disruptive effect is not discovered until the associated impacts are, or inevitably will be, manifested at a global scale; (TFA concentration increases globally)**
- **impacts are poorly reversible because the level of pollution in the global environment cannot be readily reduced (TFA is already diluted, stockpiles of sources exist. Most TFA we emit will exist in water for the future of Earth*)***



2. The TFA issue

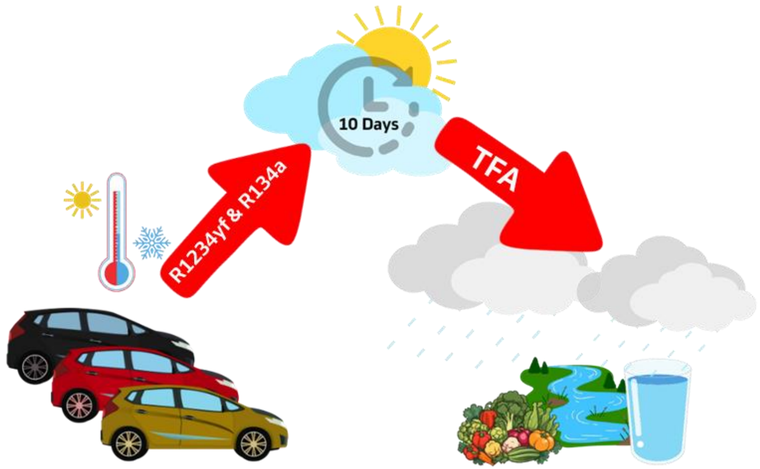
R134a and R1234yf degrade into PFAS

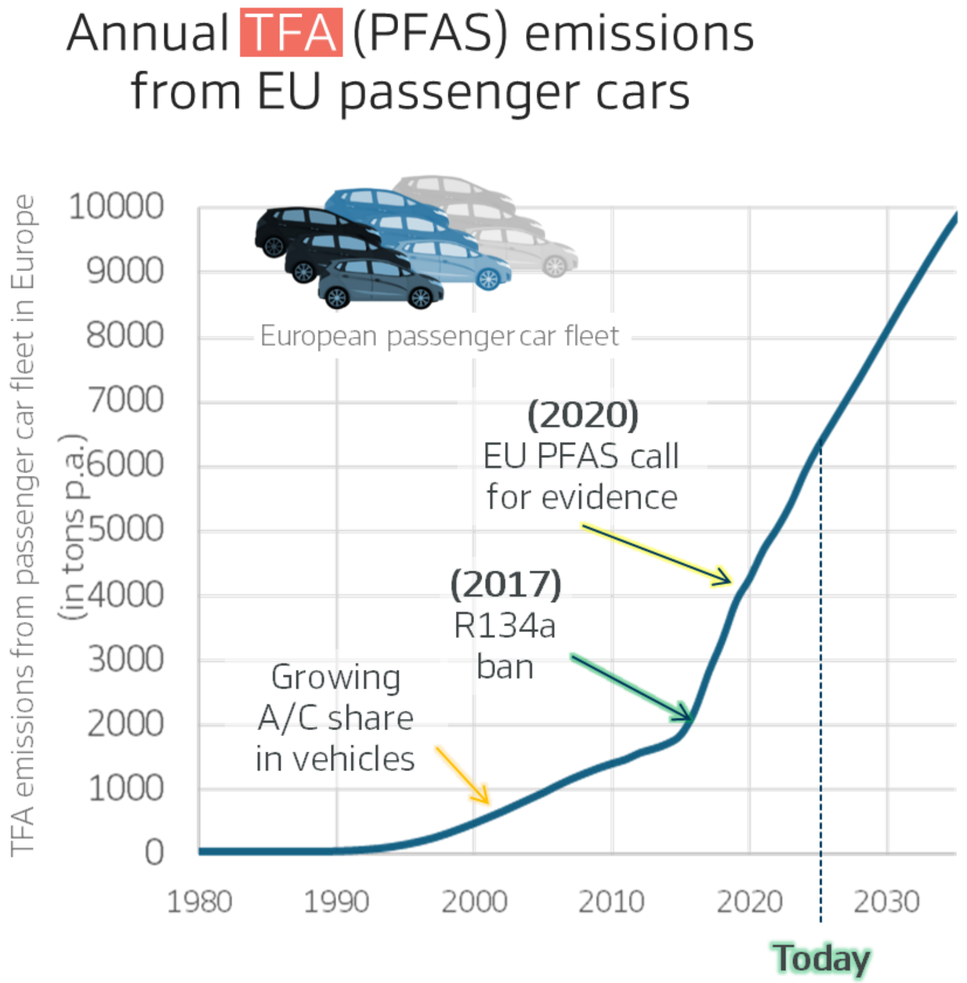
5* more

10* faster

R134a => 7-20% degradation to TFA (~2-3month)

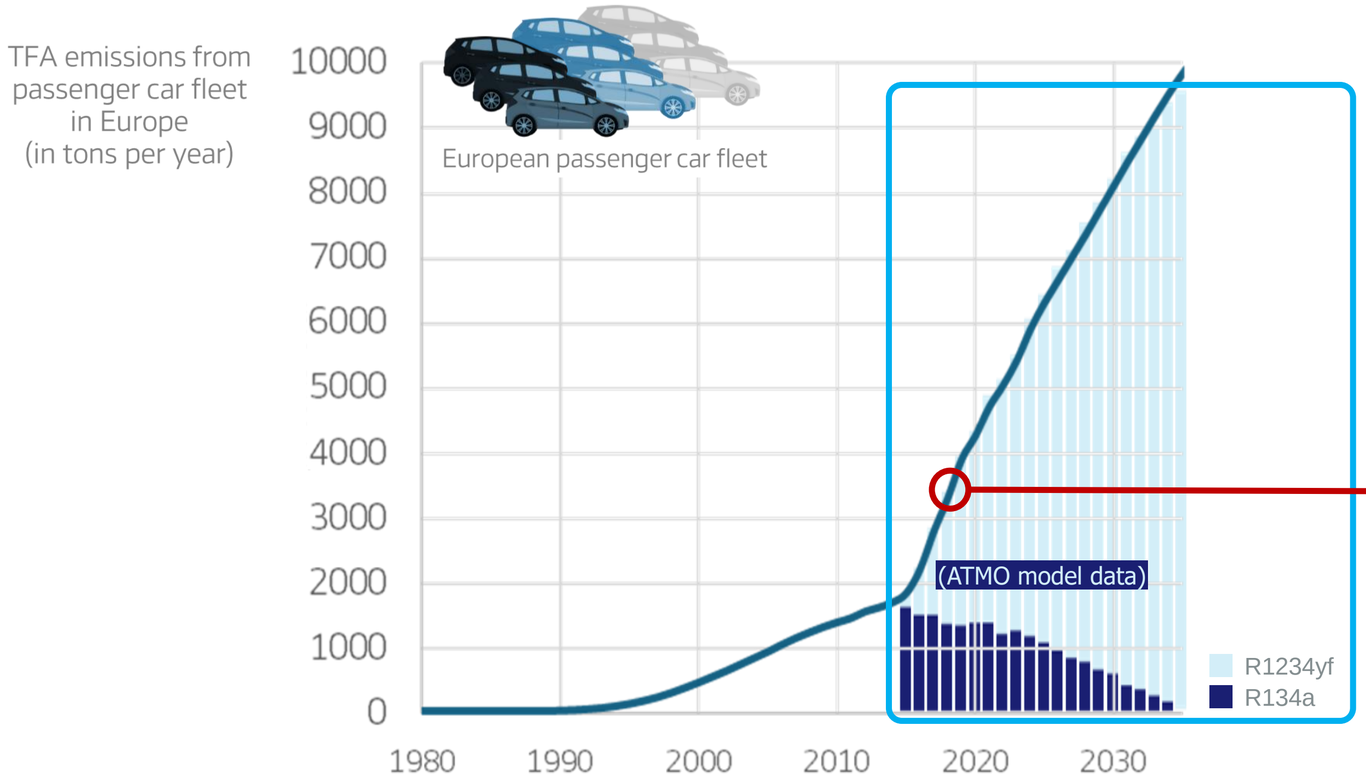
R1234yf => 100% degradation to TFA (~10days)





2. The Issue with TFA

Annual TFA (PFAS) emissions from EU passenger cars



Corresponds to 340 ng/liter

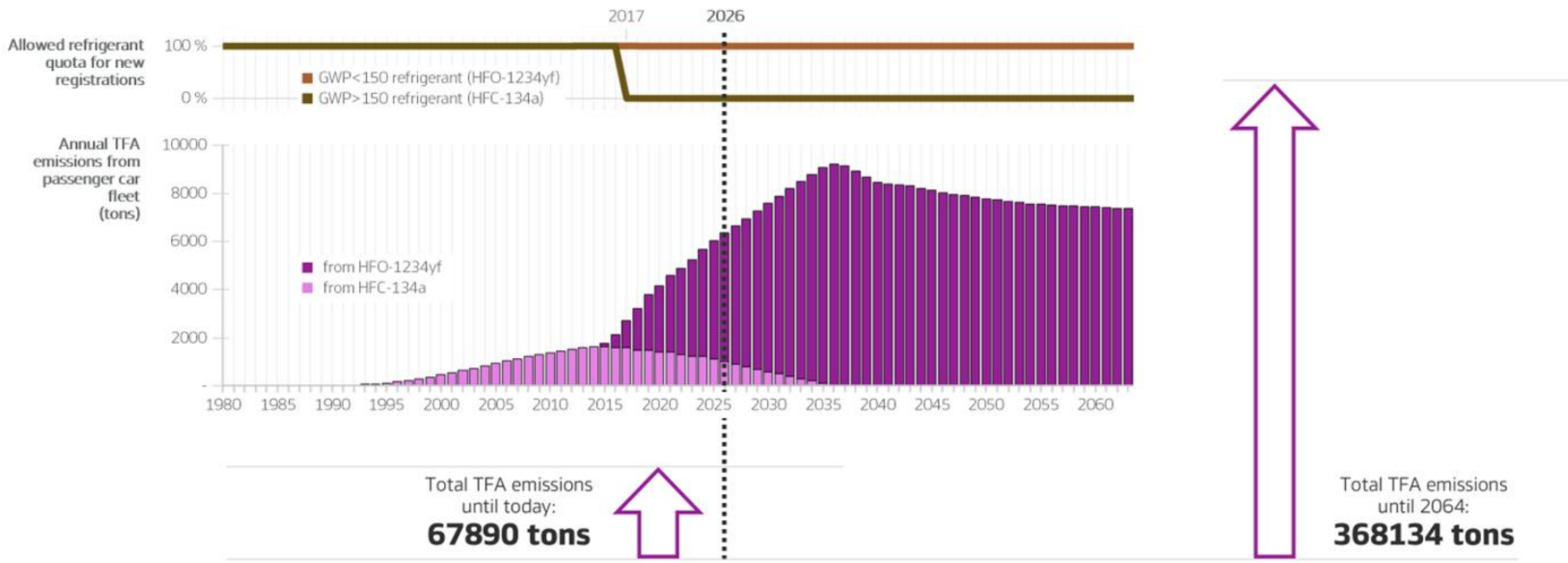
TFA-Concentration in Rain (DE) in 2018

TFA-Concentration in Rain Water in 2018

* HANON internal modeling reflects the model results presented by ATMO at the ATMO MAC Summit 2025 x TU Berlin

Baseline scenario, no regulation

ICE ban **2035** case

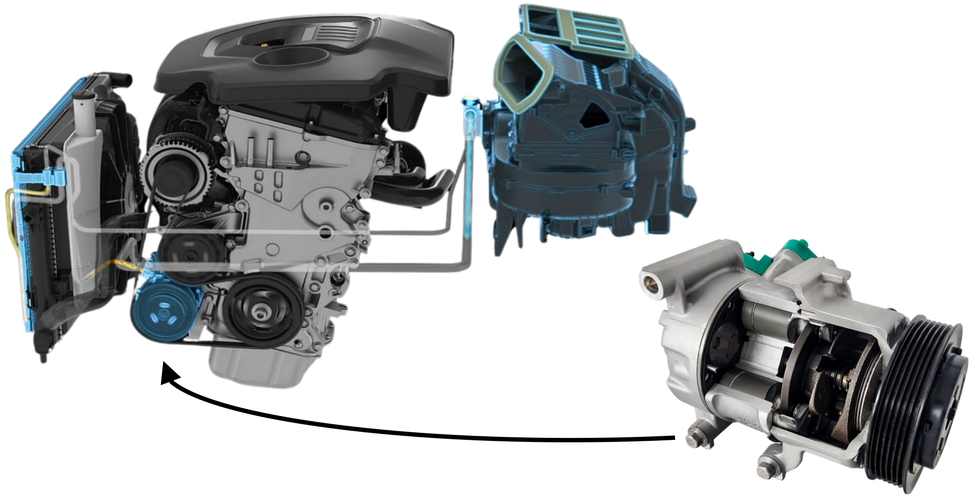


3.The TFA-free solution

It is about more than emissions…

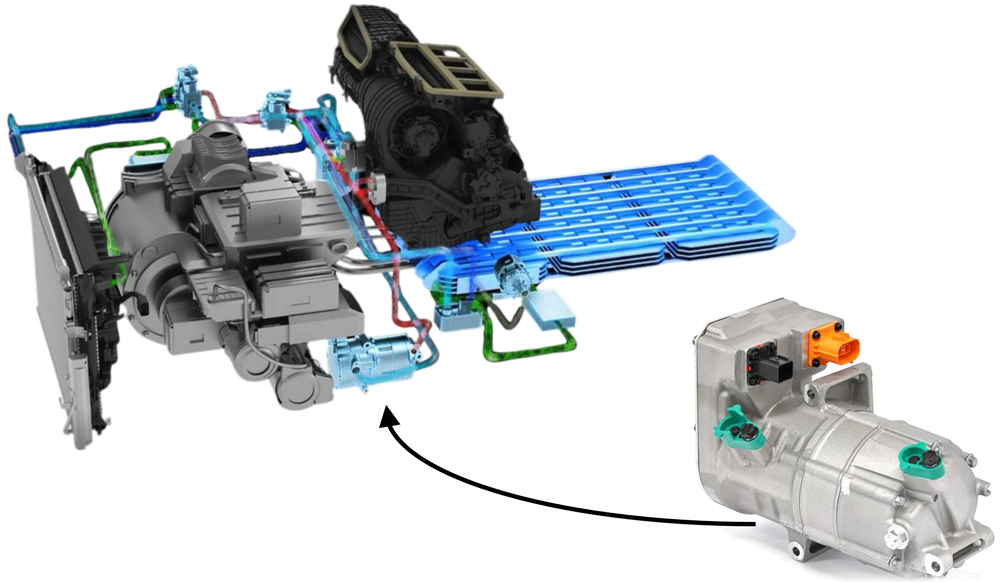
3. The TFA free solution

A/C-Architecture for ICE & HEVs (only driving with ICE on)



- **Belt driven compressor (mComp) used**
  - ➔ shaft seal inside mechanical compressor
  - risk external leakages
  - (R290: flammability, R744: service interval)
  - ➔ limited availability of this technology for R744

A/C-Architecture for BEVs & PHEVs & (HEVs) (driving even with ICE off)



- **Electric Compressor (eComp) needed**
  - ➔ no external shaft seal, hermetic compressor
  - low external leakage risk
  - **eComp R744 available**
  - **eComp R290 similar to R1234yf**
- **Compact Module recommended for R290**

eComp: electrical climate compressor systems
mComp: mechanical climate compressor systems

BEV: BatteryElectricVehicle **PHEV:** PlugInHybridVehicle **HEV:** HybridVehicle w/o Plug **ICE:** only Combustion Engine Vehicle

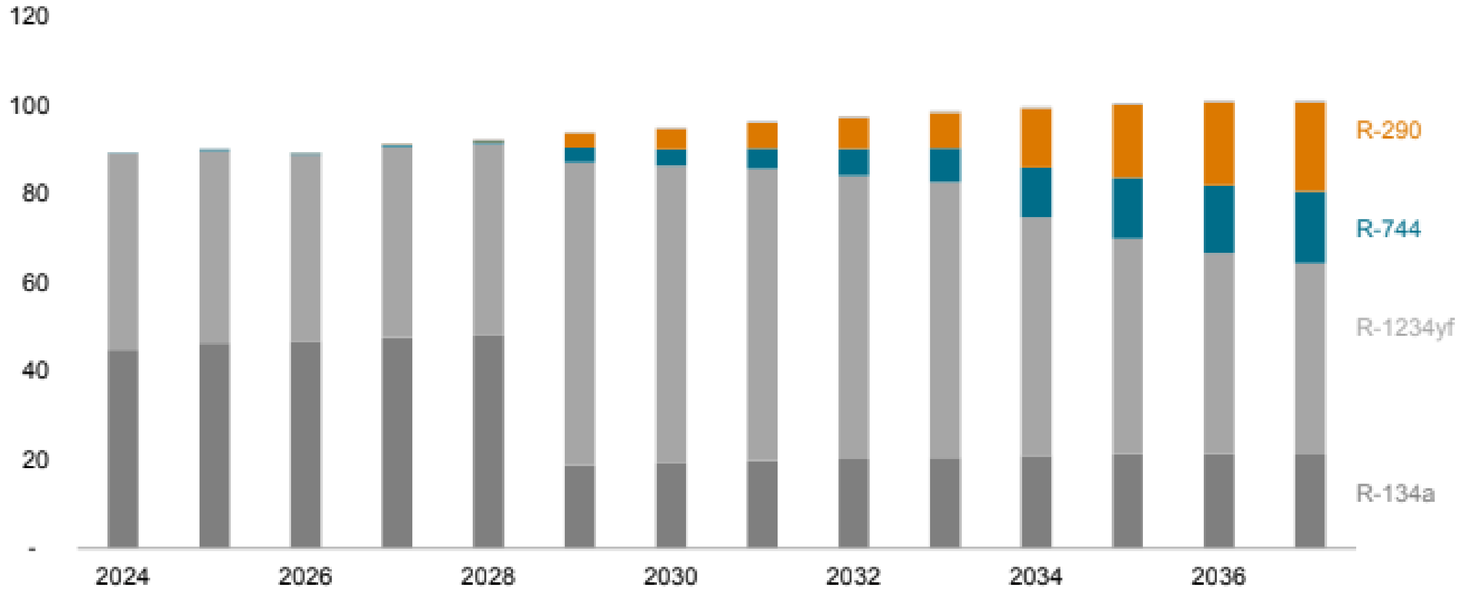
4.Market readiness and current trends

It is about more than emissions…

4. Market readiness and current trends

Natural refrigerants significant demand increase will start in 2029 and will step-up in 2034

Global light vehicle production forecast by AC refrigerant (million units)



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As of September 2025
Source: S&P Global Mobility

S&P Global Mobility

ATMO Summit × TECHNISCHE UNIVERSITÄT BERLIN

Source: S&P Global presentation at ATMO MAC Summit 2025

4. Market readiness and current trends

Hanon Systems Has Built More Than 1 Million CO_2 E-Compressors for Electric Vehicles

September 16, 2025

The e-compressors are supplied to Volkswagen, which uses them in EVs built on its MEB platform

IAA Mobility 2025: Automakers Are Showing 'High Interest' in R290 for Electric Vehicles, Says ZF

September 18, 2025

Potential U.S. regulatory updates are playing a major role in driving interest, according to Benedikt Schauder, Thermal Management Development Lead, ZF

4. Market readiness and current trends

cargo ship in Panama. Photo credit: Victor Puente for Pexels

ATMO MAC: Thermo King Set to Test Direct Expansion R290 Prototype for Maritime Shipping Containers

Related Partner

GIZ and U.K. consultant Re-Phridge are developing a risk assessment for the units that outlines safety standards and operator training

An electric bus in Washington, D.C. Photo credit: Mario Sessions for Unsplash

ATMO MAC: Aurora Involves TÜV Süd in Safety Approach to Develop and Test R290 HVAC for Electric Buses

Related Partner

The company has sold 165 of its R290 MAC systems for electric buses to date

4. Market readiness and current trends

Sebastian Wappler, thyssenkrupp Dynamic Component, presenting at the ATMO MAC Summit 2025 × TU Berlin.

ATMO MAC: In-Vehicle Tests Demonstrate High Performance of CO2 Compressor for EVs, Says Thyssenkrupp

Testing shows the R744 compressor covers the complete operating range efficiently, including effective cabin and battery cooling in temperatures above 40°C

Carsten Wachsmuth, who works in Volkswagen's R&D division on EV thermal management, presenting at ATMOsphere MAC Summit 2024 x TU Berlin.

ATMO MAC: Volkswagen Details the Steps It's Taking to Increase the Efficiency of Its CO2-Based Heat Pump System and Reduce Its Cost

VW's supplier base has greatly expanded, and the automaker now works with more than 17 companies that have experience with R744

4. Market readiness and current trends

Photo credit: DENSO

IAA 2025: DENSO Gives an Update on the R290 MAC Components Its Developing for EVs

NaturalRefrigerants.com spoke with Dr. Werner Hünemörder, Senior Technical Manager/Product Planning & Advanced Engineering, during the show.

Michael Hines October 8, 2025 Mobile Air Conditioning, World

Zhou Yi, Shanghai Highly Electrical Appliances, at the ATMO MAC Summit 2025 × TU Berlin.

ATMO MAC: Shanghai Highly to Begin Mass Production of Integrated R290 EV Thermal Management Module in 2026

The system is built around a scroll compressor, while the Chinese manufacturer is also developing a rotary compressor version

Related Partner

4. Market readiness and current trends

Marc Chasserot, CEO of ATMOsphere, at the ATMO MAC Summit 2025 x TU Berlin.

ATMOsphere Projects Annual TFA Produced by F-Gas Emissions from MAC in Europe to Quadruple by 2034

Leaks of mostly HFO-1234yf are expected to generate a peak level of about 8,000 metric tons of TFA in 2034 but then decline as electric car manufacturers increasingly use natural refrigerants

Spheros's CO2-based thermal management system for buses has been available since 2021. Photo credit: Spheros

Spheros to Debut R290-Based Thermal Management System at Busworld 2025

The new propane unit is the latest addition to Spheros's REVO-E series, which has included an R744-based model since 2021.

Related Partner

4. Market readiness and current trends

A train operated by FInland's national railway, the VR Group. Photo credit: VR Group

Finland's National Railway to Operate 20 Regional FLIRT Trains Equipped with R290 HVAC

Related Partner

Manufacturer Liebherr-Transportation Systems said it is producing the propane-based HVAC systems in series for the first time.

Eberspächer will launch a propane-based version of its AC138 EVO thermal management system in 2026. Photo credit: Eberspächer

Eberspächer to Launch Multiple R290-Based Thermal Management Systems for Buses

Related Partner

The German manufacturer plans to introduce propane versions of its AC138 EVO and AC135 systems in 2026.

4. Market readiness and current trends

CO2-Qube on display at Agritechnica 2025. Photo credit Thyssenkrupp Automotive.

Agritechnica 2025: Konvekta Showcases CO2-Qube Thermal Management System for Electric Heavy Equipment

The system, with prototypes undergoing performance testing, incorporates the company's CO2 heat pump technology.

Konvekta's CO2 heat pump for electric double-decker buses. (Source: Konvekta)

Konvekta's CO_2 Heat Pump Nominated for Busworld Innovation Award 2023

The German manufacturer's R744 heat pump provides energy-efficient air-conditioning and heating for electric double-decker buses.

4. Market readiness and current trends

> 1.000.000 R744 Systems
(2020 - August 2025)

4. Market readiness and current trends

>1 Million MAC systems with R744 in VW MEB

Volkswagen ID.3

Volkswagen ID.4

Volkswagen ID.5

Volkswagen ID.7

Cupra Born

Cupra Tavascan

Audi Q4 etron Sportback

Audi Q4 etron

Škoda Elroq

Škoda Eniaq

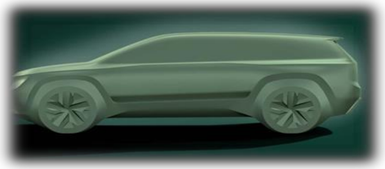
Škoda Eniaq Coupe

Volkswagen ID Buzz

Volkswagen ID. Polo

Volkswagen ID. Cross

Cupra Raval



Škoda Vision 75

on

ATMO Summit MAC × TECHNISCHE UNIVERSITÄT BERLIN

BERLIN

23-24 Sept. 2025

ATMO sphere

25th Ozone Panel, Istanbul

Clean Cooling and Heating Matters

It is about more than emissions……

Resources

ATMO MAC Summit 2025
https://atmo.org/events/atmosphere-mac-summit-2025-x-tu-berlin/

ATMO MAC Summit 2024
https://atmo.org/events/atmosphere-mac-summit-2024-x-tu-berlin/

ATMOsphere
https://atmosphere.cool/knowledge/

Natural Refrigerants news
https://naturalrefrigerants.com/news//

Thank you for listening.

Find out more on

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