



Online event

14th Feb. 1pm CET

PFAS: a growing concern for the HVAC&R industry

Join us for this online event to gain a comprehensive overview of the latest insights on PFAS, TFA and how they are connected to heating and cooling

Moderated by
Marc Chasserot, CEO of ATMOsphere

PFAS

A growing concern in the HVACR industry

Prof. Dr.-Ing. habil. Michael Kauffeld

Institute of Refrigeration, Air Conditioning and Environmental Engineering
Karlsruhe University of Applied Science

Prof. Michael Kauffeld





Michael Kauffeld



1986



Zeotropic refrigerant mixtures



Zeotropic refrigerant mixtures, air cycle - R729

1992



Micro channel HX, flat oval tube condenser
CO₂ car air conditioning

1994



Small ammonia systems, CO₂, ice slurry,
hydrocarbons, water as refrigerant

2002



Ice slurry, PCMs, solar powered ejector cooling, low charge systems, oil free refrigeration,
micro channel heat exchangers, air cycle, N₂O, heat pumps and ground probes

2008



Smart controls, micro channel HX (6-month research stay)



InspirING®



2018



Steinbeis-Transferzentrum
Kälte- und Klimatechnik – ST2K

Technology transfer to industry

2020



CO₂ refrigeration systems
(6-month research stay)

NatRefs, TFA and PFAS

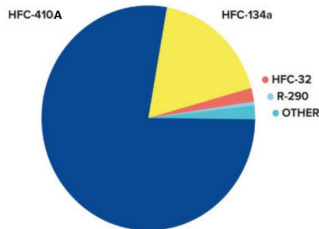
Other Occupations:

- Fellow ASHRAE
- **Member UNEP RTOC (since 1997)**
- IIR Past President Commission B2 (2011 – 2015)
- President IIR Ice Slurry Working Group (until 2005)

Innosuisse Project: PFAS- free heating and cooling solutions

- Heat pumps – a key for the energy transition,
but are heat pumps a clean heating / cooling solution?
- Renewable, environmental-friendly energy can be harvested by HPs from ground, water, air or waste heat, but **problem with F-gas refrigerants** used in most current HVACR systems together with some **components that are not PFAS-free**

Refrigerants used in Swiss Heat Pumps in 2019



- 80% of hydronic heat pumps sold in 2019 contained **HFC-410A**
- **HFC-134a** is the second most common.
- The other two refrigerants in use are **HFC-32 and R-290** and, **by 2023**, their use is expected to increase - representing a **move away from HFC-410A**

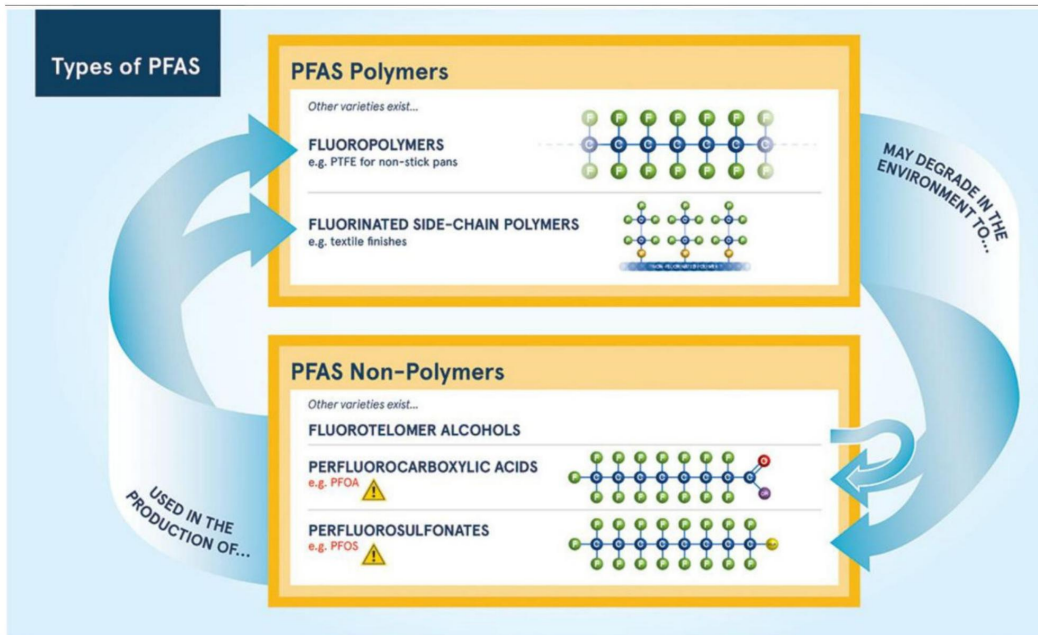
Why are F-gases a problem?

- Depletion of the ozone layer (CFCs)
Several decades atmospheric lifetime
- Global warming due to CFCs, HCFCs, HFCs and atmospheric breakdown product of some HFOs (HFC-23)
HFCs several years atmospheric lifetime
HFOs a few days atmospheric lifetime
- Acidification of our water by TFA (atmospheric breakdown product of many HFCs/HFOs)
TFA a few months atmospheric life time
But thousands of years in groundwater!
- Poisonous combustion products (hydrogen fluoride (HF), a toxic and potentially lethal gas)

Forever Chemical

TFA is the smallest PFOA – a sub-group of PFAS

PFAS – Per- and polyfluoroalkyl substances



<https://www.pfasfree.org.uk/about-pfas/pfas-science-the-basics>

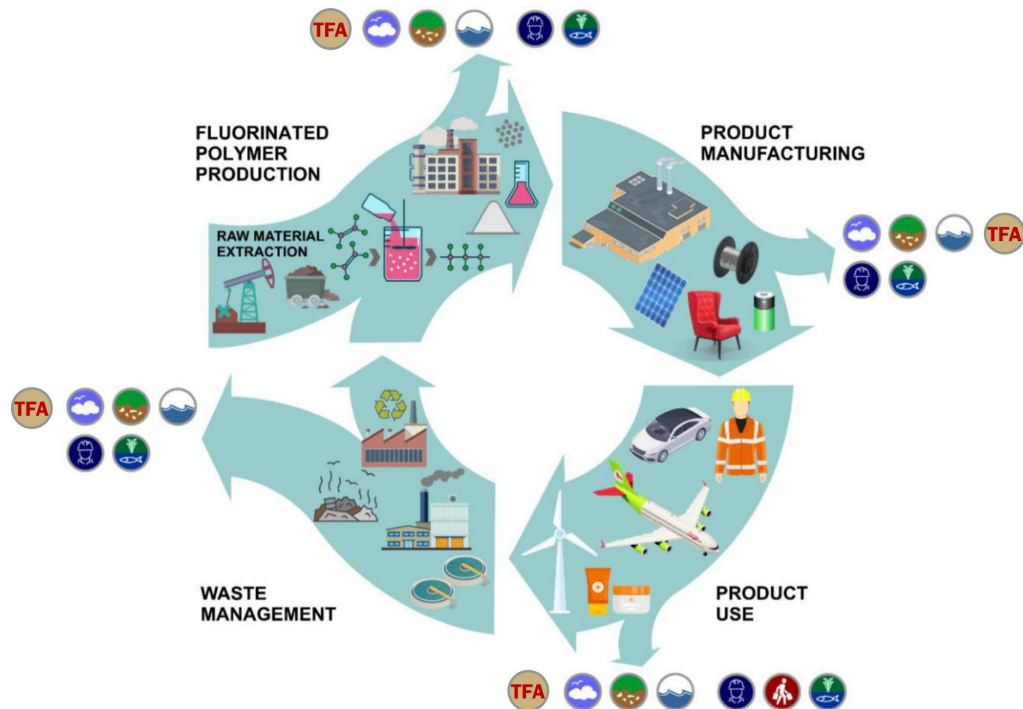


PFAS
found in these products
... and many more

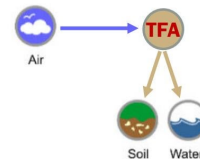
Outdoor clothing	Waterproofing spray	baking paper	ski wax
Fire extinguisher	Cosmetics spray	Coated frying pans	Dental floss
Fast food packaging	Pesticides	electronics power electron.	paint

<https://www.prosieben.de/serien/galileo/news/pfas-warum-die-ewigen-chemikalien-verboten-werden-sollen-330067>

The lifecycle of fluorinated products from feedstock extraction to end of life



TFA
as atmospheric breakdown product

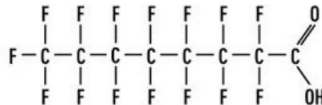


Emissions:



Exposure:



[illegible]FC(F)(F)C(=O)O

www.bola.de

❄ ❄ ❄ © Prof. Dr.-Ing. habil. Michael Kauffeld ❄ ❄ ❄

Safety Data Sheet

Skin corrosion produces an irreversible damage to the skin; namely, visible necrosis through the epidermis and into the dermis. Spillage and fire water can cause pollution of watercourses.

If swallowed, danger of perforation of the esophagus and the stomach (strong corrosive effects).

Harmful if inhaled.

Causes severe skin burns and eye damage.

Serious eye damage/eye irritation

Causes serious eye damage.

article number: 6957

Classification acc. to GHS

Section	Hazard class	Cat-egory	Hazard class and category	Hazard statement
2.16	Substance or mixture corrosive to metals	1	Met. Corr. 1	H290
3.1I	Acute toxicity (inhal.)	4	Acute Tox. 4	H332
3.2	Skin corrosion/irritation	1A	Skin Corr. 1A	H314
3.3	Serious eye damage/eye irritation	1	Eye Dam. 1	H318
4.1C	Hazardous to the aquatic environment - chronic hazard	3	Aquatic Chronic 3	H412

For full text of abbreviations: see SECTION 16

The most important adverse physicochemical, human health and environmental effects

Skin corrosion produces an irreversible damage to the skin; namely, visible necrosis through the epidermis and into the dermis. Spillage and fire water can cause pollution of watercourses.

SECTION 4: First aid measures

4.1 Description of first aid measures



General notes

Take off immediately all contaminated clothing. Self-protection of the first aider.

Following inhalation

Provide fresh air. In all cases of doubt, or when symptoms persist, seek medical advice.

Following skin contact

After contact with skin, wash immediately with plenty of water. Immediate medical treatment required because corrosive injuries that are not treated are hard to cure.

Following eye contact

In case of contact with eyes flush immediately with plenty of flowing water for 10 to 15 minutes holding eyelids apart and consult an ophthalmologist. Protect uninjured eye.

Following ingestion

Rinse mouth immediately and drink plenty of water. Call a physician immediately. If swallowed danger of perforation of the esophagus and the stomach (strong corrosive effects).

4.2 Most important symptoms and effects, both acute and delayed

Corrosion, Gastric perforation, Nausea, Vomiting, Unconsciousness, Headache, Circulatory collapse, Dyspnoea, Pulmonary oedema, Risk of serious damage to eyes, Risk of blindness

4.3 Indication of any immediate medical attention and special treatment needed

Treat symptomatically.

<https://www.carlroth.com/medias/SDB-6957-GB-EN.pdf?context=bWZldGVyfiHNiYVvaXRSRGRFOFYkNoZWV0c3wzMTIwNDI8YXBwbGljYXRpb24vcGlmfGEFZeFMmMhsTnK4NUrUyVVPVFtURRncSUUXIMMFUwW4Mk9UVTNYMGRWDWBTOxuQmtaZ3wzYmYwJfYeJNtK3Mdms40N2NmYwGwFNmE1MzYyZkZDIjYmM3YiA5YUlucNi1Ni1MjZTKjYm>

Effects of PFAS on human health



— High certainty

---- Lower certainty

Developmental effects
affecting the unborn child

Delayed mammary gland development

Reduced response to vaccines

Lower birth weight

Obesity

Early puberty onset

Increased miscarriage risk
(i.e. pregnancy loss)

Low sperm count and mobility

Thyroid disease

Increased cholesterol levels

Breast cancer

Liver damage

Kidney cancer

Inflammatory bowel disease
(ulcerative colitis)

Testicular cancer

Increased time to pregnancy

Pregnancy induced
hypertension/pre-eclampsia
(increased blood pressure)

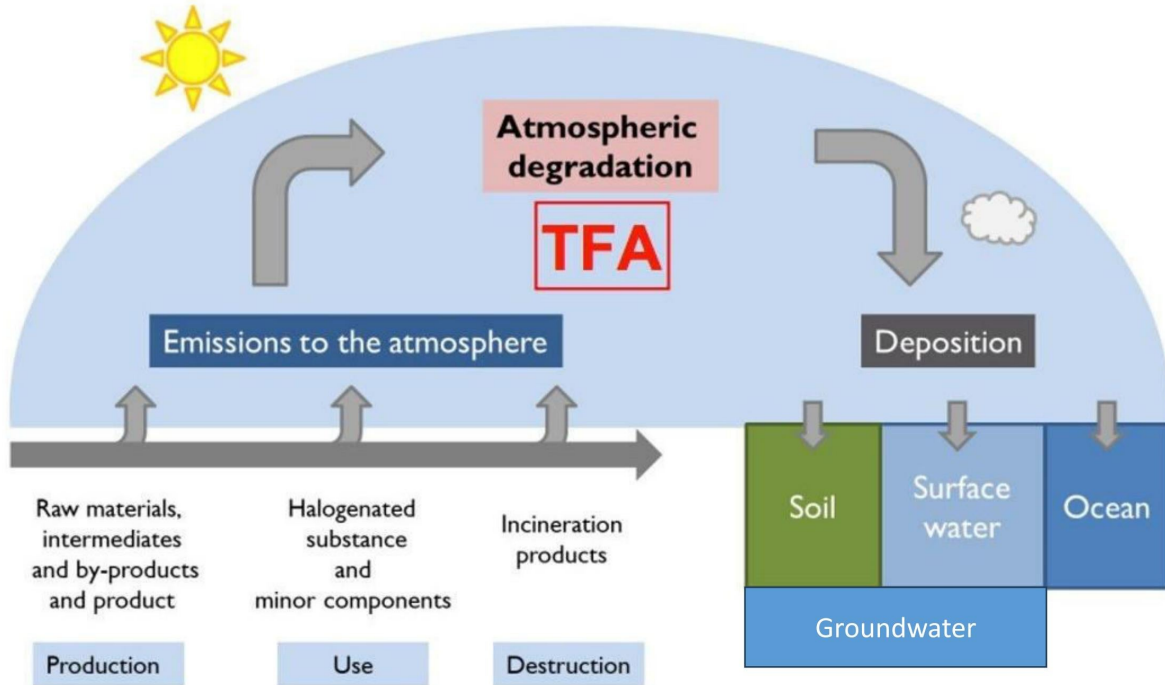
There are indications from
mammalian toxicity studies that
**TFA is toxic to reproduction and
that it exhibits liver toxicity**

Arp., H.P.H.; Gredelj, A.; Glüge, J.; Scheringer, M.; Cousins, I.T.: The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA). *Environ. Sci. Technol.* 2024, 58, <https://doi.org/10.1021/acs.est.4c06189>

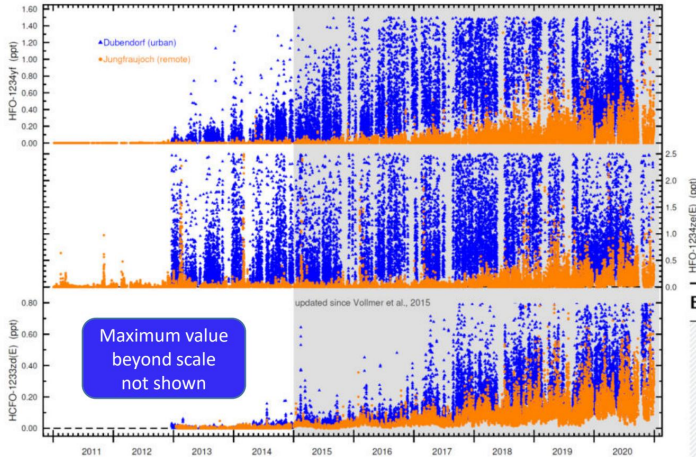
US National Toxicology Program, (2016); C8 Health Project Reports, (2012); WHO IARC, (2017); Barry et al., (2013); Fenton et al., (2009); and White et al., (2011). <https://www.eea.europa.eu/publications/emerging-chemical-risks-in-europe>



Possible sources for TFA in groundwater



Where does the TFA come from?



Results are expressed as dry-air mole fractions in parts-per-trillion (ppt, pmol mol^{-1}).

Blue - urban (Dubendorf); orange - remote (Jungfrauoch)

To expand the y-axes for better illustration of some of the smaller mole fractions, the results are omitted above the largest tick mark labels for each compound.

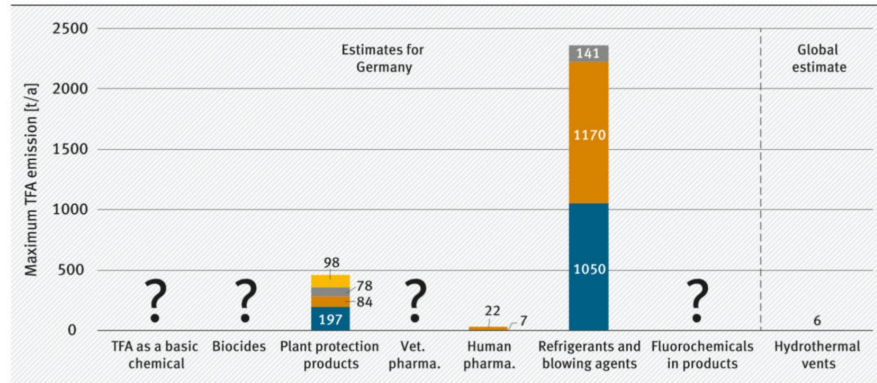
<https://www.empa.ch/documents/56101/190047/HFO+update+Report/fe3b26b5-fcb6-4cd9-a6f6-5c39ac01f20a>

Estimate of the potential quantity of **TFA from refrigerants** and blowing agents for the year 2020 on the basis of expected emissions **in Germany** and rates of TFA formation.

(blue: TFA from R-134a; orange: R-1234yf; grey: other refrigerants)

Adlunger, K.; et al.: Reducing the input of chemicals into waters: trifluoroacetate (TFA) as a persistent and mobile substance with many sources. Background, November 2021

Estimated maximum TFA emissions in t/a for the relevant groups of chemicals*



* Calculated from the respective quantities sold or the emissions (refrigerants and blowing agents), or taken from published model-based estimates (hydrothermal vents)

Source: own diagram, German Environment Agency (data basis: see Notes on Fig. 4)

How much TFA from selected refrigerants with GWP < 750



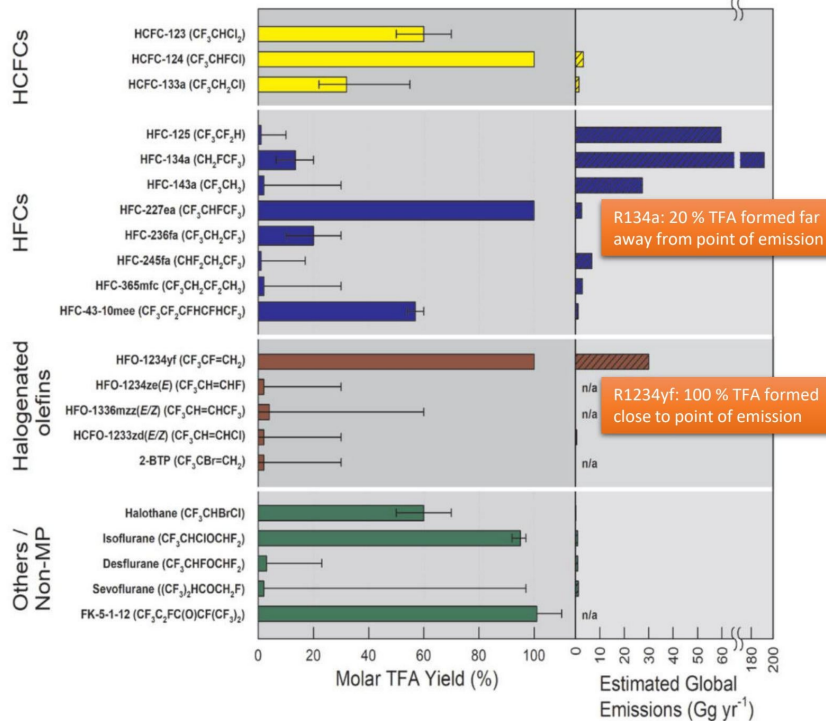
Refrigerant	Additional Information (Blend composed of)	Safety class	Normal boiling point ¹	GWP ₁₀₀ ¹	GWP ₂₀ ¹	TFA formation potential ²	HFC-23 formation potential ³
R-32	Used pure and in blends	A2L	-52 °C	749	2 620	-	-
R-125	Only in blends below GWP = 750	A1	-49 °C	3 820	6 790	-	-
R-134a	Only in blends below GWP = 750	A1	-26 °C	1 470	4 060	7-20 %	-
R-227ea	Only in blends below GWP = 750	A1	-15.6 °C	3 580	5 830	100 %	-
R-450A	R-134a and R-1234ze(E)	A1	-23.4/-22.8 °C	618	1 708	up to 14 %	0.8 - 2.6 %
R-452B	R-125, R-32 and R-1234yf	A2L	-51.0/-50.3 °C	769	2 231	26 %	-
R-454B	R-32 and R-1234yf	A2L	-50.9/-50.0 °C	516	1 806	31 %	-
R-454C	R-32 and R-1234yf	A2L	-46.0/-37.8 °C	162	565	79 %	-
R-455A	R-32, R-1234yf and R-744	A2L	-51.6/-39.1 °C	162	565	76 %	-
R-513A	R-134a and R-1234yf	A1	-29.2 °C	647	1 788	up to 65 %	-
R-1233zd(E)	Used pure and in blends	A1	18.1 °C	0.0651	4	up to 10 %	1.3 - 4.4 %
R-1234yf	Used pure and in blends	A2L	-29.4 °C	0.0268	< 1	100 %	-
R-1234ze(E)	Used pure and in blends	A2L	-19 °C	0.0459	1	up to 10 %	1.3 - 4.4 %
R-1233zd(E)	Used pure and in blends	A1	18.1 °C	0.0651	4	up to 10 %	1.3 - 4.4 %

¹ Normal boiling point and GWP values from UNEP RTOC 2022

² TFA formation rate from Behringer et al.: Umwelt- und Klimaauswirkungen natürlicher und halogener Kältemittel in Flüssigkeitskühlsätzen und Verflüssigungssätzen. German UBA (2024)

³ HFC-23 formation rate from Pérez-Peña et al. (2023) Pérez-Peña, M.P.; Fisher, J.A.; Hansen, C.; Kable, S.H. (2023): Assessing the atmospheric fate of trifluoroacetaldehyde (CF₃CHO) and its potential as a new source of fluoroform (HFC-23) using the AtChem2 box model. Environ. Sci.: Atmos., 3, 1767-1777

How much TFA from selected refrigerants & global emissions



Yields of trifluoroacetic acid (TFA) from selected individual chlorofluorocarbon (CFC) replacement compounds, as well as the estimated global emissions of these compounds.

The figure also includes selected compounds not under the purview of the Montreal Protocol.

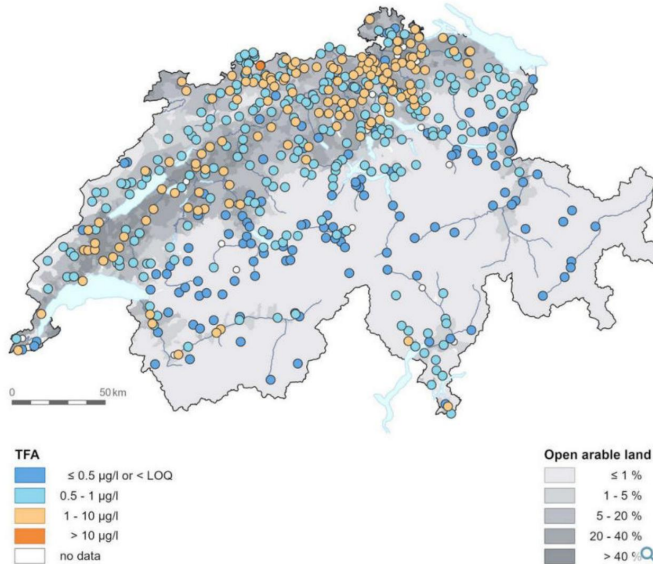
Error bars represent both experimental uncertainties and upper and lower yield ranges due to competing reaction channels that depend on environmental conditions.

The yields of TFA from individual compounds are estimated based on evaluations of the available literature.

Note split scale for the emission of HFC-134a is much higher than that of other compounds.

<https://ozone.unep.org/system/files/documents/EEAP-2022-Assessment-Report-May2023.pdf>

TFA in Switzerland



TFA in groundwater. Data: NAQUA 2022/2023

<https://www.bafu.admin.ch/bafu/en/home/topics/water/info-specialists/state-of-waterbodies/state-of-groundwater/groundwater-quality/tfa-im-grundwasser.html>

When selecting an HVACR system,
no criteria for PFAS-free equipment exist.

But various criteria for permitting, consulting, planning, etc.

TFA in Switzerland



TFA found in all Swiss lakes (0,25 to 0,91 µg/L)



Trifluoroacetat – für immer in unserem
Trinkwasser? | Naturschutz.ch

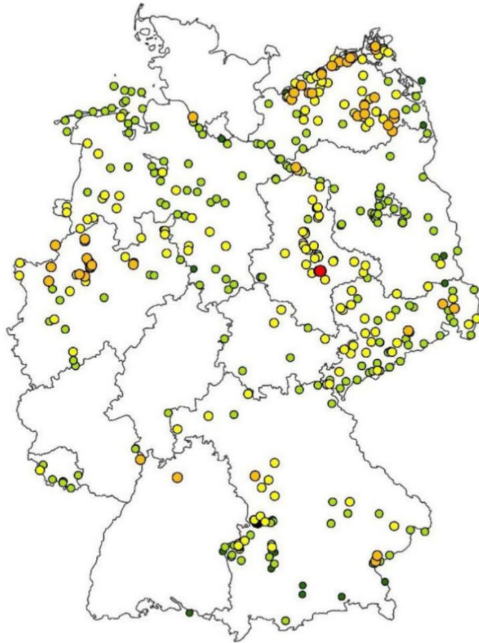
- ✎ Swiss drinking water 0,25 to 0,80 µg/L TFA
- ✎ via process water TFA also present in beer

In 104 beer samples from 23 countries,
**TFA was detected up to 51 µg/L with a
median concentration of 6.1 µg/L.**

Scheurer, M.; Nödler, K.: Ultrashort-chain perfluoroalkyl
substance trifluoroacetate (TFA) in beer and tea – An
unintended aqueous extraction, Food Chemistry, Volume 351,
2021, <https://doi.org/10.1016/j.foodchem.2021.129304>

No longer only water, hops and barley ☹
German purity law from 1516

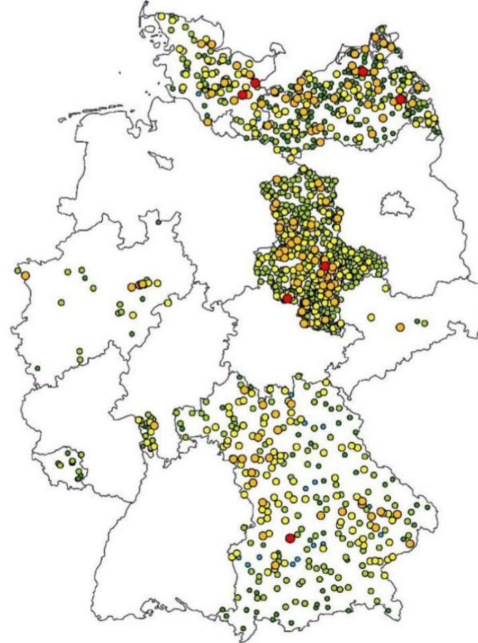
TFA in surface water and groundwater in Germany



Legend

Median TFA concentrations
at individual surface water
sampling sites in µg/L

- > 0.1 - 0.3
- > 0.3 - 1.0
- > 1.0 - 3.0
- > 3.0 - 10
- > 10 - 30



Legend

Median TFA concentrations at
individual groundwater
sampling sites in µg/L

- <= 0.1
- > 0.1 - 0.3
- > 0.3 - 1.0
- > 1.0 - 3.0
- > 3.0 - 10
- > 10 - 30

Source: own illustration, TZW.

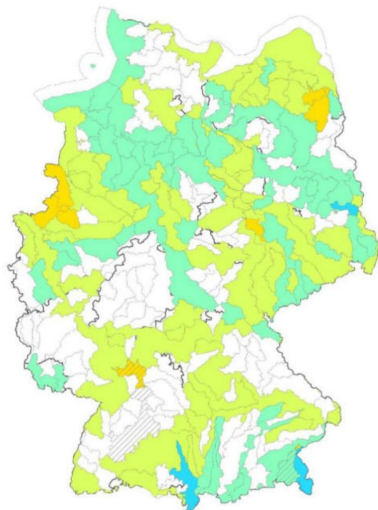
Source: own illustration, TZW.

German UBA: Trifluoroacetate (TFA): Laying the foundations for effective mitigation. Spatial analysis of the input pathways into the water cycle. Texte | 167/2023. December 2023

TFA in rivers and ground water in Germany



Average median TFA concentrations and maximum TFA concentrations in river catchments with an area > 500 km² in µg/L

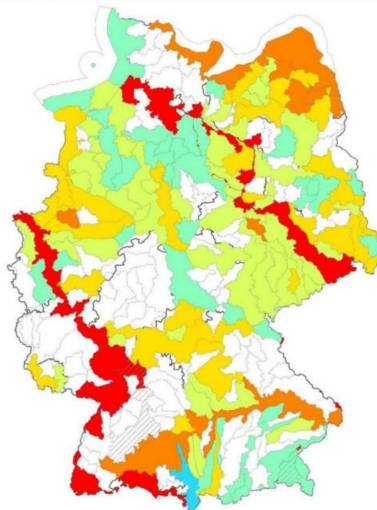


Average median TFA concentration per catchment in µg/L



Catchment area of Neckar and Alz*

TZW
Technologiezentrum



Maximum TFA concentration per catchment in µg/L

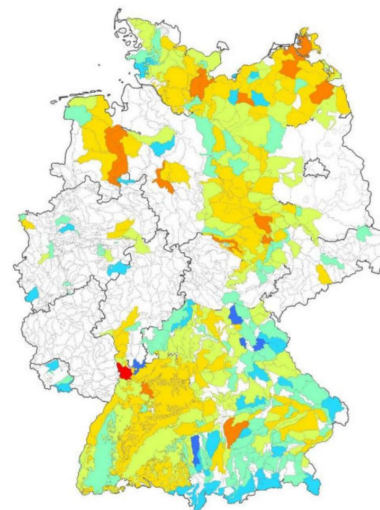


Catchments of Neckar and Alz*

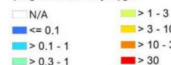
TZW
Technologiezentrum
Wasser



Maximum TFA in groundwater bodies in µg/L

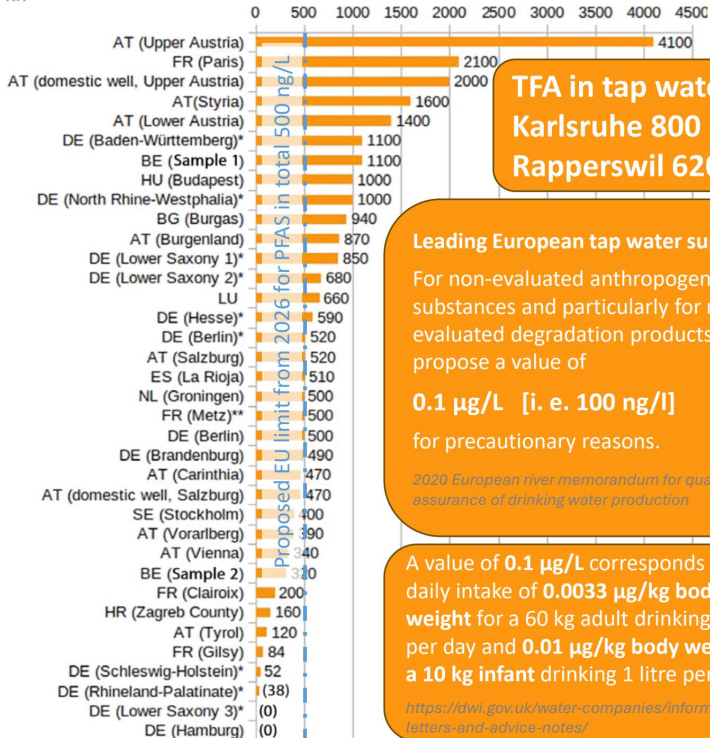


Maximum TFA concentration per groundwater body in µg/L



TZW
Technologiezentrum
Wasser

TFA – a forever chemical in the water we drink



**TFA in tap water in
Karlsruhe 800 ng/L
Rapperswil 620 ng/L**

Leading European tap water suppliers:

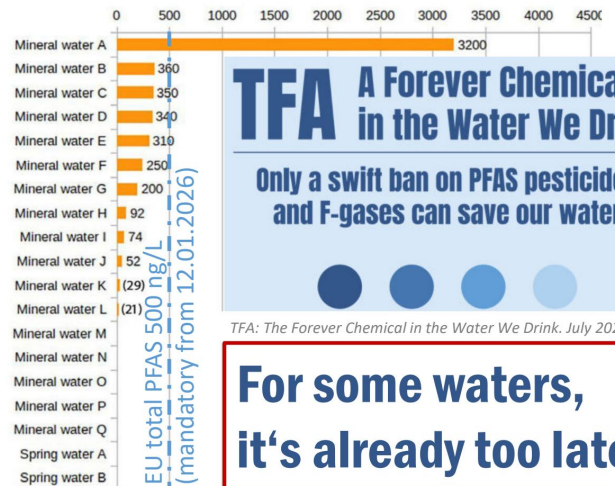
For non-evaluated anthropogenic substances and particularly for non-evaluated degradation products propose a value of

0.1 µg/L [i. e. 100 ng/l]
for precautionary reasons.

2020 European river memorandum for quality assurance of drinking water production

A value of **0.1 µg/L** corresponds to a daily intake of **0.0033 µg/kg body weight** for a 60 kg adult drinking 2 litres per day and **0.01 µg/kg body weight** for a 10 kg infant drinking 1 litre per day

<https://dwi.gov.uk/water-companies/information-letters-and-advice-notes/>



**TFA A Forever Chemical
in the Water We Drink**

**Only a swift ban on PFAS pesticides
and F-gases can save our water**



TFA: The Forever Chemical in the Water We Drink. July 2024

**For some waters,
it's already too late!**

↑ TFA in mineral and spring waters in ng/L

⇐ TFA in tap waters in ng/L (34 public, 2 private sources)

**TFA detected in 34 of 36 European tap water samples (94 %)
from 11 EU-countries**

**TFA detected in 12 of 19 bottled mineral and
spring waters (63 %)**

Removing TFA from the water we drink



For now, water providers in the U.S. are preparing to comply with EPA's new limits on PFAS in drinking water.*¹⁾ Cost concerns are already on the horizon. To comply, **many utilities will turn to a filtration method known as granular activated carbon treatment**, Steve Via, manager of federal relations at the American Water Works Association, said.

TFA is extremely small, mobile and water soluble. As a result, it cannot be removed from water using the filtration systems that many communities are installing now for large, widely studied forever chemicals, said Rainer Lohmann, a professor of oceanography at the University of Rhode Island.

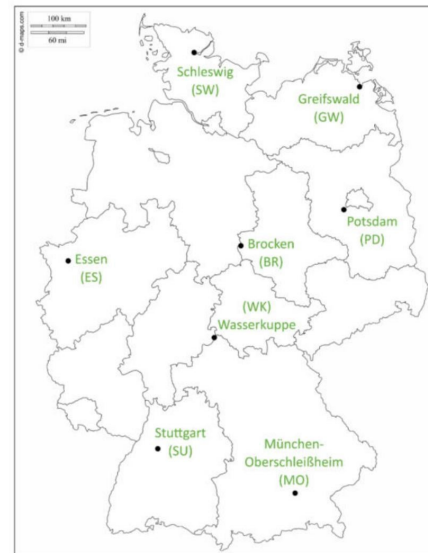
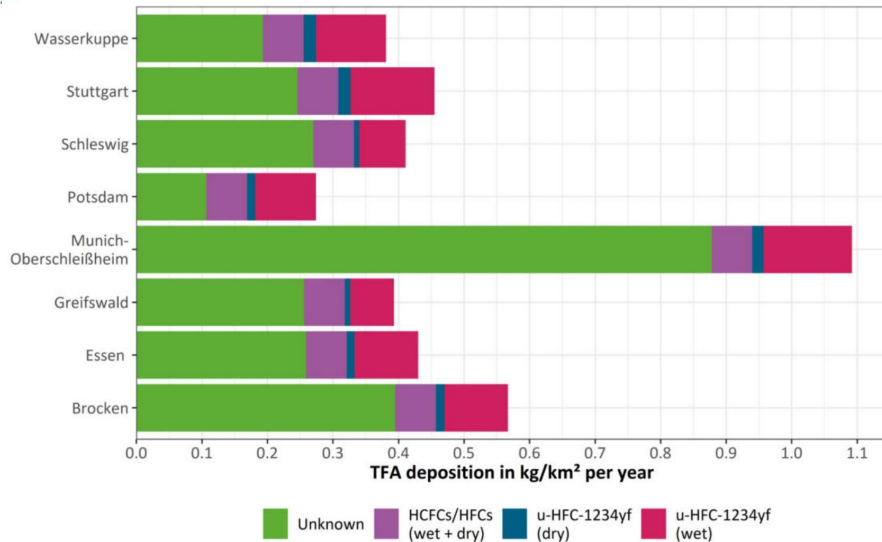
By comparison, **the main filtration method for smaller forever chemicals like TFA is known as reverse osmosis. That system is more expensive and more energy-intensive**, and it creates PFAS-laden wastewater that is not easy to dispose of, Via said.

**¹⁾ Currently, EPA does not define TFA as a PFAS, but some scientists and environmental groups say that it should be classified as such.*

<https://www.eenews.net/articles/youve-probably-never-heard-of-this-forever-chemical-scientists-say-its-everywhere/>



German UBA Study 2021



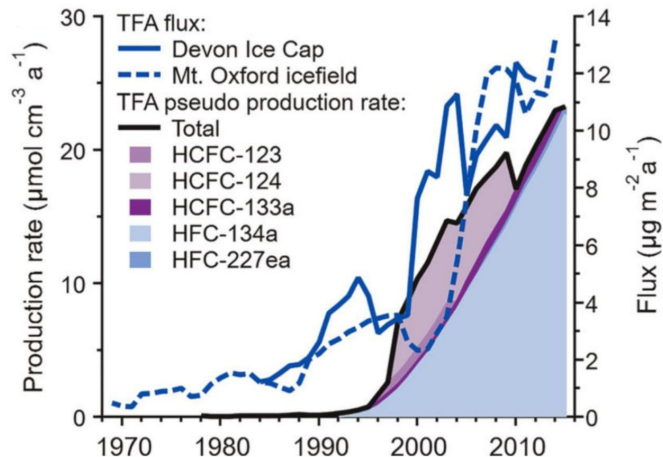
Behringer, D.; Heydel, F.; Gschrey, B.; Osterheld, S.; Schwarz, W.; Warncke, C.; Feeling, F.; Nädler, K.; Henne, S.; Reimann, S.; Bleep, M.; Jörß, W.; Liu, R.; Ludwig, S.; Rüdenauer, I.; Gartscher, S.; (2021), Report No. FB000452/ENG, Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential, Published by German Environment Agency May 2021.

Assuming that the concentrations in Bayreuth in 1995/1996 (Klein 1997) were representative for the whole of Germany, the trifluoroacetate deposition in these periods amounted to 54 to 65 g/km² or 19 to 23 tonnes, which would also be about 3 to 5 times lower than the values determined in February 2018 to January 2020

TFA in Nature – impact of HFCs and HFOs



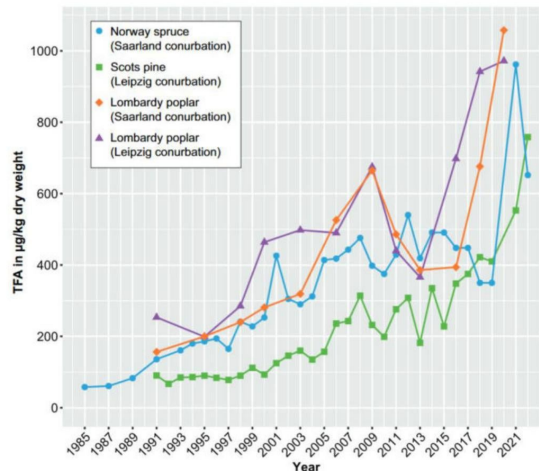
Pseudo production rates and measured deposition fluxes from Devon Ice Cap and Mt. Oxford icefield for TFA



Pickard, H. M., Criscitiello, A. S., Persaud, D., Spencer, C., Muir, D. C. G., Lehnher, I., et al. (2020). Ice core record of persistent short-chain fluorinated alkyl acids: Evidence of the impact from global environmental regulations. *Geophysical Research Letters*, 47, e2020GL087535. <https://doi.org/10.1029/2020GL087535>



Temporal **concentration trends of TFA** in leaf samples from the sampling sites Saarland conurbation and Leipzig conurbation in Germany



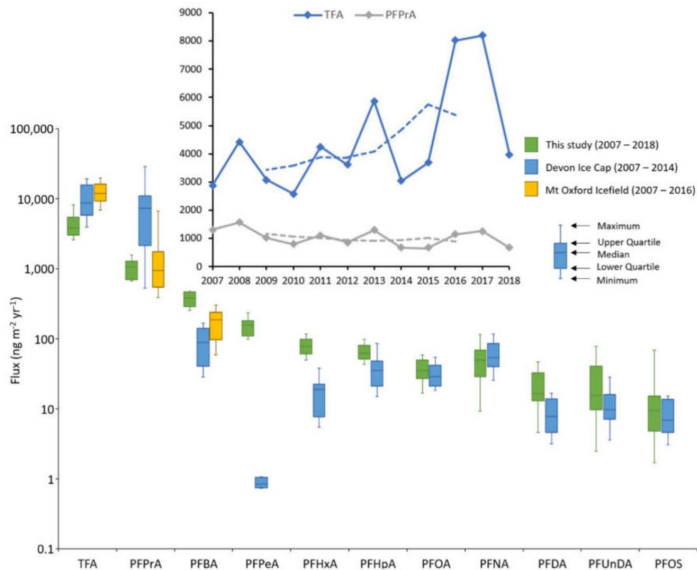
Current Opinion in Green and Sustainable Chemistry

Freeling, F.; Björnsdotter, M.K.: Assessing the environmental occurrence of the anthropogenic contaminant trifluoroacetic acid (TFA), *Current Opinion in Green and Sustainable Chemistry*, Volume 41, 2023, doi.org/10.1016/j.cogsc.2023.100807

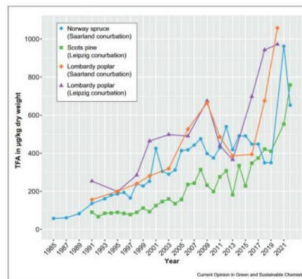
TFA in Nature – Impact of HFO-1234yf



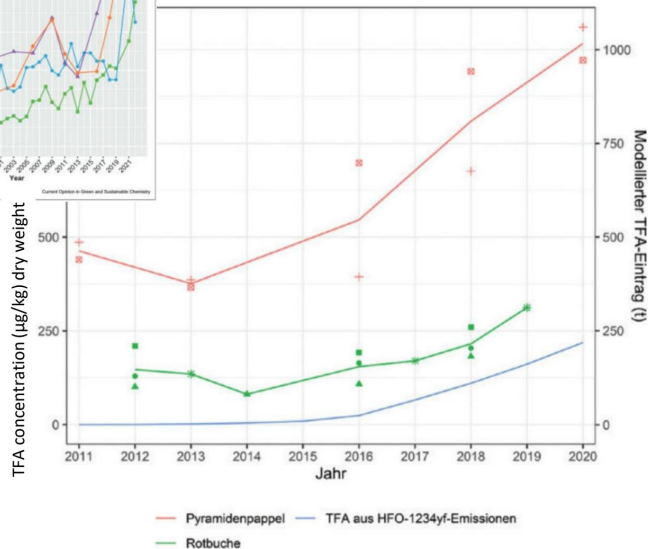
Levels and distribution profiles of PFAS in a high Arctic Svalbard ice core



Hartz, W.F.; Björnsdóttir, M.K.; et al.: Levels and distribution profiles of Per- and Polyfluoroalkyl Substances (PFAS) in a high Arctic Svalbard ice core. *Science of The Total Environment*, Vol. 871, 2023, <https://doi.org/10.1016/j.scitotenv.2023.161830>.

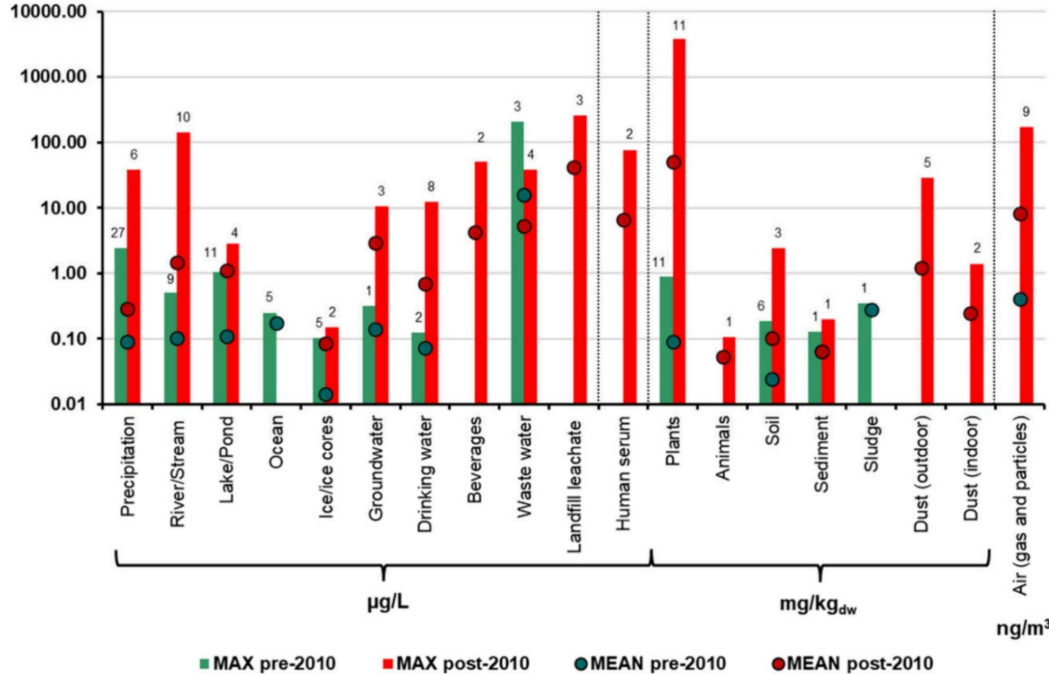


TFA concentration in leaf samples



Behringer, D.: TFA as a persistent degradation product of fluorinated hydrocarbons. *Public Health Forum* 2022; 30(4): 269–272
<https://doi.org/10.1515/pubhef-2022-0077>

TFA concentrations detected in different media before and after 2010



Reported values of **maximum concentrations** found in the literature are shown as **vertical bars**

Mean values of reported monitoring means and medians are shown with **overlapping dots**

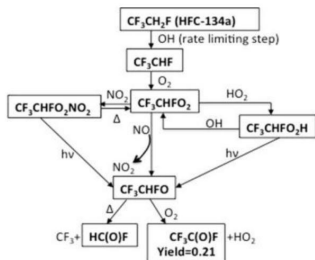
Numbers indicating the number of summarized individual data points are shown above the corresponding bars

Increase in TFA distributions when changing from HFC-134a to HFO-1234yf



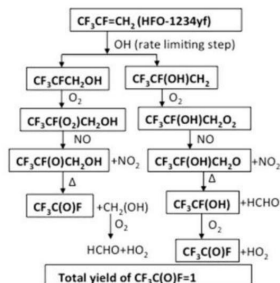
Degradation Mechanisms of (oxidation by OH)

HFC-134a



Yield 21 %

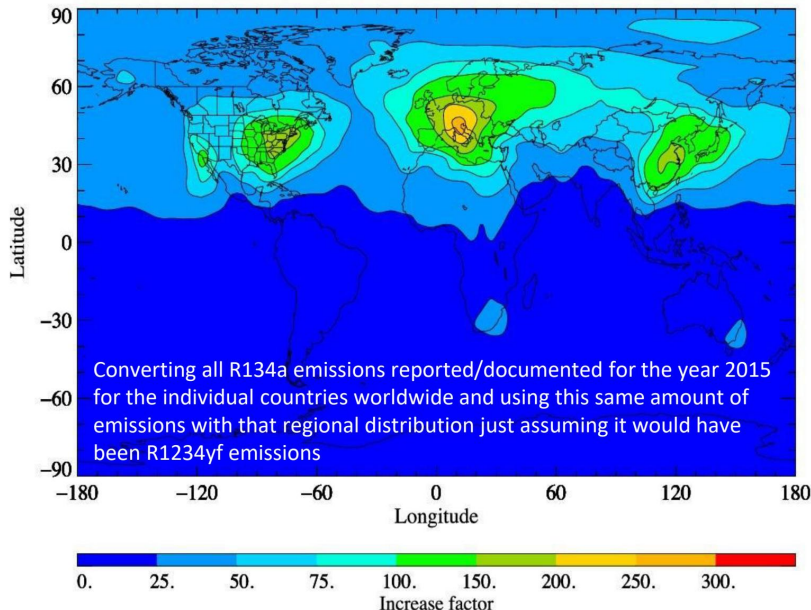
HFO-1234yf



Yield 100 %

For HFO-1234yf, the formations of organic hydroperoxides (reaction between a peroxy radical and HO_2 radicals) and peroxy nitrates (reaction of peroxy radicals with NO_2) from the OH-initiated oxidation products, and their fates, occur in the same way as shown for HFC-134a but are not shown in the diagram.

Holland, R.; Khan, M.A.H.; Driscoll, I.; Chantyal-Pun, R.; Derwent, R.G.; Taatjes, C.A.; Orr-Ewing, A.J.; Carl J. Percival, C.J.; Shallcross, D.E.: 2021. Investigation of the production of Trifluoroacetic Acid from two Halocarbons, HFC-134a and HFO-1234yf and its fates using a global three-dimensional chemical transport model. ACS Earth Space Chem.

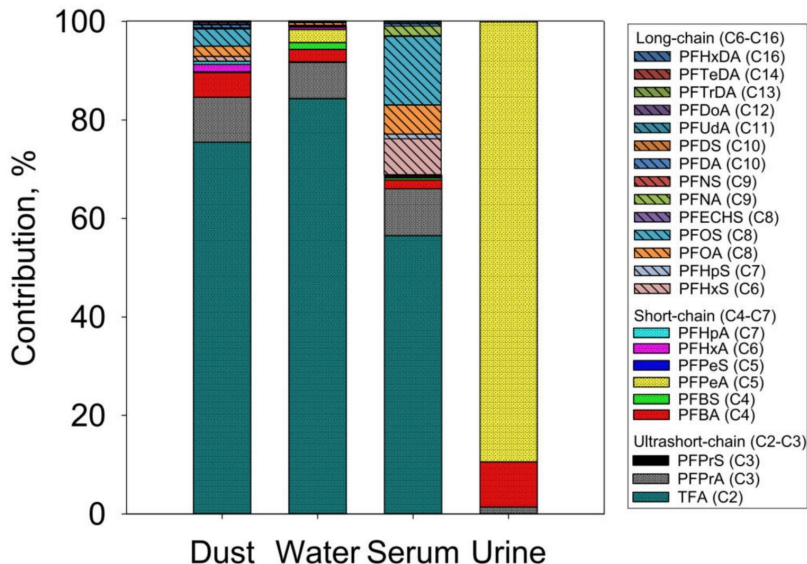
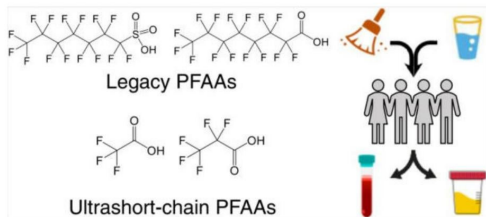


Surface distribution plot depicting the **multiplicative increase in TFA** distributions predicted **by changeover** from the STO-HFC-SCI scenario to the STO-HFO-SCI scenario.

Elevated levels of PFAS in US homes and people

Dust

TFA, a PFAA with the shortest carbon chain, was **detected in 84 %** of the dust samples and was by far the most abundant PFAA (median of 220 ng/g), **contributing 75 % to the dust total PFAA concentration**.



PFAA – perfluoroalkyl acid

In humans, the **half-life** for renal excretion of **TFA** administered intravenously is **16 hours**

Zheng, G.; Eick, S.M.; Salamova, A.: Elevated Levels of Ultrashort- and Short-Chain Perfluoroalkyl Acids in US Homes and People. *Environmental Science & Technology*, 2023, doi: 10.1021/acs.est.2c06715

Kaminsky, L.S.: Toxicology of atmospheric degradation products of selected hydrofluorocarbons. *Dep. Env. Health & Toxicology, State Univ. Of NY at Albany, 1990*

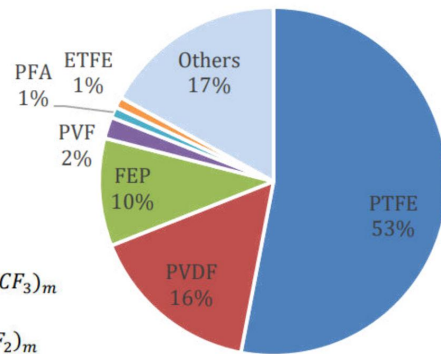


- PFAS only make up a small percentage of a heat pumps weight.
- Main fraction is the refrigerant
- In the environment, 60 % of PFAS is from refrigerants



Examples of common commercial fluorinated polymers and trade names

Abbreviation	Trade name examples	Full name	Repeat unit
PTFE	Teflon, Zonyl	poly(tetrafluoroethylene)	$(CF_2 - CF_2)_n$
PCTFE	Neoflon, Voltalef, Aclon, Aclar, Hostaflon C2, Fluon, Plaskon, Halon	poly(chlorotrifluoroethylene)	$(CF_2 - CClF)_n$
PVF	Tedlar	poly(vinylfluoride)	$(CH_2 - CHF)_n$
PVDF	Kynar, Solef, Hylar	poly(vinylidene fluoride)	$(CH_2 - CF_2)_n$
FEP	Teflon FEP, Neoflon FEP, Dyneon FEP	poly(tetrafluoroethylene-co-hexafluoropropylene)	$(CF_2 - CF_2)_n \cdots (CF_2 - CFCF_3)_m$
ETFE	FluonETFE, Tefzel, Neoflon	poly(ethylene-co-tetrafluoroethylene)	$(CH_2 - CH_2)_n \cdots (CF_2 - CF_2)_m$
ECTFE	Halar ECTFE	poly(ethylene-co-chlorotrifluoroethylene)	$(CH_2 - CH_2)_n \cdots (CClF - CF_2)_m$
PFA	Teflon-PFA, Hostaflon-PFA, Chemfluor	poly(tetrafluoroethylene-co-perfluoropropylvinylether)	$(CF_2 - CF_2)_n \cdots (CF_2 - CFO - C_3F_7)_m$
PFPE	Krytox, Fomblin, Galden, Fluorolink, Demnum	per- and polyfluoropolyethers	various (often copolymers with an ether polymer backbone with F atoms directly attached to carbon backbone)
FKM, FFKM, FEPM	Viton, Aflas, Kalrez, Daiel, Silastic	fluoroelastomers, perfluoroelastomers, tetrafluoroethene-propene rubbers	various



Global consumption of fluorinated polymers in 2018, 320 300 tonnes

PFAS can be measured in samples

- Attenuated total reflectance – ATR with a diamond crystal
- Integrated sphere measurement for very accurate measurements



<https://www.spectroscopyworld.com/product/new-compact-ft-ir-spectrometer?page=1>



PFAS containing components in a heat pump



heat pump/component production

PFAS in production process – a selection

utilities

- solvents
- cleaning agents

electronics:

- photolithography
- antireflective coatings
- developers
- rinsing solutions
- etching
- vacuum pumps
- vapor phase soldering
- components
- inert equipment

Heim LWKMasp 1-30 (reversible)

Outdoor air to water heat pump

Heating capacity 30 kW

Total mass of this heat pump 800 kg

PFAS 11.4 kg (1.4 %) (11 kg of 22 kg R410A is R32, i.e. no PFAS)

Fraction of refrigerant of total PFAS 11.0 kg (97 % of PFAS)



© Heim AG

Component	Material	Quantity	Unit	Material	Quantity	Unit	Material	Quantity	Unit
Compressor	Compressor	1	kg	Compressor	1	kg	Compressor	1	kg
Condenser	Condenser	1	kg	Condenser	1	kg	Condenser	1	kg
Evaporator	Evaporator	1	kg	Evaporator	1	kg	Evaporator	1	kg
Expansion valve	Expansion valve	1	kg	Expansion valve	1	kg	Expansion valve	1	kg
Refrigerant	Refrigerant	22	kg	Refrigerant	22	kg	Refrigerant	22	kg
...	...	...	...	...	...	...	...	...	...

element



element level 2



element level 3



REACH proposal

Proposed restriction of around 10 000 per- and polyfluoroalkyl substances (PFASs)



European
Commission



ECHA carries out tasks related to the implementation of the EU's chemicals legislation and policy.



2025 Decision of EU Commission

Changeover timeframe 1.5 to 13.5 years

12 years service on existing systems allowed

REACH regulation is the main EU chemicals safety law

REACH introduced in 2006 to better protect people, wildlife, and the environment from harmful chemicals, while enhancing competitiveness and innovation towards safer chemicals.

But we are facing a chemical pollution problem and REACH is not up to the task.

Our lives have been silently polluted by harmful chemicals. Study after study shows that toxic chemicals are found in our everyday products¹, our drinking water² and in our bodies³. And we are finding more and more health problems linked to them: cancers^{4, 5}, reduction in children's IQ⁶ and infertility^{7, 8}.

¹ BEUC, 2024. Repository of consumer products tested for harmful chemicals since 2017 until present

² CHEM Trust, 2023. PFAS water contamination scandals unfold across Europe

³ E. Govarts et al, 2023. Harmonized human biomonitoring in European children, teenagers and adults: EU-wide exposure data of 11 chemical substance groups from the HBM4EU Aligned Studies (2014–2021)

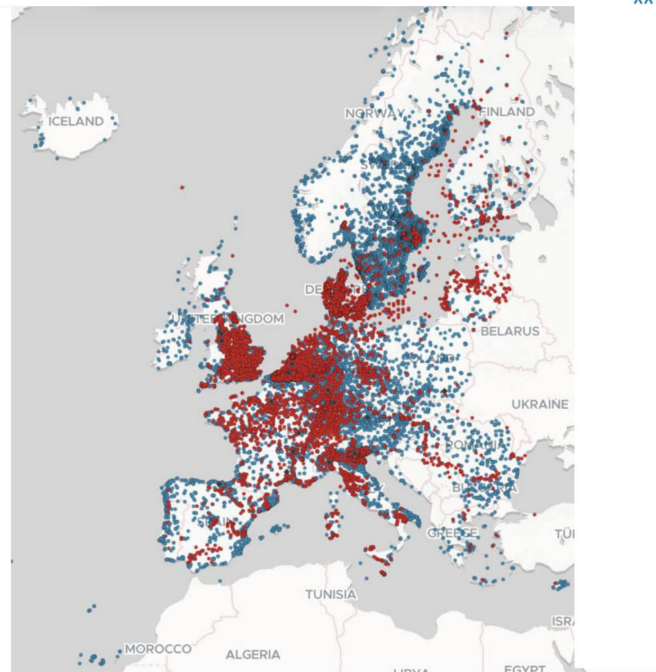
⁴ Breast Cancer UK, 2022. BCUK Briefing: Bisphenols and Breast Cancer

⁵ European Environment Agency, 2019. Emerging chemical risks in Europe - 'PFAS'

⁶ CHEM Trust, 2017. No Brainer: The impact of chemicals on children's brain development: a cause for concern and a need for action

⁷ Levine et al, 2017. Temporal trends in sperm count: a systematic review and metaregression analysis. Human Reproduction Update

⁸ Kortenkamp et al, 2022. Combined exposures to bisphenols, polychlorinated dioxins, paracetamol, and phthalates as drivers of deteriorating semen quality. Environment International



● Known contamination ● Known PFAS User ● Presumptive contamination ◆ PFAS manufacturing facility

Source: Forever Pollution Project

<https://chemtrust.org/wp-content/uploads/ABCs-of-REACH-2024.pdf>

EU is not alone



US EPA PFAS National Primary Drinking Water Regulation

On April 10, 2024, US EPA announced the final **National Primary Drinking Water Regulation (NPDWR) for six PFAS**. EPA expects that over many years the final rule will prevent PFAS exposure in drinking **water for approximately 100 million people**, prevent thousands of deaths, and reduce tens of thousands of serious PFAS-attributable illnesses.

EPA is also making unprecedented funding available to help ensure that all people have clean and safe water. In addition to the final rule, EPA announced [\\$1 billion in available funding through the Infrastructure Investment and Jobs Act](#) to help states and territories implement PFAS testing and treatment at public water systems and to help owners of private wells address PFAS contamination.

EPA established legally enforceable levels, called Maximum Contaminant Levels (MCLs), for six PFAS in drinking water: PFOA, PFOS, PFHxS, PFNA, and HFPO-DA as contaminants with individual MCLs, and PFAS mixtures containing at least two or more of PFHxS, PFNA, HFPO-DA, and PFBS using a Hazard Index MCL to account for the combined and co-occurring levels of these PFAS in drinking water. EPA also finalized health-based, non-enforceable Maximum Contaminant Level Goals (MCLGs) for these PFAS.

<https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas>

Compound	Final MCLG	Final MCL (enforceable levels) ¹
PFOA	Zero	4.0 parts per trillion (ppt) (also expressed as ng/L)
PFOS	Zero	4.0 ppt
PFHxS	10 ppt	10 ppt
PFNA	10 ppt	10 ppt
HFPO-DA (commonly known as GenX Chemicals)	10 ppt	10 ppt
Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS	1 (unitless) Hazard Index	1 (unitless) Hazard Index

¹ Compliance with MCLs is determined by running annual averages at the sampling point.



October 15, 2024,
Brazilian chemical law
(PL 6120/2019) – inspired
by EU REACH – passed the
the Federal Senate Plenary.
PFAS Control Policy 2726/2023

PFAS free is possible



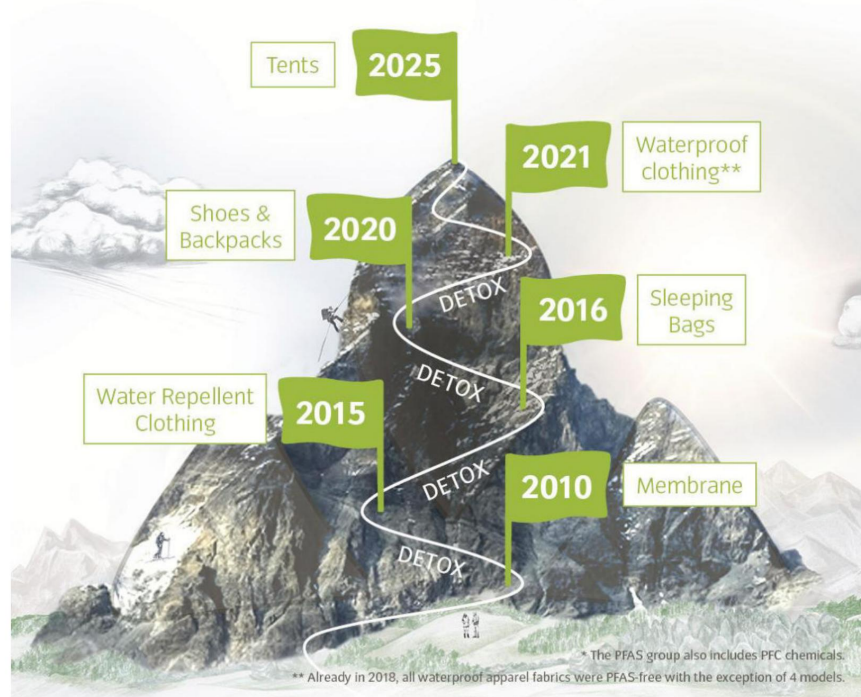
Performance meets Ecology

VAUDE hasn't used C8 technologies in their Apparel Collection since the Summer 2015 Collection.

In the Summer Season 2018 VAUDE successfully transitioned nearly their entire VAUDE Apparel Collection to becoming PFC-free by using VAUDE Eco Finish. A major portion of the rest of the product range in this collection also has fluorocarbon-free waterproofing.

Since 2021, the fabrics of all VAUDE products are PFC-free with the small exception of a few tents.

Step by step towards the elimination of PFAS* in all fabrics with Eco-Finish



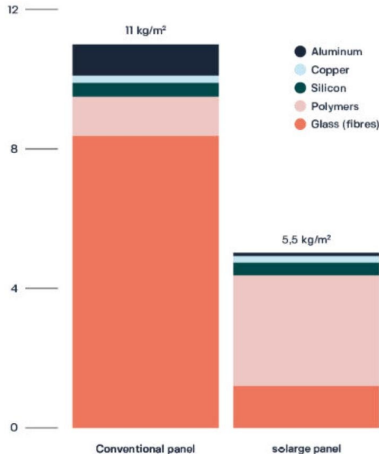
<https://csr-report.vaude.com/gri-en/product/water-repellent-materials.php>

Examples for PFAS free technologies



PFAS free cells

Leclanché enhances value proposition with new PFAS-free and Niobium Oxide cells, enters testing phase with Key Partners
<https://www.leclanche.com/leclanche-achieving-new-milestone-cell-technology-recognition/>



PFAS free frying pans



Stainless steel, cast iron, ceramic coating
 Photo: Caraway, Consumer Reports, OXO
www.consumerreports.org/home-garden/cookware/best-frying-pans-if-you-want-to-avoid-pfas-chemicals-a1006253549/

PFAS free ski wax



<https://ceh.org/yourhealth/pfas-free-ski-wax/>

PFAS free PV panels

For more than 15 years, Endurans, Crown, Solarge and Futurasun have been producing PFAS-free solar panel backsheets with equivalent cost and performance.

<https://chemsec.org/reports/busted-five-industry-myths-about-the-pfas-ban/>



Examples for PFAS-free technology projects at HKA



SOPHIA
Sustainable Off-grid solutions for
Pharmacies and Hospitals In Africa

Solar thermal ejector cooling system

Surface = 400 m² (Net 360 m²)
Rated power = 200 kW
140 °C, 3.7 bar

Vacuum Tube Solar
Collector with Plasma
Technology

Latent Heat
Storage



Heat Storage capacity = 30 kWh
 $t_{\text{melt}} = 125 \dots 135 \text{ °C}$

Steam Jet Ejector

Evaporator

Nominal Cooling Power = 82 kW
12 °C, 14 mbar



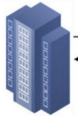
Latent Cold
Storage
Cold Storage capacity = 20 kWh

to solar field

R718

Cooling Tower
nominal power = 480 kW
e.g. 35 °C

Condenser



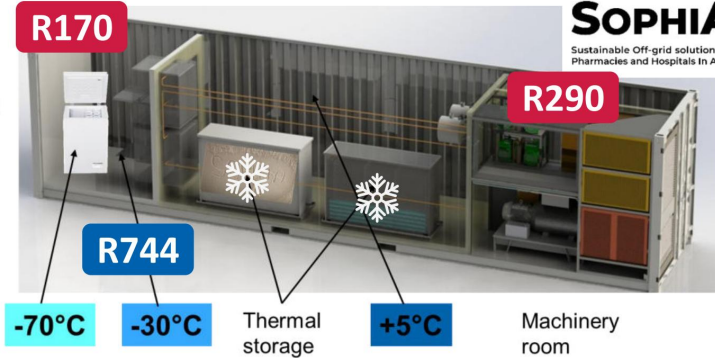
Building LB (HSKA)

Building Surface = 3130 m²

Electrical efficiency COP_{el} :

→ Values between 5 – 9
reached in steady state

www.SophiA4Africa.eu

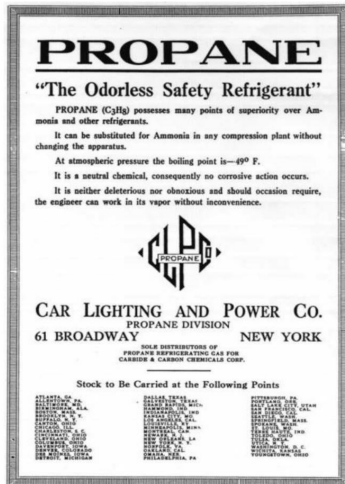


Component	Value
Propane cycle	16 kW cooling capacity
CO ₂ cycle	2 kW cooling capacity
Bridge time	36 h

PFAS free refrigerants for HVACR systems

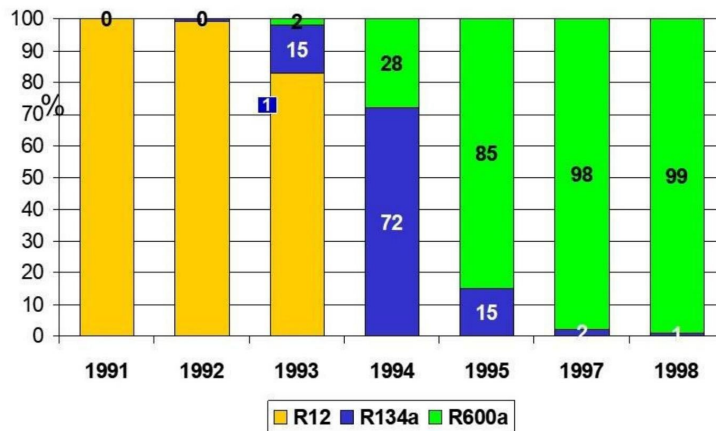


- ☐ Ammonia
- ☐ CO₂
- ☐ Propane
- ☐ Propene
- ☐ Iso-Butane
- ☐ Pentane
- ☐ Water



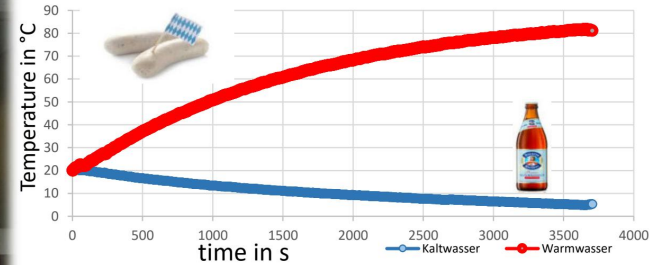
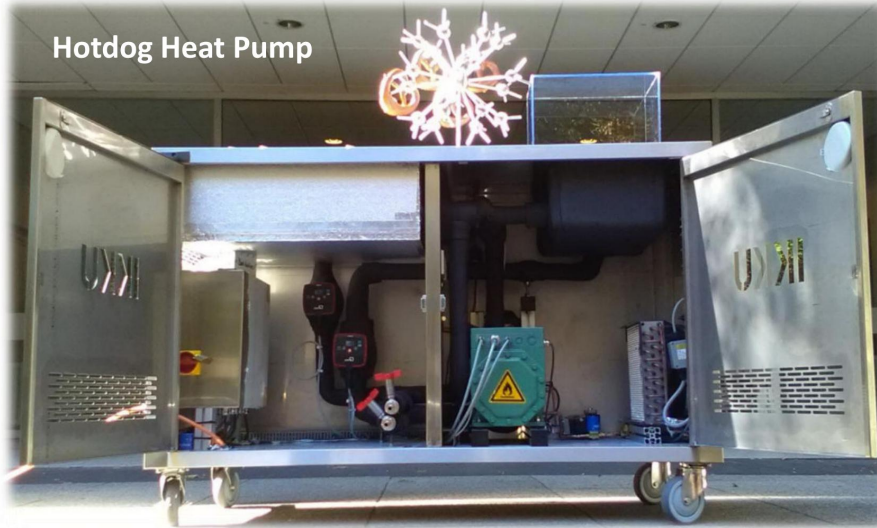
Ad in American refrigeration magazine, 1922

Refrigerants used by German refrigerator manufacturers



Heat pump industry will follow same pattern
just 30 years later and with R290 instead of R600a

Another great Heat Pump Fluid: Iso-Butane



385 g R600a
COP Heating 3.5
45 Minutes for 35 beer bottles (0.5 l) and 3 kg sausages



Ammonia Chiller



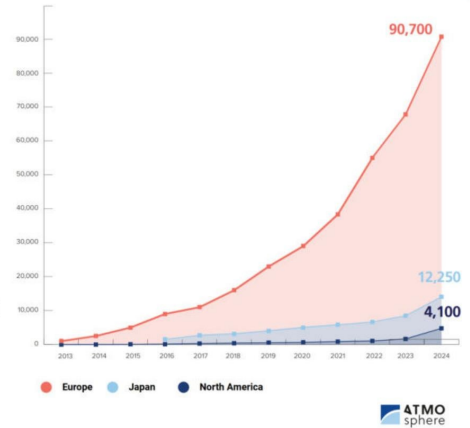
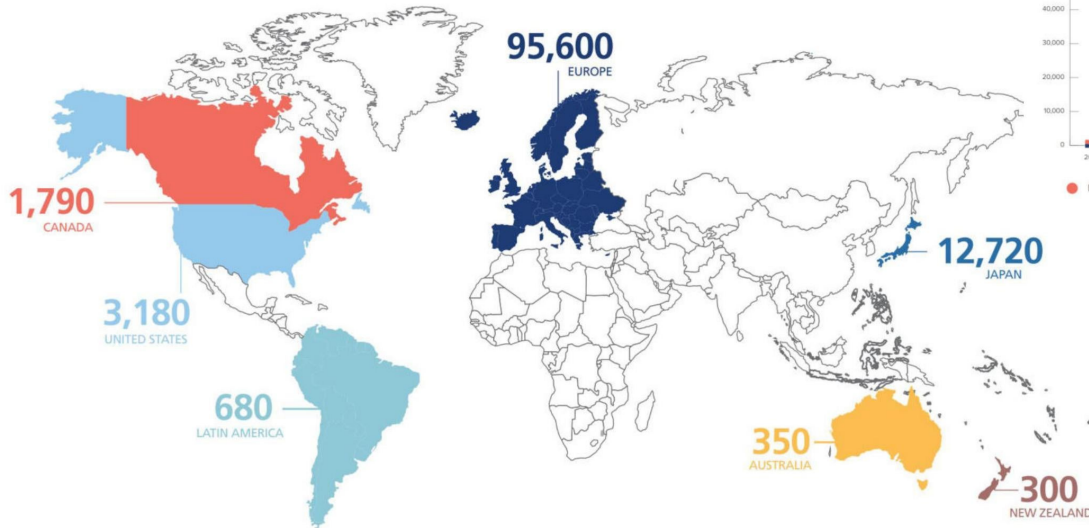
- Ammonia is poisonous – but it stinks !!!
→ Built-in leak detector
- Ammonia achieves highest COP
- Low charge possible (30 g/kW)
indirect and cascade systems
- Examples of ammonia chillers:
*Scandinavian Congress Center (1200 kW) and
Salling department store in Aarhus, Denmark,
Shopping Center Fields in Copenhagen,
Copenhagen Airport and Heathrow Airport, UK*
- Even in the ISS because of performance



Transcritical CO₂ Installations in Major Regions

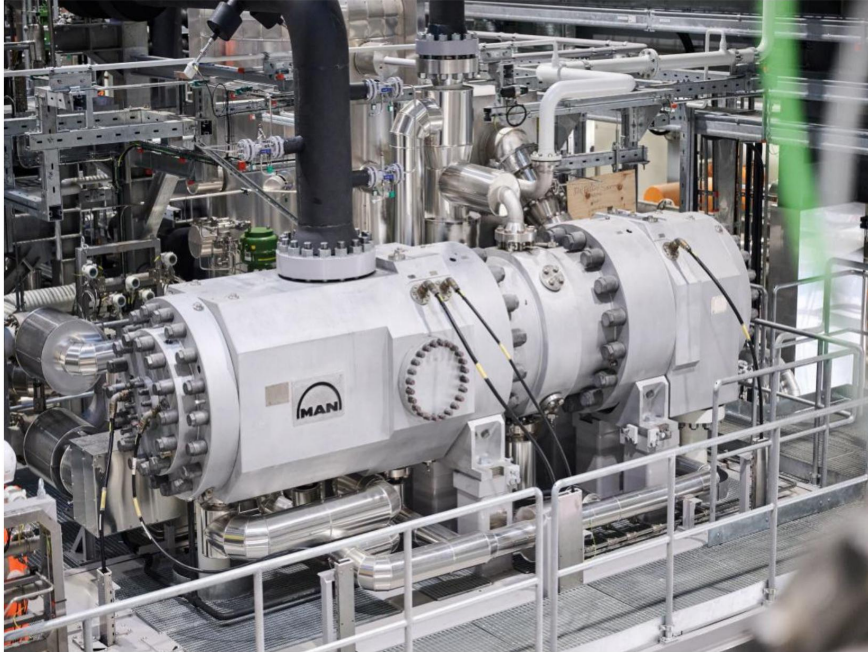
Natural Refrigerants: State of the Industry

Stores and industrial sites, as of December 2024



https://atmosphere.cool/wp-content/uploads/2025/02/2024_ATMO_Marketreport-compressed.pdf

CO₂ heat pumps for district heating



MAN Energy Solutions has successfully commissioned the first unit of its industrial-scale heat pump in Esbjerg, Denmark.

Heat pump plant will supply approximately 280,000 MWh of climate-neutral heat annually to the district heating networks of Esbjerg and the neighboring town Varde

Total heating capacity of 70 MW, the CO₂-based heat pump system is the largest of its kind ever brought into operation globally.

Oil-free, hermetically-sealed HOFIM® motor-compressor at the core of MAN's industrial-scale heat pump system.

<https://www.man-es.com/company/press-releases/press-details/2024/11/28/mega-heat-pump-delivers-first-heat-in-esbjerg>

Water as refrigerant (Århus, Denmark)

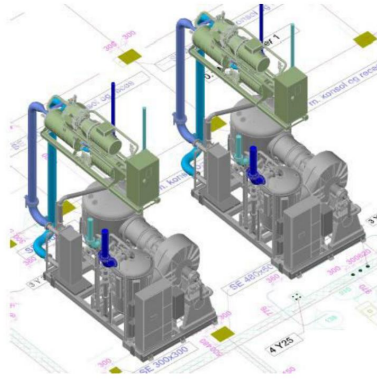


© Jyllands Posten, Foto: Mathilde Bech

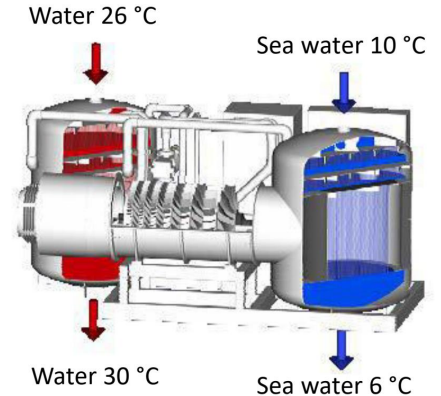


© Affald Varme Aarhus

Ammonia-water-cascade
1070 kW Heating capacity
 $COP_{\text{Heating}} 3,3$
Sea water $10\text{ }^{\circ}\text{C} \rightarrow 6\text{ }^{\circ}\text{C}$
District heating $45\text{ }^{\circ}\text{C} \rightarrow 65\text{ }^{\circ}\text{C}$



© Johnson Controls International



Air as refrigerant for low Temperatures (below -50 °C)



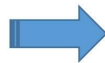
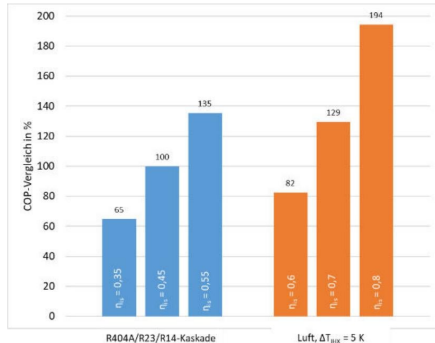
© Hof



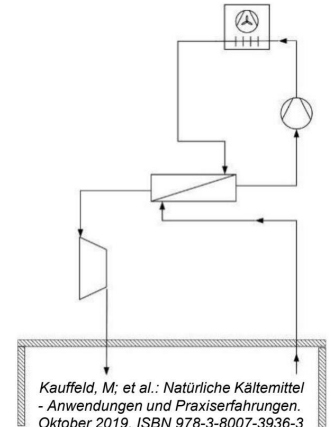
© Mirai



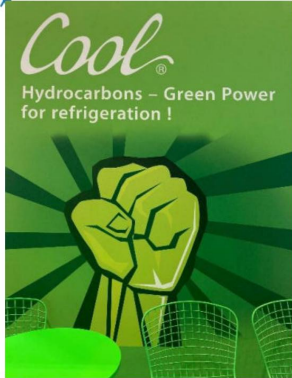
© Mirai



At low temperatures more efficient than vapor compression process



HVACR industry is going PFAS free – examples from chillventa 2024



PFAS free - really?



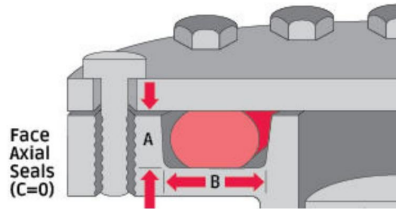
GEA BluX

GEA BluX is among the world's first ammonia chillers with a semi-hermetic compact screw compressor,



If you want to go all the way: Solid PFAS free technologies in HVACR industry

Compressor Cylinder head - PFAS



<https://www.applerubber.com/seal-design-guide/oring-basics/definition/>

Compressor Cylinder head – PFAS free



IQSdirectory.com

PFAS free shaft seals

Application from -200 °C to 80 °C,
some types up to 95 °C

[https://www.fipur.de/en/News/News/
The-Fietz-Group-offers-PFAS-free-alternatives](https://www.fipur.de/en/News/News/The-Fietz-Group-offers-PFAS-free-alternatives)

Fi 1901

FiPur®150

PFAS FREE COATINGS

Home / PFAS free coatings

Coating Technology S.r.l. is proud to offer a range of cutting-edge treatments, **completely free of PFAS**, designed to meet the most advanced needs of our customers. The PFAS-free treatments we offer ensure excellent performance **without the use of perfluoroalkyl substances**, thus providing safe and sustainable solutions. Here is an overview of the PFAS-free coatings available:

www.coatingtechnology.net/coating-pfas-free-en

PFAS free sealing sheets

SIGRAFLEX UNIVERSAL PRO sealing sheets for high leak tightness comply with TA Luft, are PFAS-free and suitable for all common pipework, including steam pipework in heating equipment, and vessel flange designs.

<https://www.sglcarbon.com/en/markets-solutions/component/sigraflex-universal-pro/>

PFAS-free O-Rings



Think they are the same ORs as yours?
They are not



100% PFAS-FREE



OLAB EcoSystem offers **EPDM** gaskets (-50 to +150 °C) and **HNBR** (-40 to +15 °C) made with **OLAB** certified **100 % PFAS-FREE** elastomers — with excellent performance in terms of compression set and hardness.

<https://www.olabitaly.com/products/refrigeration-systems/olab-ecosystem-100-pfas-free/>

Back to refrigerants: **There will not be a 5th Refrigerant Generation !**

Concluding Remarks

- Thermodynamic properties determine the performance of a refrigerant
 - critical parameters & heat capacity of vapor are most important
 - also underlie flammability
- Design engineer must manage tradeoffs among these parameters
 - modify cycle to match fluid, if necessary
- Will there be a “5th generation” of refrigerants
 - No! But we may well “recycle” refrigerants from earlier generations

Mark McLinden, NIST: *Thermodynamics of the new refrigerants*. IIR ICR 2019, Montreal

Thermodynamic Analysis of
60 Mio. Chemicals

After HFO, only
natural fluids left





Kauffeld, M.; Dudito, M.: *Environmental impact of HFO refrigerants & alternatives for the future*. Open Access Government, 11. Juni 2021, <https://www.openaccessgovernment.org/hfo-refrigerants/112698/>

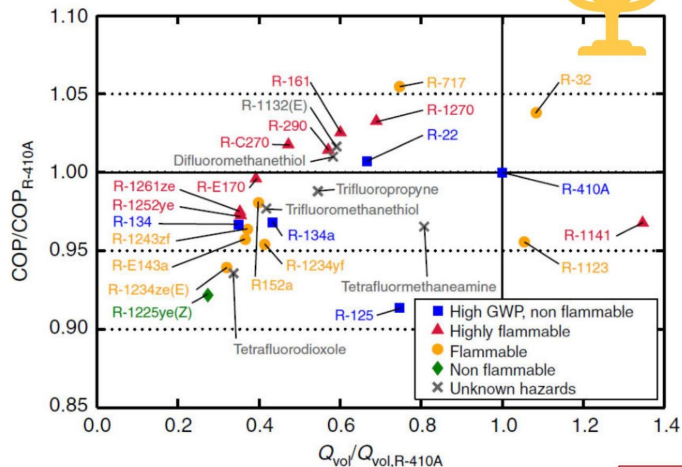


❄ ❄ ❄ © Prof. Dr.-Ing. habil. Michael Kauffeld ❄ ❄ ❄

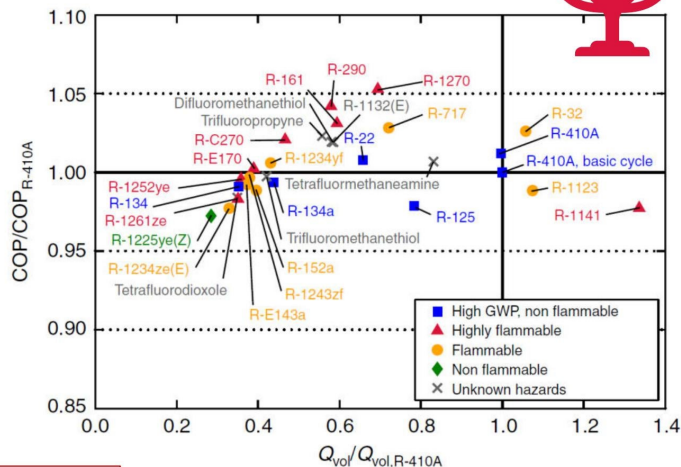
Energy efficiency of various refrigerants



Without suction line heat exchanger



With suction line heat exchanger



$t_0 = 10\text{ }^{\circ}\text{C}$ $t_c = 40\text{ }^{\circ}\text{C}$

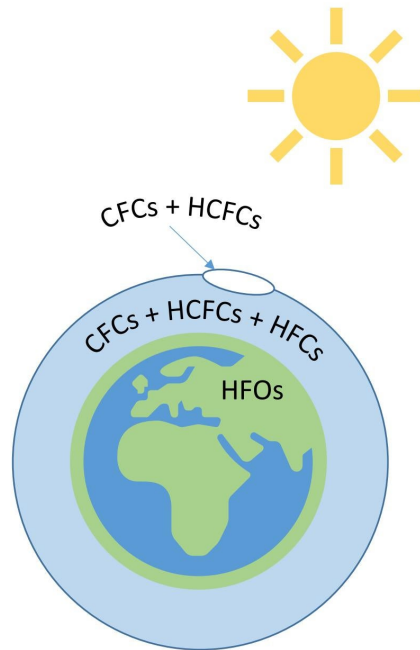
Natural refrigerants result in highest energy efficiency due to their thermophysical properties

McLinden, M., Brown, J., Brignoli, R. et al. Limited options for low-global-warming-potential refrigerants. Nat Commun 8, 14476 (2017). <https://doi.org/10.1038/ncomms14476>

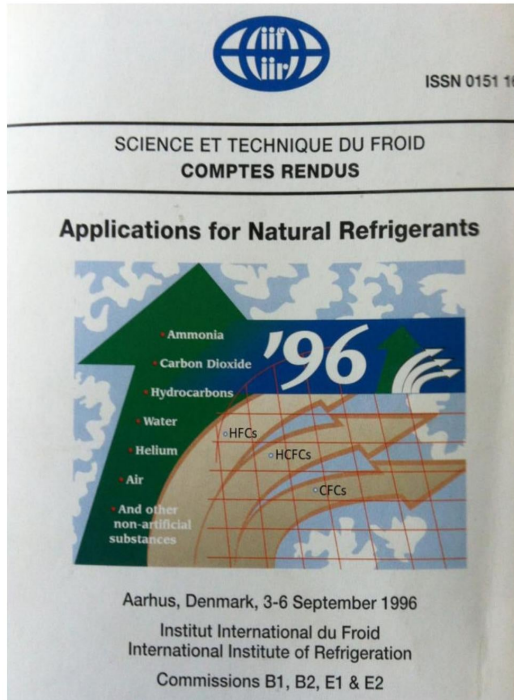


60 – 30 – 15

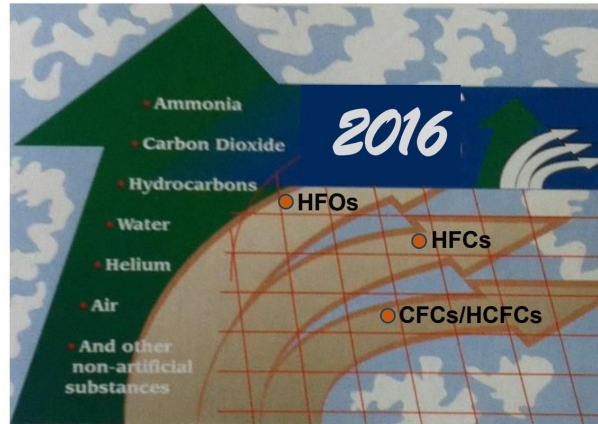
- It took 60 years (1930 to 1990) to find out that CFCs damage the ozone layer
- It took 30 years (1990 to 2020) to acknowledge HFCs contribute noticeably to global warming
- It will take 15 years to accept that HFOs are harmful to the local environment *(technician's health and terminal water bodies)*



Conclusion



GAME OVER for HFOs



Questions?



Are you heating/cooling, cooking, and wearing PFAS-free?

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Environmental Engineering

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Partners in the
„PFAS- free heating and cooling solutions“
project financed by the **Innovation Booster Energy Lab**
via **Innosuisse** in the Pitch & Fund of Call #5



Steinbeis Transfer Center
Refrigeration and Air Conditioning

