Chemours Thermal & Specialized Solutions (TSS) contribution to the universal PFAS restriction

ECHA Public Consultation

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<u>Attachment 2</u>

Table of Contents

A. Mobile air conditioning and heat pump application specific submission

INTRODUCTION

Mobile Air Conditioning (MAC) is a generic term used across various on-road and off-road transport applications intended for the vehicle or equipment cabin cooling. This broad term (MAC) can encompass vehicles in the following vehicle classifications M, N, O, R, S T, and G, as noted per EU Regulations (EU) 2018/858 and EU 2016/1628 (amended version of EU 1025/2012 and EU 167/2013) and shown in Table A.1.[1, 2] Furthermore, as an illustration, the European light duty automotive sector (vehicle classes M and N) alone represent 7% for the total EU Gross Domestic Product (GDP). There are 42 light duty vehicle factories in Germany, which is also the largest vehicle exporter (59% of the total European export).[3] When including all of the vehicle and equipment classifications that are impacted by this proposed regulation, the economic impact is projected to be much higher.

Table A.1: Vehicle classification

EU Vehicle Classification	
Vehicle Category	Description
Standards	**REGULATION (EU) 2018/858**
M	**Motor vehicles designed and constructed primarily for the carriage of persons and their luggage**
M1	Vehicles used for carriage of passengers, comprising not more than eight seats in addition to the driver's (passenger car, taxi cab, motor caravan)
Code SA	Motor caravan: A vehicle of category M with living accommodation space which contains rigidly fixed equipment.
M2	Vehicles of category M, comprising more than eight seating positions in addition to the driver's seating position and having a maximum mass not exceeding 5 tonnes. Vehicles belonging to category M2 may have space for standing passengers in addition to the seating positions. (mini-shuttles, mini-buses)
M3	Vehicles of category M, comprising more than eight seating positions in addition to the driver's seating position and having a maximum mass exceeding 5 tonnes. (buses)
N Type	**Power-driven vehicles having at least four wheels and used for the carriage of goods**
N1	Vehicles with max mass < 3,5 tonnes. (pick-up trucks, vans)
N2	Vehicles with max mass>3.5 tonnes and <12 tonnes (26,448)
N3	Vehicles with max mass> 12 tonnes (26,448)
O	**Trailers (incl. Caravans)**
O1	trailers with max mass ≤ 0.75 tonnes [1,653 lbs]
O2	trailers with max mass > 0.75 tonnes and ≤ 3.5 tonnes [7,716 lbs]
O3	trailers with max mass > 3.5 tonnes and ≤ 10 tonnes [22,046 lbs]
O4	trailers with max mass > 10 tonnes
Code SE	Trailer caravan: A vehicle of category O which is designed for road use and provides mobile living accomodation.
Standards	**Agricultural and Forestry vehicles REGULATION (EU) No 167/2013**
C	track-laying tractors propelled by endless tracks or by a combination of wheels and endless tracks
T1 - T8	wheeled tractors (number depends on track width, mass, dimensions) a: max speed ≤ 40 km/h b: max speed > 40 km/h
R1 - R4	trailers (number depends on mass) a: max speed ≤ 40 km/h b: max speed > 40 km/h
S1 - S2	interchangeable towed equipment (number depends on mass) a: max speed ≤ 40 km/h b: max speed > 40 km/h
G	"Off-road vehicle (ORV)" means a vehicle that belongs either to category M or N, having specific technical features which permit its use off the normal roads.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0956
[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R0720
[3] https://gmk.center/en/posts/eu-automotive-sector-shows-good-growth-how-will-it-affect-steel-consumption/#:~:text=The%20importance%20of%20the%20automotive,EU%20in%202022%20were%20cars.

Typically, MAC is associated with vehicles/equipment that employ internal combustion engines (ICE) and used to provide driver cabin comfort (air conditioning (AC)) or vehicle operator safety (air ventilation). In traditional ICE vehicles or equipment, excess thermal energy is scavenged from the ICE to heat the driver/operator cabin in colder weather. Depending on the vehicle or equipment type, if the ICE is too small (hybrid) or non-existent (full Electric Vehicle (EV)), alternative vehicle or equipment thermal management systems, such as heat pumps (reverse AC systems for heating and cooling) will be employed. The belt driven conventional AC system is substituted with a Heat Pump (HP) system driven by an electric compressor in EVs.

Therefore, in electrified vehicles or equipment a heat pump system's role is two-fold. The HP not only provides critical comfort systems for the passenger or operator cabin, but also the necessary thermal management for the electric battery. EV batteries require continued cooling to ensure thermal runaway does not occur. Thermal runaway can produce fire, smoke and in extreme cases cause uncontrollable fire events. Due to the critical uses of HP systems in electrified vehicles or equipment, the HP system takes on a life-saving parameter that requires high levels of reliability and safety.

As noted above, thermal management system in the electric vehicles covers both the battery and passenger comfort systems and is one of the biggest remaining challenges. The performance on battery, fast charging capability and e-powertrain are all significantly dependent on the outside ambient temperature. Thermal management therefore has a decisive influence on the performance relevant to the customer such as driving range and vehicle comfort, and this becomes a brand-defining factor for light duty automotive manufacturers.

The uses and sub-uses of mobile air conditioning (MAC) have been evaluated by several studies across different industries.[4,5,6,7,8] As it currently stands, the main refrigerants in use today for MAC applications are HFC-134a (R-134a) and HFO-1234yf (R-1234yf), in ICE and EV. HFO-1234yf as ultra-low Global Warming Potential (GWP) Original Equipment Manufacturer (OEM) refrigerant used extensively across M, N, O, R, S, T, and G applications in ICE and EV systems has shown to be irreplaceable due to its good system performance, energy efficiency and reliability in use. Other in-kind and not in-kind alternatives do not provide even a near adequate substitute for the reasons outlined below.

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[4] Calm, J.M. (2008) 'The next generation of refrigerants – historical review, Considerations, and outlook', *International Journal of Refrigeration*, 31(7), pp. 1123–1133. https://www.sciencedirect.com/science/article/abs/pii/S0140700708000261 .

[5] Manoj, V., Balamurugan, V. and Kumar, B.S., (2016). A Review on selecting an eco-friendly refrigerant alternate to R134a in domestic refrigerators. *International Journal of Science, Engineering and Technology Research*, 5, pp.2992-9.

[6] Koban, M., (2009). HFO-1234yf low GWP refrigerant LCCP analysis (No. 2009-01-0179). SAE Technical Paper.

[7] Park, K.J., Lee, Y.H., Choe, D.S. and Jung, D.S., (2010). Performance of R1234yf and R1234yf/R134a mixture under mobile air-conditioner operating conditions. *Korean Journal of Air-Conditioning and Refrigeration Engineering*, 22(12), pp.837-844.

[8] Chen, J., Zhao, Y. and Qi, Z. (2011) 'New developments in Mobile Air Conditioning Systems in China', *Frontiers in Energy*, 5(1), pp. 53–58. https://link.springer.com/article/10.1007/s11708-010-0137-3

THE CURRENT REGULATIONS ARE THE BEST TOOLS TO MANAGE F-GASES AND MINIMIZE THEIR EMISSIONS

The Dossier Submitters (DS) conclude that the F-gas Regulation (FGR) and MAC Directive are insufficient to manage the risks associated with F-gases. The conclusion appears to be based on two arguments: that the FGR "does not per se restrict the use of the substances but rather aims for a reduction of their use" and that the current FGR does not regulate all fluorinated gases fulfilling the DSs' PFAS definition. Rather, they argue a REACH restriction is required because that would limit as many uses as practically possible and thereby minimize F-gas emissions (and hence exposures), cover current and future F-gases, and prevent regrettable substitution. Derogations are proposed for "some key applications of fluorinated gases [where] alternatives are not yet available."

We believe this conclusion is unfounded. F-gases are already strictly regulated under the current Regulation 517/2014 (FGR)[9]. It establishes a phasedown schedule for HFCs – consistent with a substitution objective of the proposed REACH restriction – as well as stringent provisions to require training and certification of technicians and to minimize leakages throughout the lifecycle of the F-gases. The Commission Proposal to review the F-gas Regulation ("Commission Proposal")[10] currently under discussion extends the containment, training and certification, and recovery measures to Annex II – Section I F-gases (HFOs and HCFOs). The Commission Proposal therefore addresses the principal concerns expressed by the Dossier Submitters about the suitability of using the FGR to manage F-gases and the risks associated with them. As a result, Chemours considers that the F-gas regulation is the best tool to manage F-gases and reduce their emissions and has the necessary measures in its current version and the revision proposals by the commission and council to achieve this. Further details are presented in Attachment 1, section 1.5. The rest of this submission will focus on other issues raised by the proposed restriction.

EMISSIONS ESTIMATE

Baseline MAC emissions are overestimated in the REACH restriction dossier; we would like to propose an alternative estimate.

In the case of MAC, we believe that the emissions have been overestimated in the Annex XV report artificially increasing the positive socio-economic impact of a ban. In annex B table B.37 page 270, the annual emission rate used for MAC is 9.7%, resulting in annual emissions of 11 726 ton/yr.[11] Another estimate is reported in Annex E table E.112 page 347, where the emissions in 2020 are stated as being, 6 723 tons. In this document, to estimate the emissions reduction, based on an emission estimate used in the restriction dossier proposal, we have used the emissions value from annex B since table B.37 contains emissions rates of all F-gas applications. The source of the emission calculation in table E.112 cannot be

[9] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006;

[10] Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014;

[11] Exponent Report: (2021). Application of Fluorinated Gases (F-Gases) in the European Economic Area. Project number: M-2088|2021

verified. Chemours has calculated an alternate emissions estimate that can also be used to estimate an emission reduction based on the proposal in this document.

A more reliable MAC emission rate would be approximately 2 200 tons/year in 2020 due to a lower refrigerant leakage rate, despite a larger estimated vehicle fleet.

The revised estimate is based on default volumes of F-gases in Heating, Ventilation and Air Conditioning (HVACR)-systems (ca. 0.6 kg/personal vehicle, ca. 1 kg/unit per truck and ca. 6 kg/unit per bus)[12] and the total number of registered passenger cars (242,727,242), trucks (sum of light and heavy commercial vehicles: 34,340,233) and buses (692,207) in the EU (ACEA 2019).[13] From this analysis, it can be assumed that a total amount of approximately 180,000 tons (184,130) of F-gases are used in AC systems for passenger comfort in road traffic in the European Economic Area (EEA). Based on an average leak rate of 1.21% per vehicle per year.

Based on an average leak rate of 1.21% per vehicle per year. We can derive F-gas emissions in 2020.

The 1.21% was derived using existing data from Minnesota State[14] in the United States of America (USA), where car makers are required to report the refrigerant leakage rate for every vehicle they sell in Minnesota (this is the only publicly available data on vehicle leak rates). More than 70 vehicles were referenced for the 2021 to 2023 model years. From this publicly available data, the geometric mean F-gas leak rate from these models represents 1.21% per year.[15]

Emission: 180 000 tons F-gas x 1.21% average leak rate= 2 178 tons emissions in EEA/year (yr.).

Using the current emission rate is important to calculate the future emissions since new vehicles with the latest technological advancements will have a lower emission rate than the existing stock of cars.

With the transition to EV, the charge will increase, but the emissions rate will continue to reduce with the implementation of the emissions reduction targets that are proposed in the section "Cost-effectiveness of additional F-gas-based MAC system measures" below in this document.

Furthermore, the estimated stock of F-gases used in MAC is underestimated (121,000 tons) compared to our calculation of approximately 180 000 tons, described above.

THE PROPOSED DEROGATIONS ARE INSUFFICIENT

Existing proposals for derogations

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[12] Chemours TSS submission, 2nd Stakeholder Consultation on a Restriction for PFAS

[13] https://www.acea.auto/nav/?content=publications&tag=vehicle-fleet

[14] https://www.pca.state.mn.us/business-with-us/high-global-warming-potential-greenhouse-gases

[15] The geometric mean is used in this case to calculate the average leak rate. Geometric mean is more accurate approach when there is large variability in the data set as it is the case in the leak rate information used as it dampens the effect of very high or low values.

On the basis that the FGR and the MAC Directive are deemed insufficient to manage the risks of F-gases, the DSs propose a general ban on the use of F-gases, except in a limited number of "key" applications where they conclude that alternatives are not yet available and hence derogations are required. In the MAC domain specifically, the DSs propose the following derogations:

- Refrigerants in mobile air conditioning-systems in internal combustion engine (ICE) vehicles with mechanical compressors until 6.5 years after entry into force (EiF), and
- Refrigerants in transport refrigeration other than in marine applications until 6.5 years after EiF.

There is also the following proposed derogation:

- Use as refrigerants and for mobile air conditioning in vehicles in military applications until 13.5 years after EiF.

Therefore, the DSs propose to ban the use of PFAS in MAC systems in all electric vehicles from 1.5 years after EiF, and in all ICE vehicles after 6.5 years (except military applications).

Based on the available data we consider that the derogations proposed by the dossier submitter are not sufficiently wide to avoid disproportionate impacts to society. In addition, the derogations which are suggested are too short to allow substitution to take place in a cost-effective manner.

Derogation for maintenance and refilling of existing F-gas MAC systems

First, the proposed restriction bans the use of F-gases in MAC in all electric vehicles from 1.5 years after EiF, and in all ICE vehicles from 6.5 years after EiF. These bans fail to take into account that such vehicles already in use at these dates would be expected to remain in service for many years yet, and that many ICE vehicle and EV type-approved models using F-gases for MAC and HP would normally still be in production for around 10 years after type approval. Thus, these bans would prevent the servicing and maintenance of existing F-gas MAC and HP systems and the production of vehicle models using F-gas for their MAC and HP systems. This would lead to the premature retirement of millions of vehicles and associated vehicle models, with expected economic and environmental costs.

Derogation 5i proposed by the DSs explicitly relates to the servicing of existing HVACR equipment which uses F-gases:

- maintenance and refilling of existing HVACR equipment put on the market before [18 months after EiF] and for which no drop-in alternative exists until 13.5 years after EiF

The DSs propose this derogation because:

"The lack of drop-in alternatives means that equipment that would currently need servicing including some top up of refrigerant levels could not be repaired. Added costs would arise from the premature retirement of existing equipment, the early purchase of replacement equipment and added environmental burdens from disposal of equipment."

It is not clear why the same argument was not recognized for MAC (although it should be noted there is some ambiguity over whether MAC could be considered a subset of HVACR or whether the DSs use the term HVACR to refer only to stationary equipment). Indeed, the Transport section of Annex E recognizes that.

"Retrofit of existing [MAC] systems to permit use of alternatives is not feasible. These systems would therefore require availability of fluorinated gases for vehicle servicing if they are to continue operating."

However, immediately following this the DSs state:

"[A] major stakeholder for the automotive industry indicated that the transition from fluorinated gases was not a problem for electric and hybrid vehicles, but some additional time would be needed for combustion-engine vehicles with mechanical compressors."

However, the available data does not support a conclusion that there would be minimal impacts on the light duty automotive sector, which we will elaborate below. Here, though, we note that the statement reported by the DSs does not relate to existing vehicles or existing vehicle models – retrofitting existing MAC systems to use non-fluorinated alternatives is not feasible. This is because a model of a vehicle which uses F-gas generally cannot be fitted with an alternative substance because the model design will not allow it, for instance due to safety concerns in the case of propane (R-290) or due to a lack of space, inability to change piping layouts for Carbon Dioxide (CO2), etc. Current MAC systems cannot be retrofit to these two refrigerants.

Thus, we agree with the DSs' conclusion on the need for the maintenance and refilling of existing HVACR equipment to continue but argue that it applies equally to MAC equipment.

However, the proposed maintenance should not be time-limited, since this would inevitably mean that some existing equipment would lose its value and, in the limit, be retired earlier than necessary. An evaluation of the costs of the time limit on the MAC maintenance derogation, for the European light duty vehicle fleet, was carried out by the independent consultancy firm RPA[16] on behalf of Chemours (available in Attachment 3, Annex V). In this study, it was assumed that the time limit will mean that, once the derogation has finished, vehicle owners will not be able to service their MAC equipment, which over time will suffer a reduction in performance and ultimately fail. This will mean their vehicles will suffer an increased loss of value over time, and ultimately could cause vehicle owners to dispose of their vehicles (which otherwise are functioning adequately.) Some owners may have to scrap their vehicle entirely which could incur premature new vehicle purchase costs. The result of the analysis shows that consumers and European society is estimated to incur a total cost of between € 52 billion and € 383 billion due to the 5.i maintenance derogation not being indefinite. An unlimited derogation for existing vehicles (which is *in practice* time-limited by the remaining lifetime of the vehicle stock) would allow this cost to be avoided.

In this regard, we support the analysis and conclusions of the European Automobile Manufacturers' Association[17] (ACEA) calling for an indefinite derogation for the use of F-gases in MAC equipment placed on the market before the EiF of any restriction. Moreover, we propose that the scope of this derogation is extended to all existing MAC systems, not just those in passenger cars, because the same retrofit

[16] https://rpaltd.co.uk/about/
[17] https://www.acea.auto/

arguments are applicable to all other transport modes including M2-2, N2-3, O, R, S, T and G type vehicles and/or equipment but also trains, ships, airplanes, etc.

We also support the analysis and conclusions of ACEA that derogations need to take account of the duration of the normal production of vehicle model types, not just the lifetimes of actual vehicles, given that it cannot be assumed that MAC systems using alternative substances are technically feasible or can be retrofitted in all current vehicle models. Thus, even if F-gas refrigerants could be phased out in MAC systems after, for example, 10 years, this means there could still be a new vehicle model placed on the market in, say, Year 7 which is fitted with a MAC system using F-gases. As ACEA explains, a new vehicle model can be expected to have a lifetime of 10 years, which means that new vehicles of this model, fitted with MAC systems using F-gases and which, as above, cannot be retrofitted with alternatives, will still be on the market in Year 17 (7+10). Thus, it is not just premature retirement of vehicles which needs to be avoided with derogations, but also premature retirement of vehicle models.

Length of derogation for internal combustion engine vehicles

The previous discussion explains why the derogation of "refrigerants in mobile air conditioning-systems in combustion engine vehicles with mechanical compressors until 6.5 years after EiF" is too short. First, it will not exempt existing vehicles placed on the market before this point (which hence require an exemption for maintenance and refilling of existing systems). Second, it will not exempt existing *models* placed on the market before this point (which hence require an exemption for maintenance and refilling of systems in new vehicles of existing models).

Two additional factors are also relevant to the question of how long should be allowed for substitution to occur in ICE vehicles.

The first is how long is likely to be necessary to develop and implement new MAC technologies. The implementation of the MAC directive (2006/40/EC) required that refrigerants used in passenger cars should have a GWP below 150. As a result, the industry transitioned to HFO-1234yf, which was as close as possible to a drop-in solution since only relatively small system adjustments were needed to accommodate it (in contrast to the proposed alternatives in the DS proposal). The major focus was on the flammability classification, which changed from class1 (non-propagation of a flame) to class 2L (lower flammability). The implementation of HFO-1234yf took more than 17 years of preparation to ensure that HFO-1234yf was widely available for the whole industry. Below in Table A.2 you will find a timeline required for the new technology introduction, based on the HFO-1234yf market introduction in the past, which can be considered as a reasonable approximation of future "drop-in" technology introductions. If 17 years is required to introduce a "drop-in" technology, substituting a non-drop-in alternative can be expected to take much longer.

SAE International[18] worked on a number of programs between 2000 and 2006 looking at alternative refrigerants and at improving existing HFC-134a systems. One SAE investigation, the ***SAE Alternative Refrigerant Cooperative Research Program*** included the following evaluations:[19]

- Production HFC-134a system

[18] https://www.sae.org/about/
[19] https://www.sae.org/standardsdev/tsb/cooperative/altrefsched.htm

- Enhanced HFC-134a system
- Carbon Dioxide system
- Secondary loop using a hydrocarbon refrigerant

Even after this work, SAE International found that more work was needed to evaluate alternative refrigerants. In 2006, SAE launched another Cooperative Research Program (CRP), ***SAE CRP 150*** to investigate low GWP refrigerants to meet the EU MAC directive[20]. Results from this workstream helped reduce the number of low GWP candidate refrigerants, but still more work needed to be done to successfully transition the industry from R-134a to a low GWP alternative. From 2006 to 2008, SAE International conducted three CRPs (***SAE CRP1234 Phase I, II, and III***) to investigate not only the performance but also the risks of using HFO-1234yf in an automotive AC system[21]. Note that even though HFO-1234yf was a very near drop-in there were questions regarding refrigerant leakage into the vehicle cabin that needed to be well understood along with potential for ignition in the unlikely event of a high-speed crash damaging the AC system. Vehicle prototype testing only started after this final SAE CRP research phase was completed and the final industry guidance regarding light duty vehicle architecture changes were determined.

Table A.2. Timeline required for new technology introduction

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
SAE investigates refrigerant GWP <150	■	■	■	■	■	■	■										
EU Regulators discuss MAC Directive		■	■	■	■	■											
MAC Directive Signed							■										
SAE CRP 150							■										
SAE CRP1234 Phase I& II							■	■									
SAE CRP1234 Phase III									■								
OEMS Vehicle Prototype Testing									■	■	■						
MAC Directive Begins												■					
EU OEMs get vehicles type listed to low GWP refrigerant											■	■	■	■	■	■	
MAC Directive Completes Entry into Force																	■

The second factor is the EU legislation to reduce carbon emissions from cars and vans to zero, by banning the sale of internal combustion engine (ICE) cars and vans from 2035[22] and promoting the movement to electric vehicles (EVs). Intermediate EU carbon emission targets require at least a 50% reduction in emissions by 2030. We have already described the long testing timeline required for converting to non-fluorinated MAC technology in vehicle models which were not designed for it (>17 years as noted above), which means that a manufacturer would only be likely to consider offering non-fluorinated MAC technologies in new vehicle models. But the ban on combustion ICE vehicle sales, from 2035 on, will effectively limit the economic return vehicle manufacturers will be able to earn from new ICE vehicle models. This ban could prevent new models coming onto the market with CO_2 technology, since the time available to obtain an adequate return on the investment will be too short. Banning the use of F-gas MAC technologies from 6.5 years after EiF would therefore prevent the introduction of new vehicle models after the end of this derogation.

TECHNICAL FEASIBILITY OF ALTERNATIVES

[20] https://www.sae.org/standardsdev/tsb/cooperative/gwp150spon.pdf
[21] https://www.sae.org/standardsdev/tsb/cooperative/crp1234-3.pdf
[22] https://www.europarl.europa.eu/news/en/headlines/economy/20221019STO44572/eu-ban-on-sale-of-new-petrol-and-diesel-cars-from-2035-explained

CO2 (R-744)

We disagree with the "major stakeholder for the automotive industry" that the transition from fluorinated gases would be "not a problem" for electric and hybrid vehicles. We note that a major automotive manufacturer did recently introduce a CO2-based MAC system as an optional extra (at considerable cost) in two of its electric car models. However, this manufacturer was also forced to offer compensation to customers who opted for the system, because of its poor performance and lack of reliability.[23,24] Nevertheless, it is likely these technical issues can be overcome in time so that performance is eventually adequate in a given vehicle platform (larger engine area). However, the point is not whether a CO2 system can be made to work, but whether such a system can be made to work across the whole range of conditions experienced by drivers (and other vehicle users) in the EU. The same is true for all alternatives to F-gas MAC systems – all can "work" under certain circumstances, but no single alternative can work (as well and reliably) across the whole range of environments which systems are required to work, particularly when it comes to ambient temperature conditions and environmental variation. This in essence means that a CO2-based MAC system might be made to work adequately in colder climates, for instance, but will be completely ineffective in southern Europe. A ban on F-gas MAC systems would therefore effectively segment the automotive market by limiting the choice of suitable technologies available in different parts of the single market. It will also require manufacturers to offer multiple MAC technologies across its vehicle ranges, and to design its vehicle models to be able to accommodate different systems. This will inevitably increase costs and will still mean that people in one part of the EU will own a vehicle which will not work effectively in other parts of the EU, restricting movement and trade.

It has been established that CO2-based system can operate adequately in lower temperature environments, but that efficiency significantly decreases as ambient temperatures rise. The recent study by Canteros and Polanksy (2022) shows that R-1234yf has a much better coefficient of performance (COP) or energy efficiency over the entire temperature range vs R744 (CO2), with the difference becoming greater as temperature rises, as shown in **Error! Reference source not found.** [25]

[23] https://driveteslacanada.ca/news/volkswagen-refunds-id-3-and-id-4-owners-for-underperforming-heat-pump-cuts-price-for-option-in-new-cars/

[24] https://www.rueden.de/blog/verbraucherrecht/vw-entschaedigt-besitzer-des-vw-id-3-oder-id-4-wegen-falscher-reichweitenversprechen-durch-waermepumpe/

[25] Canteros and Polansky (2022) 'Study of the heat pump for a passenger electric vehicle based on refrigerant R744', *Archives of Thermodynamics*, 43. https://journals.pan.pl/dlibra/publication/141976/edition/123864/content/archives-of-thermodynamics-2022-vol-43-no-2-study-of-the-heat-pump-for-a-passenger-electric-vehicle-based-on-refrigerant-r744-br-canteros-maria-laura-polansky-jiri?language=en .

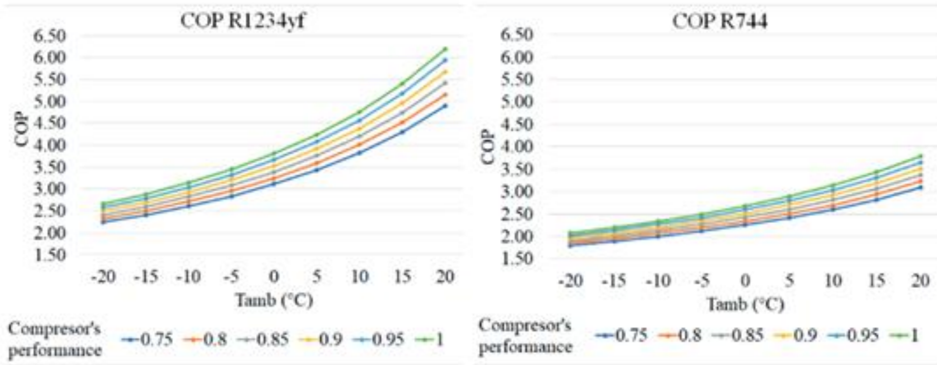

Figure A.1 Comparison of coefficient of performance of CO2 and F-gas heat pumps

These performance deficiencies on their own have significant impacts on the cost-effectiveness of CO2-based MAC systems (see below). However, they are doubly important in the case of electric vehicles because of the dual role which the MAC system (here it is a HP system) plays in controlling the temperature of the cabin *and* the battery. Performance in terms of battery life, range, fast-charging capability and e-powertrain are all significantly dependent on the outside ambient temperature. CO2-based systems are far more sensitive to ambient temperature variations and are much more susceptible to complete failure at higher temperatures – which can lead to so-called "thermal runaway events"[26] in EVs. As noted above, this is because EVs use a "single thermal management[27]" approach whereby the thermal management system not only heats and cools the cabin but also the battery. For some vehicle models, the thermal management system is also known to transport thermal energy from the battery to the cabin and back[28], which is required to extend driving range. Lithium-ion batteries have an extremely narrow operating temperature range of between 15-45 Celsius. [29] Adequate battery thermal management is essential to extend the vehicle driving range.

Battery thermal management is also critical to vehicle safety. An overtemperature event (e.g., electric motor malfunction), in combination with a working but performance-limited CO2-based heat pump system in a high ambient temperature environment, could lead to an overheated battery pack. If a battery pack reaches a high enough temperature, it can lead to chemical reactions occurring within the battery, which further increase the temperature and develop into a thermal runaway event, which can cause the battery to catch fire extremely quickly. Ultimately, what this means is that the performance of CO2-based MAC systems can fall so low at higher ambient temperatures that battery cooling is insufficient, and the inbuilt safety system will simply shut down an electric vehicle, even mid-journey. This can happen at ambient temperatures (e.g., 35 degrees C) which are already relevant today in some parts of the EU and are likely to become increasingly relevant across the world in the face of climate change. To illustrate the impact of this limitation, on July 18th, 2023, large parts of Southern Europe were registering temperatures above 36 Deg C[30].

[26] https://www.powerelectronictips.com/reliable-real-time-control-in-automotive-hvac-compressor-applications-for-hevs-and-evs/
[27] https://www.ti.com/lit/wp/szzy015a/szzy015a.pdf
[28] https://insideevs.com/news/452464/tesla-model-y-heat-pump-system-details/
[29] https://elmelin.com/what-is-thermal-runaway-and-how-can-it-be-addressed/
[30] https://www.ecmwf.int/en/about/media-centre/science-blog/2023/european-heatwave-july-2023

As the industry and global regulations promote and, in some cases, force the use of electric vehicles,[31,32] the need for effective thermal management of the lithium-ion batteries, e-motor, and power electronics are critical to safety. Fluorinated fluids are an important keystone to help make these electrification goals possible.

An electric vehicle has many electrified components which require thermal management, including the battery cells, busbar, power electronics such as the inverter and onboard charger, the electric motor, and perhaps even EV charging stations. The use of a fluorinated immersion cooling dielectric fluid can allow for the energized EV components to be safely cooled by direct contact with hot surfaces. More information on thermal management of electrified components is provided in the Annex A.1 to this application.

The disadvantages of CO2-based MAC systems, including the lower COP (energy efficiency) shown in **Error! Reference source not found.**, also mean that total carbon emissions would be expected to be h igher than MAC systems using HFO-1234yf. Papasavva and-Moomaw (2014)[33] used the GREEN-MAC-LCCP© life-cycle assessment model and projected carbon emissions in 2017 if all cars sold after 2011 used either HFC-134a, HFO-1234yf or CO2 (R-744). The GREEN-MAC-LCCP© life-cycle assessment model was developed by Pappsavva and others and has now become a standard tool accepted by SAE International, a USA automotive industry professional association and standards body.[34,35] The model calculates direct carbon emissions as a result of leaks of the refrigerant into the atmosphere, and indirect emissions resulting from energy consumption during manufacture, operation, transportation and end of life disposal, considering the carbon content of the fuel utilised in each process and during product operation.

The results are presented in

. They show that using HFO-1234yf results in lower carbon emissions than CO2 in all areas of the world, but particularly in warmer climates, further indicating the potential impact of switching to CO2 in a world subject to global warming.

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[31] https://electrek.co/2021/09/23/norway-bans-gas-cars-in-2025-but-trends-point-toward-100-ev-sales-as-early-as-april/

[32] https://www.politico.eu/article/france-attack-dangerous-germany-effort-change-eu-car-combustion-engine/

[33] Papasavva, S. and Moomaw, W. (2014) Comparison between HFC-134a and Alternative Refrigerants in Mobile Air Conditioners using the GREEN-MAC-LCCP© Model. *International Refrigeration and Air Conditioning Conference*: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2474&context=iracc

[34] https://www.sae.org/standards/content/j2766_201908/

[35] https://www.sae.org/

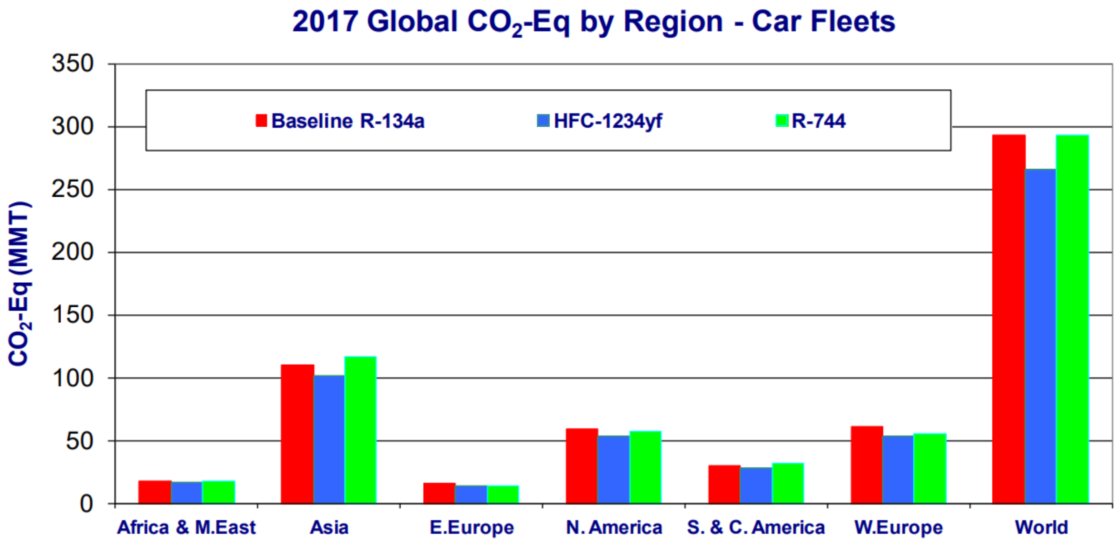

Figure A.2 Estimated total CO2 emissions from car MAC systems using different refrigerants

Compared to HFO-1234yf, CO2 also has a disadvantage of low efficiency at idling and high load conditions, especially for compact vehicles. Tests have shown that in compact vehicles, the increase in compressor power consumption with CO2 has an adverse effect on vehicle driving characteristics such as acceleration and fuel economy (Kobayashi et al., 1999)[36]

Other disadvantages of using CO2 relate to potential safety concerns associated with these systems. CO2 based system operate at significantly higher pressures than current refrigerants HFC-134a and HFO-1234yf. Technician injuries resulting from unexpected pressure relief (pipe or gasket) could occur during servicing.[37] According to one of the SAE CRP Risk Assessment's, the potential risk of leaks of CO2 into the vehicle cabin could exceed health-based limits under certain situations. Table A.3 represents results of ***SAE CRP1234 Phase III*** analysis. The data shows that large diameter leaks or line ruptures of CO2 systems can exceed health-based exposure limits for at least five minutes and up to 30 minutes.

[36] https://www.ipcc.ch/site/assets/uploads/2018/03/sroc_full-1.pdf Page 307, section 6.4.2.2 Energy efficiency
[37] https://e360blog.emerson.com/co2-as-a-refrigerant-five-potential-hazards-of-r744/

Table A.3 Risk assessment for alternative refrigerants HFO-1234yf and R744 (CO_2), Phase III, SAE International, 17-12-2009

Table 6-2. Results of Air Modeling Simulations for Passenger Scenarios, R-744 [Uniform Mixing Model]

Conditions	Maximum Concentration (ppm)*	5-minute TWA (ppm)*	30-minute TWA (ppm)*
small diameter leak (0.01 mm orifice), vehicle idling, low fan, recirc mode	1,867	1,867	1,857
medium diameter leak (0.1 mm orifice), vehicle idling, low fan, recirc mode	13,700	13,700	12,900
large diameter leak (0.5 mm orifice), vehicle idling, low fan, recirc mode	99,500	95,000	75,400
rupture of evaporator hose, vehicle idling, low fan, recirc mode	119,800	107,800	85,700

Shading indicates an exposure scenario where the health-based limit is exceeded.
* Includes the contribution of 1,800 ppm CO_2 due to passenger respiration in addition to the CO_2 contributed by the refrigerant leak
Health-based limits for R-744. Peak – 90,000 ppm, 5-minute TWA – 60,000 ppm, 30-minute TWA – 40,000 ppm.

Furthermore, it should also be noted that heavy duty on-road and off-road equipment have unique safety and reliability requirements that CO2 systems cannot currently meet. Generally, heavy duty on-road vehicles and heavy-duty off-road equipment are more robust versus M1 and N1 vehicles. However, the MAC systems employed in these vehicles and equipment are continually under stress due to the extreme operating environments, (construction sites, agricultural fields, underground and remote mines) long distances traveled on rough terrain, and varying road surfaces. The AC system needs to be extremely reliable to provide the operators a safe environment during long shifts (typically six-eight hours). System reliability in these applications, particularly off-road equipment, is a requirement due to the life safety parameter that AC provides operators.

Operators need to be in an enclosed environment with adequate airflow due to the continued hazards encountered during equipment use (fertilizer application, particulates from cutting wood, dust and debris from construction, etc.) Additionally, equipment manufacturers must meet minimum airflow requirements for safe operation of off-road equipment. Table A.4 below shows the continual airflow requirements that heavy duty off-road equipment **must meet** to comply with current regulations[38].

Table A.4: Heavy duty off-road equipment continual airflow requirements

Standard	Min Airflow m3/hr	Title
SAE J1503	43	Performance Test for Air-Conditioned, Heated, and Ventilated Off-Road Self-Propelled Work Machines
ISO 10263-4	43	Earth-moving machinery - Part 4: Heating, ventilation and air conditioning (HVAC) test method and performance
ISO 14269-2	43	Tractors and self-propelled machines for agriculture and forestry -- Operator enclosure environment -- Part 2: Heating, ventilation and air-conditioning test method and performance

Heavy duty AC systems are typically larger with longer refrigerant lines due to the expansive sizes of vehicles and equipment. However due to the continual road vibration and harsh under the hood environments, CO2 systems will be challenged. Metal lines are employed to hold the high pressure of CO2

[38] EPA-HQ-OAR-2021-0347-0021 Attachment "Risk Assessment for HFO-1234yf in Construction, Forestry, and Mining Equipment", pg 45.
https://www.regulations.gov/search?filter=epa-hq-oar-2021-0347

systems would be at risk of failure due to continual road vibration. Note that polymerics currently used with HFO-1234yf systems can more readily absorb perpetual vibrations seen by these systems. Given the timeline shown above for the light duty vehicles to transition to a near drop-in replacement, one would expect a much longer timeframe for new technologies in these demanding applications. Furthermore, the heavy duty off-road has not transitioned to low GWP refrigerants. Heavy duty equipment makers need the completed regulations in both North America (NA) and EEA to move forward with new technology, such as low GWP refrigerants. [39, 40]

Propane (R-290) and 1,1-Difluoroethane (HFC-152a)

Another alternative that is proposed by the DS are flammable refrigerants used with secondary loop systems (SL-MAC) (a secondary fluid (such as water) is used to transfer heat between the refrigerant and the substance being cooled). Safety issues associated with highly flammable (A3) refrigerants do not allow them to be used in direct expansion systems (Air is pushed across a heat exchanger where refrigerant resides and if leaked will go directly into the cabin. Hydrocarbons are highly flammable making an event extremely probable). In annex E p250 2.8.2.2 it is stated that "Secondary loop systems (SL-MAC) based on 1,1-Difluoroethane (HFC-152a) as refrigerant have been shown to be efficient and safe" and that "SL-MAC systems with propane (HC-290) as an efficient refrigerant are also currently being explored". However, this overstates the level of technological development of systems based on these substances. No SL-MAC system has been fully developed or demonstrated in a commercial application, nor have they gone through a thorough safety and risk assessment. To date, only small-scale demonstrators have been developed that are not road worthy. A risk assessment is a key criterion in selecting a refrigerant solution and to date the risk assessment for using highly flammable refrigerants in MAC systems has not been validated. There are videos[41] publicly available which help to show the differences in flammability levels.

It is highly uncertain whether an affordable SL-MAC system can be developed which can sufficiently mitigate the risk of using highly flammable refrigerants. As highlighted by Mei et al (2017), results show that the efficiency of SL-MAC systems is lower than that of direct expansion systems and they have lower thermal performance[42].

Anderson (2017) confirms that secondary loop with HFC-152a is lower efficiency, due to cooling pump power limitations compromising heat transfer efficiency. SL-MAC HFC-152a systems also have a longer pull-down time (i.e. time to cool the passenger cabin), as well, and that the secondary loop system minimizes temperature variation in the cabin/vent outlet temperatures due to the [single-phase] coolant's more uniform temperature distribution (it would take longer to cool down for example than a direct expansion system).

Summary and Conclusion:

To summarize, non-fluorinated alternatives are not market ready:

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[39] https://www.epa.gov/system/files/documents/2022-01/snap-notice-37-1-20-22-87-fr-3037.pdf

[40] https://www.epa.gov/system/files/documents/2022-04/fact-sheet-final-rule-24-mvac-nonroad-vehicles.pdf

[41] https://www.youtube.com/watch?v=MWD9-aykQtc

[42] Mei, Z., Hwang, Y. and Kim, J. (2018) Transient simulation of Secondary Loop Mobile Air Conditioning Systems, *Purdue e-Pubs*.: https://docs.lib.purdue.edu/iracc/1987/

- CO_2 systems underperform F-gas systems.
- There are safety concerns with CO_2 systems linked to the high operating pressure, leaks into the driver/operator cabin and required reliability in critical systems (e.g., off-road forestry, mining equipment).
- The dossier submitters state in annex E page 358 that "CO_2 based systems are on the market from one OEM". [Confidential] CO_2 AC and Heat pump systems have reliability and performance issues and require significantly more maintenance. [Confidential]. The limited number of OEMs offering CO_2-based systems [Confidential] are testimonials to the unavailability at a large scale and the lack of market readiness of this technology in the automotive sector today.
- The dossier submitters state in Annex E page 250 that "For trucks CO_2 reliability/durability has not yet been proven. Extensive field testing covering different aspects of operation should be fulfilled prior to introduction", which is not reflected in the derogation proposals. Light duty vehicles took >17 years for transition, so it is expected that NIK refrigerants will take much longer.
- Secondary loop technology is still to be developed and not available today.
- Transparent Industry-wide risk assessments have not been completed by leading trade organizations (SAE, JAMA[43], ACEA, VDA[44]) to validate the use of class 2 and 3 flammable refrigerants. Therefore, use of refrigerants with flammability greater than class 2L (HFO-1234yf) may not meet the industry acceptance criteria for current and future safety.

The conclusion is that the technical feasibility of alternatives in MAC systems is far behind that of systems based on F-gases, especially for electric vehicles, and far further behind than the DSs submitters contend on the basis of the information they have collected.

COST-EFFECTIVENESS OF NON-FLUORINATED MAC SYSTEMS

The DSs argue that the cost of preventing PFAS emissions through substitution with alternatives in MAC systems is relatively low at €300/kg. This is based on a simple comparison of one estimate of the cost of installing a CO_2-based MAC system in an ICE vehicle, and an estimate of the volume of an average HFO-1234yf MAC system (1kg). Thus, the DSs calculate that replacing one PFAS-based MAC system would cost €300 and would prevent 1kg of PFAS from entering the environment.

However, this is a significantly oversimplified comparison of the impacts of moving to a non-fluorinated MAC system and the likely savings in PFAS emissions. It fails to account for actual leak and recovery rates of PFAS from MAC systems during use and at end of life. It also ignores several other additional associated costs with using non-fluorinated systems, including reduced efficiency and additional maintenance requirements.

A switch to non-fluorinated refrigerants, such as CO_2 in MAC systems from the result of the proposed restriction would be expected to result in a disproportionate cost impact on society in the following areas:

1. Higher energy use due to lower efficiency

[43] http://www.jama.or.jp/english/
[44] https://www.vda.de/en

2. Additional service requirements associated with higher pressure systems
3. Higher purchase costs
4. Higher carbon emissions associated with higher energy use

1. Energy consumption costs

Available research shows that energy savings can be achieved using HFO-1234yf compared to R-744 systems or secondary loop propane systems and can be up to approximately 81 Euro per light-duty vehicle per year:

Assumptions in EU:

- Average car drives 15 000 km per year.
- The average annual energy consumption of a vehicle is 655 Kilowatt per hour (kWh)[45] per year.

A Chemours study demonstrated, more than 40% energy saving when using R-1234yf versus R-744, or 283.5kWh saving per year[46].

- For an estimated car park of 250million (M) vehicles[47], this is 250M * 283.5 kWh = 71 Terawatt per hour (TWh) which is similar to the total amount of renewable energy generated in France in 2020 (52TWh)[48];
- At 28.4 Euro cents[49] / kWh this equates to approximately 80.5 Euros per vehicle per year;
- Assuming that the car life is 18 years and that the existing fleet transitions to non-fluorinated technologies at a rate of 1/18th every year, for the period 2025-2055, this represents EUR 432.8 billion (bn) additional energy cost of using an alternative compared to F-gases;
- Representing EUR 14 bn for the entire fleet per year between 2025 and 2055 and EUR 20.1bn in 2055.

2. Additional service requirements

The R-744 (CO2) system inherent nature to leak due to the small molecule size, higher working pressure and the system complexity, we can estimate that CO2 systems will need to be serviced every 2 years as opposed to every 6 years for F-gas based systems, resulting in additional service costs of EUR 600 per vehicle over the 18 year period.

Assumptions in the EU:

- EU Heat pump / AC service price ranges from €75 – €125 incl. refrigerant (€100 on average);
- Traditional HFO-1234yf heat pump system requires a top up when the AC desiccant bag is replaced during service every 6 years[50] (hence 2 times in the vehicle life) = €200;

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[45] Chemours study in Annex A.3 of this application
[46] Mei, Z., Hwang, Y. and Kim, J. (2018) Transient simulation of Secondary Loop Mobile Air Conditioning Systems, *Purdue e-Pubs*. https://docs.lib.purdue.edu/iracc/1987/
[47] ACEA (2023). *Vehicles in Use, Europe 2023*. https://www.acea.auto/files/ACEA-report-vehicles-in-use-europe-2023.pdf .
[48] https://ember-climate.org/insights/research/eu-power-sector-2020/
[49] https://www.euronews.com/next/2023/03/29/
[50] https://www.tesla.com/ownersmanual/model3/en_gb/GUID-E95DAAD9-646E-4249-9930-B109ED7B1D91.html

- Assumptions: CO_2 heat pump top up / service required at least every 2 years on average[51] (due to small molecule, high pressure system and current system issues described above), hence 8 times in the vehicle life = €800;
- Difference: €600 / vehicle for 18 years;
- This averages to 33.3 Euro per vehicle per year, which equals 8.3bn Euro for the entire fleet per year.

3. *Additional initial purchase costs*

For CO_2 systems, the actual cost per vehicle increase is more than €300 per vehicle (mentioned in Annex XV section 2.10.2.1, page 358). However, the cost seen by consumers today are for example €990-1 250 per vehicle as an option on the VW ID3 and ID4[52] models. By assuming a cost increase of €1 000/vehicle on average, CO2 systems would equate to an additional cost to consumers of EUR 13.9bn per year assuming a vehicle life of 18 years and 1/18th of the estimated fleet of 250M cars is converted to CO2 systems each year.

4. *CO2e costs*

The higher energy consumption of non-PFAS alternative based systems described under point 2 can be translated into increased CO2 emissions. At an estimated CO2 intensity of 238g/KWh[53], and a cost of carbon permits of 95 €/CO_{2e}[54] / ton, using the same transition rate assumption as above this equates to EUR 34.5bn between 2025 and 2055 and EUR 1.6bn in 2055.

In recent literature, energy efficiency of HFO-1234yf vs CO2 in HP systems has also been compared. The recent 2022 paper, "Study of the heat pump for a passenger electric vehicle based on refrigerant R744" shows that HFO-1234yf has much better coefficient of performance over the entire temperature range vs R-744 as shown previously in Figure A.1.

It should also be noted that unlike for F-gases, CO2 and propane are not recovered today and under several regulatory frameworks, CO2 could be released into the atmosphere. Currently, there are no commercially available Recover, Recycle and Recharge (RRR) machines for propane. Even many CO2 systems do not recover and recycle the CO2, they only remove oil before venting into the atmosphere, which would increase their CO2 emission profile even further or require a high investment to develop RRR equipment and make it available in all garages along with the recovery cylinders necessary to store the recovered gas.

Summary of the cost-effectiveness of non-fluorinated MAC systems:

The cost effectiveness of non-fluorinated MAC systems can be summarized as follow:

1. Higher energy use due to lower efficiency

[51] Confidential

[52] https://driveteslacanada.ca/news/volkswagen-refunds-id-3-and-id-4-owners-for-underperforming-heat-pump-cuts-price-for-option-in-new-cars/

[53] https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-13#tab-googlechartid_chart_11

[54] https://tradingeconomics.com/commodity/carbon

2. Additional service requirements associated with small molecule, much higher pressure systems.
3. Higher purchase costs
4. Higher carbon emissions associated with higher energy use

Result in an additional cost to society of the proposed bans of:

- 432.8 bn € additional energy costs
- 179.2bn € additional services costs
- 430.6 bn € additional initial purchase costs
- 34.5 bn € additional CO_2e emissions

Total: € 1 077 bn additional costs between 2025-2055 and € 44.0 bn additional cost in 2055.

The total additional cost per vehicle is € 2,685 on average between 2025-2055 and € 3,165 in 2055.

Emission reduction and cost of a ban to reduce emissions:

The emission reduction and cost of a ban to reduce emissions can be estimated as follow:

Emission reduction:

- Using the current average emission level from the Dossier Submitters 2025-2055: 14,653 tons per year as shown in Table A.5;
- Using the Chemours suggested estimate emission level 2025-2055: 2,722 tons per year;

Cost of a ban:

- EUR 12.8M per ton of emission reduction on average between 2025-2055 using the Chemours suggested emissions;
- in 2055: EUR 14.0M per ton of emission reduction using the Chemours suggested emissions (EUR 2.6M per ton of emissions using the DS emissions baseline);
- Which demonstrate the underestimate of the cost estimate of the dossier submitters of EU 300/kg, or EUR 0.3M per ton of emissions prevented.

Table A.5: Emission projection in tons

Emissions DS baseline, Annex B table B.37

	2025	2030	2035	2040	2045	2050	2055
PFAS emissions per year	12,572	13,213	13,887	14,596	15,340	16,123	16,945
PFAS Emissions over the 5-year period	64,129	67,400	70,838	74,452	78,250	82,241	
Total emissions over the period 2025-2055	454,256						

Emissions with Chemours suggested leak rates based on publicly available data

	2025	2030	2035	2040	2045	2050	2055
PFAS emissions per year	2,335	2,454	2,579	2,711	2,849	2,995	3,147
PFAS Emissions over the 5-year period	11,911	12,519	13,158	13,829	14,534	15,276	
Total emissions over the period 2025-2055	84,374						

These calculations demonstrate that a switch to non-fluorinated alternative in MAC applications right after the transition period or after a time-limited derogation period would result in significantly higher costs in terms of direct resource use, and also total EU energy requirements and impacts of carbon emissions and that the socio-economic cost of the emissions reduction would be disproportionate.

COST-EFFECTIVENESS OF ADDITIONAL F-GAS-BASED MAC SYSTEM MEASURES

MAC systems using F-gases are extremely high-performing, versatile and durable, and are also integral to improving the future performance of electric vehicles, a key part of the EU's decarbonisation strategy. F-gases can be used safely, vehicle classification M and N have been using Recover, Recycle and Recharge (RRR) machines successfully for over 10 years[55] with high rates of recovery and hence low emissions to the environment. However, emissions of F-gases from MAC systems do occur during the course of use and at end of life, so it is important to try and reduce these as far as is reasonable.

The previous analysis has demonstrated that a ban on the use of F-gases in MAC systems would be extremely costly. However, Chemours believes that further emission reduction can be achieved more cost-effectively through the mandating of simple good-housekeeping measures into MAC system maintenance and recovery regimes. These conditions could be included in the proposed REACH restriction or form part of an extension to some other relevant legislation. In this section, we will demonstrate how such measures could be a cost-effective way of reducing emissions to a fraction of what they are today by 2055. These measures fall under four headings:

1. Reclaim end-of-life, circularity
2. Leak-testing
3. Technician certification
4. System architecture

1. Reclaim end of life, circularity

Refrigerants like HFC-134a and HFO-1234yf are already recycled during servicing and can be re-used again and again at end of life of the vehicle once reclaimed. The EU Council proposal on F-gas revision[56] recognizes the opportunity to reclaim these refrigerants at end of life for several mobile applications "unless it can be established that it is not technically feasible or entails disproportionate costs".
Also, that "for the recovery of fluorinated greenhouse gases listed in Annex I and Annex II, Section 1, from air-conditioning equipment in motor vehicles falling within the scope of Directive 2006/40/EC only natural persons holding at least a training attestation in accordance with Article 10(2) shall be considered appropriately qualified".

With the phasedown of HFCs under the F-gas regulation proposal, the value of recovered F-gases is going to increase, and this measure will be at worst cost neutral for the companies performing F-gas recovery and should only require an incentive for it to be implemented.

[55] https://www.sae.org/news/2016/02/sae-standards-point-way-to-service-of-r-1234yf-systems
[56] https://www.consilium.europa.eu/media/63509/st08162-en23.pdf

This reclaim activity is already part of the F-gas regulation and its review and could be extended to vehicle reclaim activities and monitored through electronic logbooks such as those available in Poland and used by the industry today: www.bds.ichp.pl

2. *Required leak test at road worthiness test*

Consumers often do not realize their vehicle has a refrigerant leak that requires repair[57] . According to existing procedures e.g., as defined in SAE J2845 describing Technician Training Certification Program using leak detection probes according to e.g., SAE J2913, procedures are available to introduce compulsory leak testing at road worthiness testing, reducing leaks and improving system tightness.

Cost implications:

- procurement of SAE J2913 leak detectors[58] (<€300/piece, every 3 years, 22 000[59] technical lines hence €2.2M/year)
- required training/refresher annually per PTI inspector[60] (2 hrs., €100/year, 95 000 inspectors hence €9.5M/year).
- Total cost impact: €12M/year

We therefore request to implement a refrigerant leak test during road worthiness testing with an obligation to repair.

Vehicle road worthiness certification is already in place and this measure will be integrated in the existing framework and could be monitored through the garage electronic logbooks such as those available in Poland and used by the industry today: www.bds.ichp.pl.

3. *Certification of technicians (existing standards recertification)*

Good HVAC system and refrigerant handling practices are essential in reducing unintended emissions during vehicle maintenance. The EU Council proposal for the F-gas revision[61] recognizes this need and defines a certification requirement for technicians. Certification programs already exist today (e.g., SAE J2845 Technician Training Certification Program).
An annual certification refresher course would mitigate the risk of unintended emissions during servicing. The training can be combined with other maintenance certificates.

Cost implication:

- required training refresher annually per mechanic

[57] REFERENCE: Chemours study
[58] https://www.underhoodservice.com/j2791-and-j2913-certified-refrigerant-leak-detector-from-tracer-products/
[59] https://unece.org/fileadmin/DAM/trans/doc/2020/SafeFITS/SIII_LT_DB.pdf
Lithuania: 69 test centers, 141 technical lines, 600 PTI inspectors. For EU scaling by population (0.63%): 11k test
[60] https://unece.org/fileadmin/DAM/trans/doc/2020/SafeFITS/SIII_LT_DB.pdf
Lithuania: 69 test centers, 141 technical lines, 600 PTI inspectors. For EU scaling by population (0.63%): 11k test centers, 22.5k technical lines, 95k PTI inspectors
[61] https://www.consilium.europa.eu/media/63509/st08162-en23.pdf

- 320 000 mechanics in EU[62], 5 hours/yr., €250/yr. hence €80M/year

Therefore, we request to implement refresher courses for technician certification for F-gases.

4. System architecture

Leakage rates have reduced significantly over the past years. Using existing procedure from Minnesota State[63] in the USA, where car makers are required to report the refrigerant leakage rate for every vehicle they sell in Minnesota, more than 70 vehicles were referenced for the 2021 to 2023 model years. The geometric mean leak rate of these models represents 1.21% a year, with rates of 0.5% per year achieved in 2022 registration of certain vehicles.

Based on the trends shown in the leak rate database from the State of Minnesota and the leak rates that are achieved in the registration of certain models in 2022 and previous years as well, shown in Figure A.3, further emission reduction is feasible.

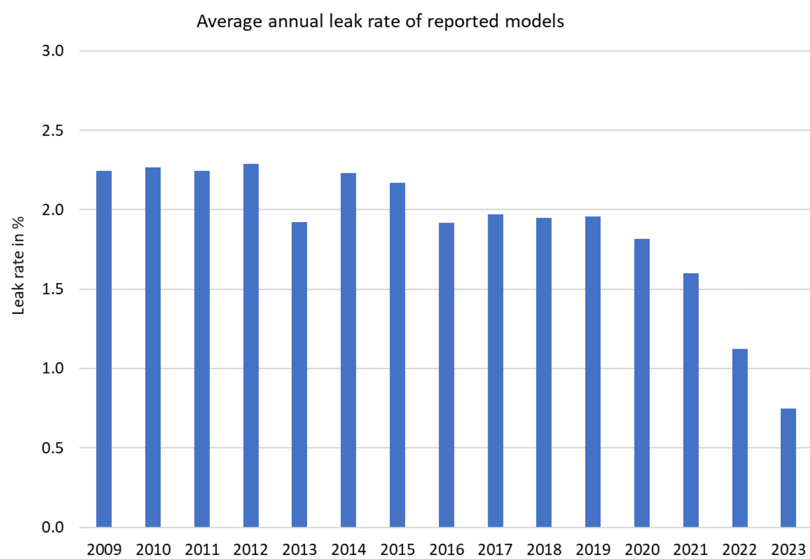

Figure A.3: Average annual leak rates of vehicle models reported in the Minnesota Pollution Control Agency database

We propose the implementation of the following leak rate targets:

- ≤ 0.7% at EIF + 18 months (several models are registered with this leak rate, several OEMs)
- ≤ 0.5% at EIF + 5 years (in 2023, one model is registered with this leakage rate)
- ≤ 0.1% at EIF + 7 years (based on the historical reduction trend)
- ≤ 0.05% at EIF + 9 years (based on the historical reduction trend)

<u>Cost implications:</u>

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[62] https://www.bls.gov/oes/current/oes493023.htm
235k mechanics in USA, scaled to the EU population results in 320k mechanics.
[63] https://www.pca.state.mn.us/business-with-us/high-global-warming-potential-greenhouse-gases

- the most significant emission reduction is the use of an electric compressor which are typically hermitically sealed, effectively reducing the emissions to zero. [64] These compressors are standard for the whole battery electric vehicle (BEV) fleet by 2050, hence no additional cost is anticipated.
- Tighter fittings and low permeable hoses are already readily available and in-use for BEV vehicles[65]. The additional cost beyond what is planned for today for BEV production is negligible (<€10/vehicle for an 18-year lifetime, 250M vehicles in EU, €138.9M/yr.).

We therefore request to demonstrate at type certification that the refrigerant leakage rate complies with the targets set out above to reduce emissions.

Impact on emissions:

The current emissions rate of 1.21% would result in estimated average emissions of 2,700 tons per year between 2025-2055, these emissions can be further deceased by the measures implemented above to:

- Emissions during use:
  0.05% per year 9 years after EiF, for 250M passenger vehicles or approximately 260 tons per year assuming 1kg charge size.
- Accidents:
  Front-end collision rate related emissions will be close to zero by 2050 (with significant reduction year-over-year due to better safe driving assists like automatic emergency braking[66] and autonomous driving technology developments[67] potentially reducing the number of collisions close to zero by 2050).
- Emissions at end of life:
  End of life emissions (which are not evaluated in the restriction dossier) can be further reduced by implementing the EU Council proposal on reclaim for F-gases for all mobile applications.

These measures result in estimated emissions of 260 tons in 2055

Summary of the cost-effectiveness of additional F-gas-based MAC system measures

The cost effectiveness of the additional F-gas-based MAC system measures can be summarized as follow:
Total cost to reduce emissions between 2025-2055:

- 68M € leak testing equipment
- 294.5M € inspector training costs
- 2.4bn € Mechanics training and certification
- 4.3bn € tighter fitting costs

Emission reduction and cost to reduce emissions:

[64] https://www.denso-am.eu/news/how-do-the-compressors-differ-in-hybrid-and-electric-vehicles
[65] Most hoses fulfill SAE J3062 ultra-low permeation criteria for R-1234yf today:
https://hydroline-service.ch/wp-content/uploads/2019/10/Fluid-Conveyance-Master-Catalog.pdf
https://www.industrialhose.com/products/PDF/Parker/HPD_4400_Catalog.pdf
https://www.eaton.com/content/dam/eaton/hydraulics/hose-tubing-fittings-and-connectors/fc-documents_catalogs_brochures_articles/eaton-gh001-evercool-ac-hose-mobile-ac-hose-pct_1207714.pdf
[66] https://spectrum.ieee.org/europe-mandates-automatic-emergency-braking
[67] https://ec.europa.eu/research-and-innovation/en/horizon-magazine/self-driving-cars-emerge-sci-fi-realm

- Total cost of the Chemours proposed emission reduction measures: € 7.1bn between 2025 to 2055 and € 230.6M in 2055.
- Projected emission reduction 2025-2055: 1,741 tons per year on average or 53,956 tons for the period.
- Projected emission reduction in 2055: 2,887 tons equivalent to an 92% reduction of suggested estimated leak rates.
- Cost per ton of emission reduction 2025-2055: EUR 0.1M on average per ton of emissions prevented.
- Cost per ton of emission reduction 2055: EUR 0.08M per ton of emissions prevented.

In summary the emissions of F-gases can be better handled by alternative RMMs at a lower cost to the European society:

- DS proposal in 2055: EUR 14.0M per ton of emission reduction based on our estimated emission calculation
- Chemours proposal in 2055: 92% emission reduction at a cost of EUR 0.08M per ton of emission reduction.

These emission values in Table A.6 could be slightly underestimated in the first part of the period, since the emissions from accidental release and recovery are not included and will reduce over time, but the leak reduction measures due to vehicle inspection are also not taken into account. This will however not impact the cost of the restriction or of the alternate measures in 2055.

Table A.6: Emissions projections in tons

Emissions DS baseline, Annex B table B.37

	2025	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
PFAS emissions/yr.	12,572	13,213	13,887	14,596	15,340	16,123	16,945
PFAS Emissions over the 5-year period	64,129	67,400	70,838	74,452	78,250	82,241	
Total emissions over the period 2025-2055	454,256						

Emissions with Chemours suggested leak rates

	2025	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
PFAS emissions/yr.	2,335	2,454	2,579	2,711	2,849	2,995	3,147
PFAS Emissions over the 5-year period	11,911	12,519	13,158	13,829	14,534	15,276	
Total emissions over the period 2025-2055	84,374	saved	53,956				

Emission estimates based on alternative Restriction Option based on RMMs

	2025	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
PFAS emissions/yr.	2,335	2,321	1,165	581	235	247	260
PFAS Emissions over the 5-year period	12,152	9,028	4,658	1,857	1,201	1,262	
Total emissions over the period 2025-2055	30,418						

CONTRIBUTION TO POLICY OBJECTIVES

Alternatives have a negative impact on the European sustainability objectives. HFOs in mobile air conditioning directly and indirectly contribute to the achievement of many of the European sustainability objectives. Without the use of HFOs, in the case of a ban of F-gases, many European sustainability objectives could be at risk. For example, the Fit for 55 initiative under the EU Green Deal requires all cars or vans placed on the market from 2035 to be zero-emission vehicles. Similarly, the Sustainable and Smart Mobility Strategy aims to have at least 30 million zero-emission vehicles in operation on European roads by 2030. Without the use of HFOs to support the transition to Battery Electric Vehicles, it will not be possible to achieve these targets. In addition, RePowerEU plans to make Europe independent from Russian fossil fuels before 2030 following the Russian invasion of Ukraine. Without the use of HFOs to support the transition to Battery Electric Vehicles, and without a sufficiently long implementation period that can support the supply chain to move to a new refrigerant, it is difficult to envision how these goals will be achieved.

SUMMARY AND CONCLUSIONS

- Attachment 1, Chapter 1 demonstrates that All F-gases (current and future) fulfilling the PFAS definition used by the Dossier Submitters should be exempted from the scope of this restriction because there is no risk to be addressed at EU level. This consideration also applies to the persistent degradation products of F-gases, such as TFA, for which the risks for both human health and the environment are de minimis.
- Even if this is not accepted. The cost of a ban would be disproportionate. Additional risk management measures, such as mandatory recovery at end-of-life, required inspection intervals, technician training and system design improvements, should be implemented to further minimize emissions. Emissions can be reduced by as much as 92% by 2055 with existing technology that is demonstrated at an estimated cost of EUR 0.08M per ton of emission reduction.
- If the DSs still wish to pursue their derogation-based approach, the derogations are too short, and the socio-economic consequences of a ban would be disproportionate compared to the environmental benefit of a restriction:
    - The total additional cost of alternatives to the European society (approx. 250M vehicle) equates to € 1,077bn between 2025 and 2055;
    - Alternatives require 70.9 TWh of additional energy generation in the EU in 2055 which is higher than the total amount of renewable energy generated in France in 2020 (52TWh);
    - An entry into force per 1st of January 2025 would not allow sufficient time for the European car industry to change to alternatives. The short term (10 years) Socio-Economic Impact to the European Society would in addition cost of €236bn[68];
    - Without the use of HFOs, many European sustainability objectives could be at risk
    - Historically the industry has required up to 17 years to transition to an alternative when this one was a close drop in;
    - Cost per ton of emissions saved in 2055 is disproportionate:

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[68] Report for Chemours Thermal Specialized Solutions (TSS), 2022: *Socio-Economic Analysis and Impact Assessment of a potential REACH Restriction on F-gases as PFAS.* Attachment 3 Annex IV [attached in confidential version]

    - EUR 14.0M per ton of emission reduction based on Chemours estimated emission calculation;
    - Or more than 17 times higher cost than the alternate restriction option based on RMMs proposed by Chemours (without taking the socio-economic impact of a ban of EUR 236bn over a 10-year period into consideration).
- Therefore, the following derogations will be required to avoid disproportionate socio-economic impacts on society.
  - Existing equipment using F-gas technologies:
    Existing MAC and EV equipment which uses F-gases cannot be retrofitted to use alternative refrigerants. Therefore, a ban on F-gases would prevent this equipment being serviced and maintained, and lead to premature retirement. **A permanent derogation** is therefore justified to avoid the unnecessary costs of replacing this equipment. (This justification was used by the Dossier Submitters for their proposed derogation 5i, although this derogation was time-limited and restricted to existing HVACR equipment only).

  - Mobile air conditioning and heat pumps (EV/hybrid mobile air conditioning/heat pumps) (M1 and N1)/, and ICE mobile air conditioning vehicles (M1 and N1):
    - There are fundamental problems with using F-gas alternatives in electric vehicles AC and heat pumps, due to safety concerns and poor performance, especially at higher ambient temperatures. **A derogation** for F-gases in these applications is therefore justified.
    - ICE vehicles are subject to phase out over a period of time which means investment in new MAC systems which do not use F-gases will never be commercially viable (even if it were possible). **A derogation** for F-gases in ICE MAC applications is therefore justified.

    <u>It is not possible to specify a meaningful (evidence-based) time-limited derogation/transition period because it is not clear that alternatives can ever be economically competitive. Hence the costs of a ban are expected to remain disproportionate for the foreseeable future.</u>

ANNEX A.1: INFORMATION ON BATTERY ELECTRIC VEHICLES (BEV) ELECTRIC COMPONENT IMMERSION COOLING THERMAL MANAGEMENT.

As the industry and global regulations promote and, in some cases, force the use of electric vehicles,[69,70] the need for effective thermal management of the lithium-ion batteries (LiB), e-motor, and power electronics is critical to safety. Fluorinated fluids are an important keystone to help make these electrification goals possible by decreasing the total cost of ownership, extending component life, and enabling ultrafast charging.

Current battery technologies have demonstrated that high temperatures can prematurely age batteries, leading to about a 9% decrease in capacity over 250 charge cycles relative to batteries maintained at cooler temperatures[71]. The paper concludes: "From our analysis, we can see that increasing the operating temperature increases the degradation rates of all components in the LiB which include maximum charge storage capacity".[72]

Hotter, prematurely aged batteries will need to be replaced more often, contributing to greater waste, total cost of ownership, and environmental concern from mining of cobalt, lithium, and other metals used in batteries. Prematurely aged batteries are also more reactive and prone to thermal runaway, meaning a failure of a battery cell that can spread to others and lead to a fire. They can also have battery fires at lower temperatures, meaning that they are less safe. "[The] aged cells were revealed to undergo thermal runaway at a lower temperature than new cells."[73] Even fast-charging can generate enough heat to age batteries or to send them into thermal runaway, particularly in more reactive aged batteries.[74]

An electric vehicle has many electrified components which require thermal management, including the battery cells, busbar, power electronics such as the inverter and onboard charger, the electric motor, and perhaps even charging stations. The use of a dielectric fluid can allow for the energized components to be safely cooled by direct contact with hot surfaces. This allows for more effective removal of heat from these electronic components than the indirect water-glycol cooling – which uses cold plates - can do. While water-glycol is an effective heat transfer fluid, it is electrically conductive, and therefore cannot be used directly in contact with electrified componentry, as it would lead to an electrical short and potentially even a battery fire or other unsafe situation. More effective thermal management will be critical for future EV technologies. Additionally, temperature variability in a battery pack needs to be quite narrow to limit impacts on performance. "Under temperature gradients, the cell was found to not perform as under a uniform temperature equal to the theoretical average temperature of the imposed gradient, but as a cell

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[69] https://electrek.co/2021/09/23/norway-bans-gas-cars-in-2025-but-trends-point-toward-100-ev-sales-as-early-as-april/

[70] https://www.politico.eu/article/france-attack-dangerous-germany-effort-change-eu-car-combustion-engine/

[71] https://electrek.co/2021/09/23/norway-bans-gas-cars-in-2025-but-trends-point-toward-100-ev-sales-as-early-as-april/

[72] Leng, F., Tan, C.M. and Pecht, M. (2015) 'Effect of temperature on the aging rate of Li ion battery operating above room temperature', *Scientific Reports*, 5(1). https://www.nature.com/articles/srep12967 .

[73] Abada, S. et al. (2018) 'Combined experimental and modeling approaches of the thermal runaway of fresh and aged lithium-ion batteries', *Journal of Power Sources*, 399, pp. 264–273. https://www.sciencedirect.com/science/article/abs/pii/S037877531830819X .

[74] Li, Yalun et al. (2022) 'Battery eruption triggered by plated lithium on an anode during thermal runaway after fast charging', *Energy*, 239, p. 122097.https://www.sciencedirect.com/science/article/abs/pii/S0360544221023458

at a higher average temperature."[75] In other words, even if individual cells in a pack are at a lower temperature, they will perform as poorly as a cell at a higher temperature, making it critical that their temperatures are uniform.

Immersion cooling and its advantages

A more effective thermal management strategy than an indirect liquid cooling solution like using water-glycol can be to submerge the components directly in a dielectric fluid, allowing them to be cooled more efficiently. More effective thermal management via immersion cooling can help to improve EV safety by decreasing the likelihood of a thermal runaway event, can improve battery lifetime, and can help to enable ultrafast charging by more effectively removing heat.

Some automotive OEMs are already exploring immersion cooling in their vehicles. Mercedes AMG has begun to "direct cooling" of the battery packs in their hybrid vehicles, which they claim keeps the battery pack "always in the optimum temperature window of around 45 degrees." It also facilitates their regenerative braking.[76] McLaren's Speed tail hybrid uses similar technology to cool their battery pack, designed for rapid charge and discharge cycles.[77]

Fluorinated fluids are non-flammable and several fluorinated immersion cooling fluids have flame suppression properties. This can be critical to improve safety in a thermal runaway situation. Many firefighters and fire companies are not currently equipped with equipment to effectively put out battery fires.[78] Although battery fires may not be common, they can have devastating consequences[79] [80]. While single-phase hydrocarbon battery thermal management provides a relatively inexpensive solution to cool electric vehicle batteries by immersion, the addition of combustible hydrocarbons to reactive batteries presents an additional safety risk that the use of a fluorinated fluid, either as a single-phase or two-phase coolant, would not add. The use of a fluorinated fluid may even help to suppress any fires that start.

The use of a fluorinated fluid allows for two-phase immersion cooling, which is an extremely effective cooling strategy, while also not having a flash point (does not ignite) that would prohibit the safe use of some other non-fluorinated fluids in this way. Because the fluid will boil, active circulation is not needed, and so energy efficiency may be increased.

Battery packs and power electronics with these fluids will be sealed and therefore will be non-emissive, one system by Kautex is cited as resulting in < 4 g/year per system.[81]

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[75] Troxler, Y. et al. (2014) 'The effect of thermal gradients on the performance of lithium-ion batteries', *Journal of Power Sources*, 247, pp. 1018–1025. https://www.sciencedirect.com/science/article/abs/pii/S0378775313010914 .

[76] https://www.mercedes-amg.com/en/world-of-amg/news/press-information/mercedes-amg-gt-63-s-e-performance.html

[77] https://www.thedrive.com/news/35443/the-250-mph-mclaren-speedtails-batteries-are-sealed-in-a-unique-oil-to-keep-them-cool

[78] https://www.cnbc.com/2022/01/29/electric-vehicle-fires-are-rare-but-hard-to-fight-heres-why.html

[79] https://www.theguardian.com/business/2022/feb/21/abandoned-burning-ship-had-400m-cargo-of-luxury-cars

[80]. https://www.drive.com.au/news/porsche-shipment-catches-fire-in-the-atlantic-no-australia-bound-cars-affected/

[81] Lipperheide, M. (2021). On the design and performance of an integrated 2-phase immersion cooling system in thermoplastic battery enclosures [pdf]. Presented at SAE International Thermal Management Systems Digital Summit, online.

Although immersion cooling with fluorochemicals is a new technology that likely won't see widespread implementation for five years or more, its use will help to safely implement more widespread electrification by improving safety and increasing battery lifetime to decrease waste and subsequently consumer cost.

Batteries are expected to last at least 8 years, due to the warranty lifetime, although many will last longer.[82] Still, given these numbers, many EVs will exceed the average lifetime of the battery, which will either require the vehicle or the battery to be replaced. Although replacing the battery is less expensive and resource-intensive than getting an entire new car (costing up to $16,000[83]), and generates less waste, it still requires resources and generates some waste. As discussed above, improved thermal management can help to increase the lifetime of batteries.

An immersion cooling solution with a fluorinated fluid will lead to the most consistent battery temperatures, even in extreme environments and under conditions of ultrafast charging, and the fluid will not need to be replaced in the lifetime of the battery. Over a lifetime of a decade or more, this could translate to at least an additional year of battery life, potentially increasing the total lifetime of an EV and reducing the total cost of EV ownership.

Finally, the use of a non-flammable fluorinated fluid will improve the safety of Evs, which can require tens of thousands of gallons (greater than one hundred thousand liters) of water to extinguish, while also burning for much longer times than gasoline or diesel fires.[84]

[82] https://www.caranddriver.com/research/a31875141/electric-car-battery-life/
[83] https://www.moneygeek.com/insurance/auto/electric-vehicle-insurance-costs/#why-ev-insurance-costs-more
[84] https://www.autoweek.com/news/a38225037/how-much-you-should-worry-about-ev-fires/ .

ANNEX A.2: CHEMOURS END-CONSUMER MARKET STUDY FOR CO2 REFRIGERANTS IN EVS [Attached in confidential version]

ANNEX A.3: MAC ANALYSIS OF HEAT PUMP SYSTEMS USING CO2 (R-744) AND R-1234YF

Summary of energy consumption costs and additional infrastructure requirements

Developing a comparison of energy consumption differences between R-1234yf vs. R-744 EV heat pump system in EU:

- Use an average commuter distance of 15 000 km per year;
- Attempt to compare two similar vehicles with different heat pump systems (Compact Car 2 is larger in both categories below but outperforms Compact Car 1 in all WTLC (Worldwide Harmonized Light-Duty Vehicle Test Cycles) conditions in using less energy as shown).

	Compact car 1 (R-744)	Compact car 2 (R-1234yf)
Cabin Space (liters)	565	770
Vehicle weight (kg)	1820.2	2130.8

- Energy study conducted using WLTC shown in Figure A.4 on both Compact Car 1 R-744 and Compact Car 2 R-1234yf heat pump systems for the following conditions: -10, 0, 22 & 45 deg C.

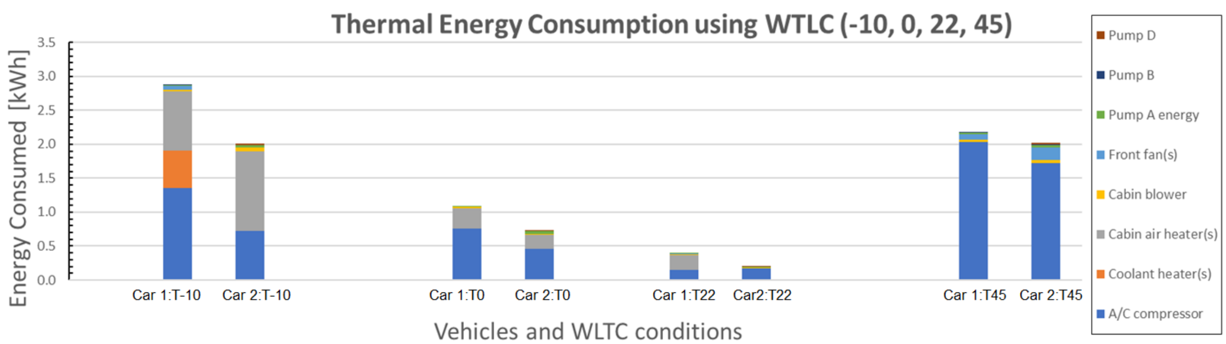

Figure A.4: Thermal energy consumption using WLTC

- An equation was derived for the energy consumed by each heat pump system from WTLC conditions, as a function of kW/km (Figure A.5), and then multiplied by the drive times (for both morning and evening commutes) per the given geographical weather based on ASHRAE Weather Viewer Version 6.0 (Key locations in Europe include: Athens, Greece and Frankfurt, Germany) (Figure A.6) (https://www.c-pdf.com/standards/Weather-Data-Viewer-DVD-Version-6-0)

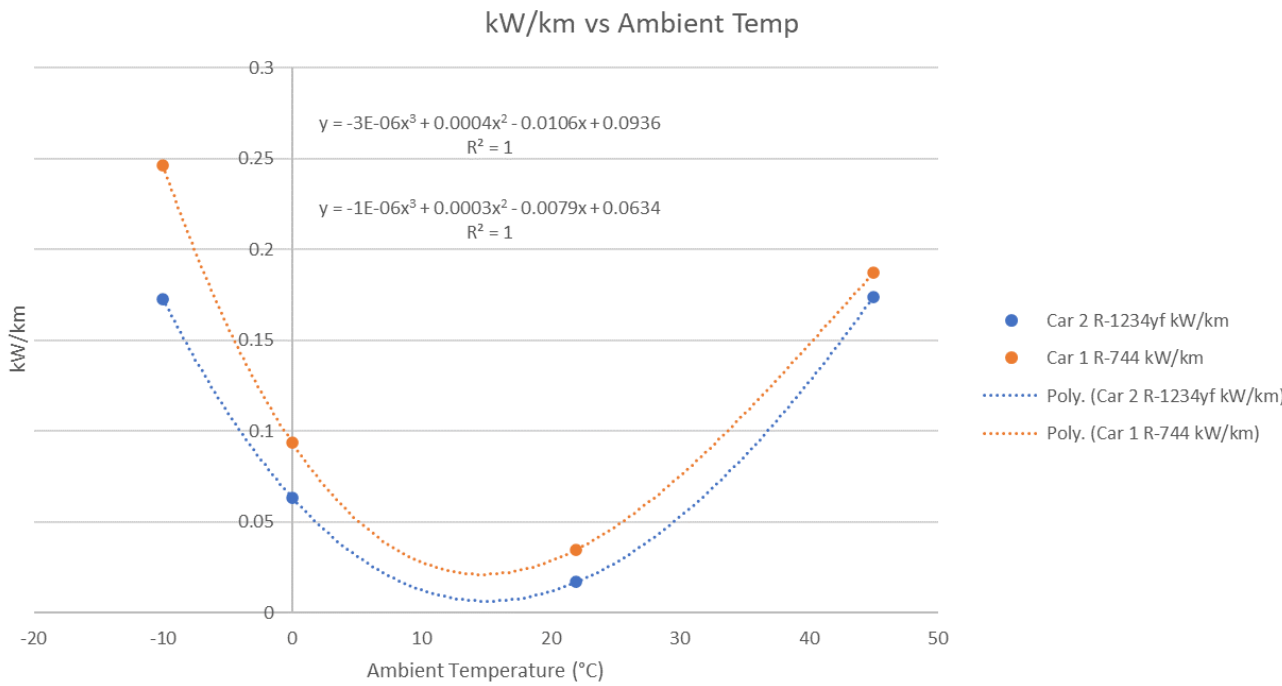

Figure A.5: Energy consumed by each heat pump system from WTLC conditions, as a function of kW/km

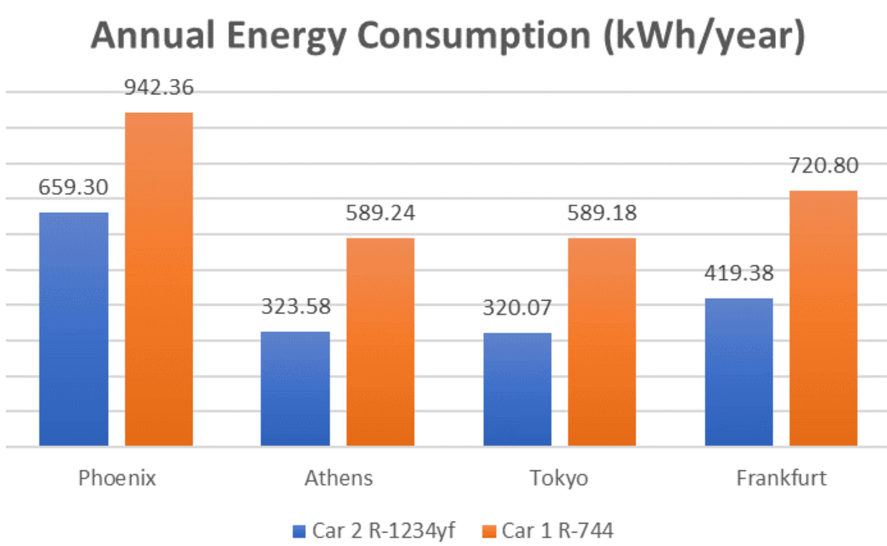

Figure A.6: Annual energy consumption

- Using energy (kW) per distance (km), an estimated energy per year was able to be determined for the cities of Athens and Frankfort for both Car 1 and Car 2 EV heat pump systems.

- Using an average for the two cities and comparing overall energy consumed yields the following difference (assuming average energy consumption for EV heat pump systems for Europe): (589.24 kWh/yr. + 720.8k Wh/yr.)/2 - (323.58kWh/yr. + 419.38kWh/yr.)/2 = <u>283.54 kWh per year</u>

System demonstrated (see above), more than 40% energy saving when using R-1234yf versus R-744
For 250M vehicles, this is 250M * 283.5 kWh = 71TWh.

B. Stationary HVACR application submission

INTRODUCTION

Heating, Ventilation, Air Condition and Refrigeration (HVACR) covers a wide range of applications such as commercial air conditioning and heat pumps (HP), domestic air conditioning and heat pumps, and industrial high temperature heat pumps and a wide range of diverse equipment designs and technical requirements in industrial and commercial refrigeration.

The stationary HVACR and transport refrigeration sector is coming from a multi-decade convergence towards a narrow range of refrigeration fluids where, like many other vapor-compression based technologies, it developed around the refrigerant HCFC-22. It then transitioned by adopting specifically developed HydroFluoroCarbon (HFC) solutions. When concerns over the potential climate impact of HFC's were identified, the industry started searching for lower global warming potential (GWP) alternatives. Over the years of this transition process, specific long term, zero ozone-depleting potential (ODP), and very-low GWP solutions were developed, based on hydrofluorolefins (HFOs).

The differentiation provided by F-gases over the last several decades was triggered by the need to address clearly identified industry needs in each individual application segment. This led to the development of specific products with very specific chemical properties to address operational performance, energy efficiency, safety and design requirements. Non-fluorinated alternatives, on the other hand, are limited in number and still present the same physical, chemical, and thermodynamic limitations, which led to their replacement in the first place. The inferior thermodynamic properties of CO2 (R-744) (as described in Attachment 1, section 3.3) lead to increased energy consumption and increased equipment complexity and cost to try to cope with this performance deficit. Hydrocarbons such as propane (R-290) have good thermodynamic properties, but cannot be used in many applications due to safety standards and codes with highly flammable refrigerants requiring limited charge sizes (as described in Attachment 1, section 3.4) and the use of secondary loop systems, increasing system cost and lowering efficiency. This is also the case for ammonia (R-717), which can only be used in limited situations due to its toxicity and effect on human health.[85]

The current F-gas regulation requires a reduction in the use of F-gases in terms of GWP, and in response, the industry has developed very-low GWP solutions based on HFOs. These solutions rely on blends of HFCs and HFOs to meet the performance requirements of the diverse array of applications. One of the potential outcomes of the F-gas regulation revision is the phase out of HFCs by 2050[86] and with it the phase out of all blends containing HFCs, representing the majority of the solutions used today in stationary HVACR, unlike other applications (mobile air conditioning, clean fire suppressants, foam, etc.) where a majority of solutions are based on pure HFO substances.

Further development will be required by the industry to bring to market the molecules of the future to replace HFCs by 2050. This novel fluorinated technology will need to balance critical properties from GWP

[85] https://www.cnn.com/2023/05/04/business/tyson-ammonia-leaks-invs/index.html.

[86] *Texts adopted - fluorinated gases regulation* (2023) *europarl.europa.eu.* Available at: https://www.europarl.europa.eu/doceo/document/TA-9-2023-0092_EN.html.

to flammability to degradation profile and performance to meet customer needs and the evolving regulatory landscape, as the commitment that Chemours made in February 2023.[87] This will have the opportunity to further lower the profile of any remaining emissions in the stationary HVACR applications that would remain after the emission reduction measures that we propose below.

In this submission, we will demonstrate that non-fluorinated alternatives exhibit serious limitations in terms of performance across different climatic conditions (especially high ambient temperatures), energy efficiency and safety constraints, making them an important part of the overall refrigerant toolbox, but in no way the universal solution that can replace decades of F-gas technological development that addressed operational performance, energy efficiency, safety and design requirements. The industry needs adequate time to develop and transition to alternatives that can meet the same performance criteria over the broad range of applications and climatic conditions that exist in the European Union.

THE CURRENT REGULATIONS ARE THE BEST TOOLS TO MANAGE F-GASES AND MINIMIZE THEIR EMISSIONS

The Dossier Submitters (DS) conclude that the F-gas regulation (FGR) is insufficient to manage the risks associated with F-gases. The conclusion appears to be based on two arguments: that the FGR "does not per se restrict the use of the substances but rather aims for a reduction of their use" and that the current FGR does not regulate all fluorinated gases fulfilling the DSs' PFAS definition. Rather, they argue a REACH restriction is required because that would limit as many uses as practically possible and thereby minimise F-gas emissions (and hence exposures), cover current and future F-gases, and prevent regrettable substitution. Derogations are proposed for "some key applications of fluorinated gases [where] alternatives are not yet available."

We believe this conclusion is unfounded. F-gases are already strictly regulated under the current Regulation 517/2014 (FGR)[88]. It establishes a phasedown schedule for HFCs – consistent with a substitution objective of the proposed REACH restriction – as well as stringent provisions to require training and certification of technicians and to minimize leakages throughout the lifecycle of the F-gases. The Commission Proposal to review the F-gas Regulation ("Commission Proposal")[89] currently under discussion extends the containment, training and certification, and recovery measures to Annex II – Section I F-gases (HFOs and HCFOs). The Commission Proposal therefore addresses the principal concerns expressed by the Dossier Submitters about the suitability of using the FGR to manage F-gases and the risks associated with them. As a result, Chemours considers that the F-gas regulation is the best tool to manage F-gases and reduce their emissions and has the necessary measures in its current version and the revision

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[87] The Chemours Company (2023). *Correcting and replacing to meet growing customer needs for Thermal Management Solutions, Chemours announces at the 2023 Ahr Expo its intention to bring next generation refrigerants to market for qualification in 2025* https://investors.chemours.com/news-releases/news-releases-details/2023/CORRECTING-and-REPLACING-To-Meet-Growing-Customer-Needs-for-Thermal-Management-Solutions-Chemours-Announces-at-the-2023-AHR-Expo-Its-Intention-to-Bring-Next-Generation-Refrigerants-to-Market-for-Qualification-in-2025/default.aspx.

[88] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006;

[89] Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014;

proposals by the commission and council to achieve this. Further details are presented in Attachment 1, section 1.5. The rest of this submission will focus on other issues raised by the proposed restriction.

EMISSIONS ESTIMATE

In the case of stationary HVACR, we believe that emissions have been overstated in Annex XV report, which has the effect of artificially increasing the positive impact of a ban on emissions and reducing the associated economic cost. In the dossier, the average annual emission rate of all stationary applications combined is assumed to be 6.7% (apparently based on modelling for the GHG inventory report), resulting in annual emissions of 20,702 tonnes/year.[90] However, an industry leak rate study published in July-August 2021[91] on actual commercial refrigeration systems reported achieving annual leak rates of 3.4%, which is an actual reported leak rate. Applying this leak rate to the stock of F-gases (296,499 tonnes) in each stationary application (commercial refrigeration, domestic refrigeration, industrial refrigeration, stationary air conditioning) results in stationary refrigeration and AC emissions of 10,081 tonnes/year, almost 50% lower.

Using the current emission rate is important for calculating future emissions since new systems, with the latest technological advancements, properly installed and maintained over their service lives will have a lower emission rate than the current installed systems. It is also important to ensure that the benefits of a ban are not exaggerated.

We consider the leak rate of 3.4% per year to be conservative given the information available from VDKF by sector described in their July-August 2022 publication[92] and presented in Table B.1 below:

Table B.1: Average leak rates by application in third column of the table. Source: VDKF (translated from German)

Application	Average total refrigerant charge 2017-2021 in tonnes	Average total amount of refilled refrigerant 2017-2021 in tonnes	Average Leak Rate 2017-2021 in tonnes
Split A/C	231.4	2.0	0.89%
Commercial Refrigeration	862.9	26.9	3.15%
Industrial Refrigeration	543.2	11.3	2.08%
Centralized A/C	318.9	3.7	1.15%
VRF A/C	172.5	2.1	1.34%
Special installations	91.0	2.3	2.51%

[90] Holland, M. and Hollins, S. (2021) Application of Fluorinated Gases (F-Gases) in the European Economic Area, *Exponent International Limited.*: https://www.miljodirektoratet.no/sharepoint/downloaditem?id=01FM3LD2VZ2PFZD5VJ2JB2ZZ2GDG7TWV6B.

[91]: https://www.vdkf.de/download/vdkf-verbandszeitung-juli-august-2021/

[92]: https://www.vdkf.de/download/vdkf-verbandszeitung-juli-august-2022/

THE PROPOSED DEROGATIONS ARE INSUFFICIENT

On the basis that the FGR is deemed insufficient to manage the risks of F-gases, the DSs propose a general ban on the use of F-gases, except in a limited number of "key" applications where they conclude alternatives are not yet available and hence derogations are required. In the stationary HVACR domain specifically, the DSs propose the following derogations:

- Refrigerants in low temperature refrigeration below -50 °C until 6.5 years after entry into force (EiF);
- Refrigerants in laboratory test and measurement equipment until 13.5 years after EiF;
- Refrigerants in refrigerated centrifuges until 13.5 years after EiF;
- Maintenance and refilling of existing HVACR equipment put on the market before [18 months after EiF] and for which no drop-in alternatives exist until 13.5 years after EiF; and
- Refrigerants in HVACR-equipment in buildings where national safety standards and building codes prohibit the use of alternatives, time unlimited derogation.

There is also the following proposed derogation:

- Use as refrigerants and for mobile air conditioning in vehicles in military applications until 13.5 years after EiF.

Based on the available data we consider that the derogations proposed by the Dossier Submitters are not sufficiently wide to avoid disproportionate impacts to society. In addition, the derogations suggested are too short to allow substitution to take place in a cost-effective manner.

Non-fluorinated alternatives have replaced F-gases in domestic refrigeration and in commercial refrigeration standalone systems, because the charge sizes in this type of equipment are relatively small, making the safety risk associated with the use of flammable substances like propane acceptable under current equipment codes and standards (see attachment 1, section 3.4). Non-fluorinated alternatives are also used across many other applications but exhibit serious limitations in terms of performance across different climatic conditions (especially high ambient temperatures), energy efficiency and safety constraints, making them an important part of the overall refrigerant toolbox, but in no way the universal solution that can replace decades of F-gas technological development that addressed operational performance, energy efficiency, safety and design requirements.

In this proposal, we will demonstrate that the shortfalls of non-fluorinated alternatives apply across all current segments in the stationary HVACR sector and that there is a need for all refrigeration technology to coexist in the marketplace to offer the most energy efficient and safe solutions for each application and design requirement.

This conclusion can also be drawn for transport refrigeration, which uses the same refrigeration fluids as stationary refrigeration and therefore has the same challenges, with the additional requirements that the equipment must be able to withstand the further strains of being in constant movement. For this reason, all argumentations drawn for stationary HVACR can be also considered valid for transport refrigeration.

Throughout the proposal, the Dossier Submitters state on numerous occasions that alternatives are not suitable for all application, or that a long transition time is needed. Despite this fact, there is no derogation for the stationary HVACR sector except for very specific and niche applications and the maintenance derogation is limited to 13.5 years after EiF. There are also many claims on parity of the performance of alternatives with F-gases and on the need to relax the safety requirements of alternatives. We have summarized these quotes in the Annex B.1 at the end of this document, and we will demonstrate that these statements do not hold true and cannot be generalized.

These comments can be summarized in four categories:

1. Performance claims
2. Use derogation
3. Safety considerations
4. Maintenance derogation

1. Performance claims

The question of performance is important to address when evaluating alternatives. We disagree with the claims by the DSs regarding the performance of alternatives and demonstrate below that there are many references pointing to the inadequate performance of non-fluorinated alternatives.

This is not to say that non-fluorinated alternatives cannot be used across many applications. However, they exhibit serious limitations in terms of energy efficiency, safety constraints and thermodynamic performance across different climatic conditions, especially in high ambient temperatures. These limitations restrict their effective use to a limited number of situations and are in fact why fluorinated alternatives were developed in the first place. It will take many years to find a solution that can replace those decades of F-gas technological development.

The DSs claim (Annex E Section 2.8.2.1) that several stakeholders have pointed to HFC-32 (CH2F2) as a viable alternative for multiple applications. However, there are several limitations with the use of HFC-32:

- It has a high GWP of 675 (AR4)[93], and is excluded from specific applications where the F-gas regulation bans refrigerants above a GWP of 150 (in the current regulation, but also in new applications in the F-gas regulation proposal) and was also excluded as a low GWP option to meet GWP phasedown targets in the Kigali agreement.
- Performance at low temperatures increases compressor discharge temperatures, which reduces compressor durability and heating performance, especially at high ambient temperatures.
- In some applications, large charge sizes with flammable refrigerants can be prohibited such as large buildings, or areas where dilution can be limited such as small spaces.
- A critical temperature of around 78 Deg C limits its use in hot water heat pumps or high temperature heat pump applications for example.

More performance details on HFC-32 can be found in Annex B.2 of this application.

The DSs refer (Annex E Section 2.8.2.2) to Hafner and Ciconkow's (2021) claim that "all temperature levels and most applications can be cooled by applying natural refrigerants," Asda (2022) (and other studies) demonstrates that this translates into financial costs and/or energy inefficiencies when compared to HFO-

[93]: https://ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf.

based solutions, which in one example were found to generate 35-40% in energy savings compared with a previously installed CO2 system.[94,95]

The DSs also refer to a report by Infinitus Energy Solutions and Entropy Cooling Solutions[96] (Annex E Section 2.8.2.2) on the use of non-fluorinated alternatives, which states that "suitable natural refrigerants are available for any heat pump applications", and that "HP with natural refrigerants are at least as efficient as HP with synthetic refrigerants." We disagree with this claim. Measurements and simulations carried out by an independent research institute in Germany have shown that F-gas heat pumps can achieve up to 22% lower indirect emissions compared to standard R-290 (propane) equipment.[97] In 2020, Stiebel Eltron (a key manufacturer of heat pumps in Europe[98]) launched residential heat pumps based on the HFO-454C, which provide up to 15% higher Coefficient Of Performance than comparable systems using HFC-410A (which is still the most used HFC refrigerant in this application).[99,100,101]

Despite referring to these positive statements about the ability of 'natural' gases to substitute for F-gases in all applications, the DSs also contradict this view in several places. For instance, in Section 2.8.2.2 of Annex E, the DSs state that "hydrocarbons are less suitable for larger multi-split and VRF systems due to the high costs and constraints of the required safety measures" and "safety measures do increase the purchase costs of heat pumps and often the maintenance costs too (more inspections/maintenance)", showing that their first statement is a generalization focusing on one specific attribute.

In Annex E Section 2.8.2.2, the DSs refer to the "Pathway to net-zero cooling product list" as providing "an overview of the availability of energy efficient and ultra-low GWP (<5) natural refrigerants that are used for various refrigeration purposes as alternatives to fluorinated gases."[102] However, this product list is limited in its coverage of equipment types. For instance, in the case of condensing units, the list only covers hydrocarbon units up to a capacity of 1kW, which only covers a very small range of the condensing until power range, which can go up to 20kW[103] and seriously limits the applications where these systems can be deployed.

For applications requiring condensing units today, the only non-fluorinated alternative that may be considered is CO2 (R-744), but even at ambient temperatures around 15-20 Deg C, the energy efficiency of CO2 is inferior to that of F-gases as shown in Figure B.1.

94: https://www.racplus.com/news/asda-trial-finds-huge-hfo-savings-versus-co2-21-03-2022/.

95 Hafner, A., & Ciconkov, R., (2021). Current state and market trends in technologies with natural refrigerants. *International Institute of Refrigeration.* https://iifiir.org/fr/fridoc/etat-actuel-et-tendances-du-marche-des-technologies-utilisant-des-144340.

96 http://infinitus-energy.com/.

97 https://www.opteon.com/en/support/resource-center/leading-efficiency-in-heating.

98 https://www.gminsights.com/industry-analysis/europe-heat-pump-market.

99 https://www.stiebel-eltron.com/en/home/products-solutions/information-engineering/refrigerant-r454c.html.

100 https://www.stiebel-eltron.de/content/dam/ste/de/de/home/produkte/informieren_planen/KltemittelR454C/Kaeltemittel_Broschuere_R454C.pdf.

101 https://www.stiebel-eltron.ch/de/home/produkte-loesungen/erneuerbare_energien/waermepumpe/luft-wasser-uebersicht.html.

102 https://cooltechnologies.org/pathway-to-net-zero/

103 Abdelaziz, O. et al. (2022) Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee: 2022 Assessment Report, *UN Environment Programme Ozone Secretariat*, pp. 102. https://ozone.unep.org/system/files/documents/RTOC-assessment -report-2022.pdf.

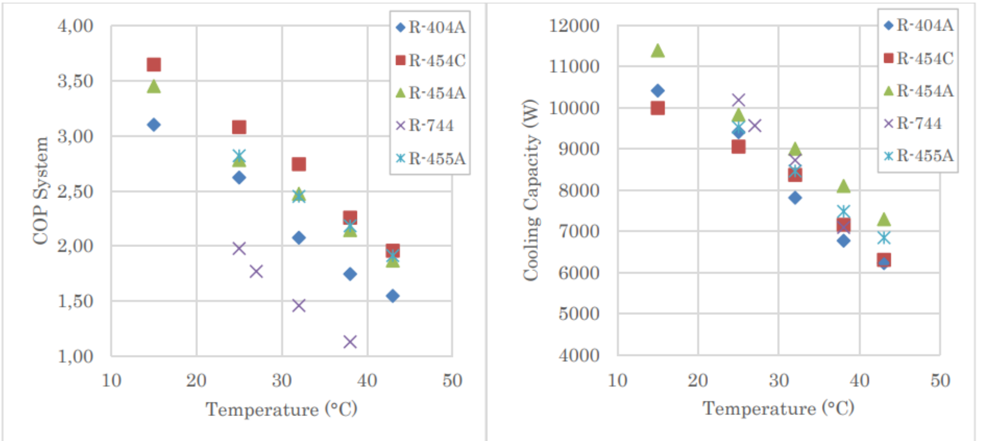


Figure 5: COP_{system} and cooling capacity (W) comparison at T_{evap}=-10°C

Figure B.3: Comparison of the coefficient of performance (COP) and cooling capacity of CO2 (R-744) condensing units compared with those operating on a range of f-gases.[104]

Figure B.3 compares the coefficient of performance (COP) and cooling capacity of CO2 (R-744) condensing units compared with those operating on a range of F-gases.[105] The COP for a condensing unit is essentially the cooling capacity achieved per unit of energy consumed. Overall, across all tested temperatures, the CO2 condensing unit COP was considerably lower than the F-gas COP (at least 20% lower, and up to 50% lower, but a conservative estimate of 25% can be assumed), and the COP of F-gases was at least 32% higher than R-744). This is a direct result of the thermodynamic properties of CO2 versus typical F-gases used in refrigeration conditions. Comparing rated efficiency of products on the "net zero product list" with F-gas equivalents is made difficult because of variations in product capacity evaporator temperatures. However, one important element to note is that all rating conditions for the CO2 condensing units are 32 Deg C[106], which represents approximately an ambient temperature of 20 Deg C. With ambient temperature above 20 Deg C, the performance of CO2 systems drops significantly (20 Deg C ambient corresponds to a condensing temperature higher than 30Deg C which imply a transcritical operation mode for CO2, where the performance of CO2 systems drops significantly, as explained in Attachment 1, section 3.3).

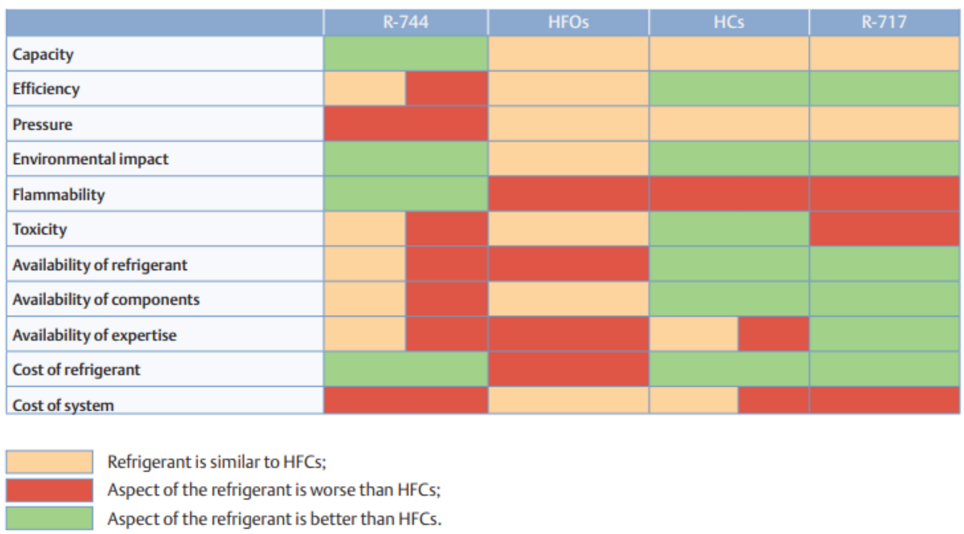
In Table E.88 of Annex E, the DSs state that, "for cost-competitive alternatives there is no evidence of a loss in efficiency" in moving from f-gas-based commercial HVACR to equipment based on "natural" refrigerants. However, previously (page 256), they admitted that there is a loss of efficiency: "Air cooled CO2 AC systems are available from 3kW to 300 kW, though systems become inefficient at high ambient temperatures." It is well known and understood in the industry that CO2 is not as thermodynamically

[104] Haddad, E., Saab, S. and Zoughaib, A. (2021) *Test of condensing units' performance and operating limits using different refrigerants.* https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3144&context=iracc.
[105] Haddad, E., Saab, S. and Zoughaib, A. (2021) *Test of condensing units' performance and operating limits using different refrigerants.* https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3144&context=iracc.
[106]: https://cooltechnologies.org/sector/commercial-refrigeration/. Select Refrigerant: Carbon Dioxide, Technology Type: Condensing Units

efficient as an F-gas, especially in warmer climates. In fact, even highly engineered CO2 systems struggle to reach the efficiency of a baseline F-gas system at temperatures above 20 Deg C.[107]

Further on in Table E.97 of Annex E, it is stated that there is “sufficient strong evidence” that “there is growing acceptance of alternatives, indicating that they are cost-competitive with fluorinated gas systems.” Yet, when considering CO2 (R-744), it is less efficient and the systems have a higher cost compared to F-gases in HVACR refrigeration in industrial and commercial settings, leading to higher emissions, and less reliability, as described in Table B.2 below sourced from a manufacturer of commercial HVACR equipment.[108]

Table B.2: Comparison of R744 with other refrigerants



The examples above, clearly show that the technical feasibility of alternatives in the stationary HVACR applications that have not already transitioned to non-fluorinated alternatives is far behind that of systems based on F-gases, and far further behind than the DSs submitters contend on the basis of the information they have collected.

The evidence is summarized below:

- CO2 has inferior thermodynamic properties leading to increased energy consumption and increased equipment complexity and cost to try to cope with this performance deficit, and even at ambient temperatures around 15-20 Deg C, the energy efficiency of CO2 is inferior to that of F-gases.
- Hydrocarbons such as propane (R-290) have good thermodynamic properties, but, due to limited charge sizes for highly flammable refrigerants necessary to meet safety standards and codes, require the use of secondary loop systems which increase system cost and lower efficiency.
- Ammonia (R-717) cannot be used in many situations due to its toxicity and effect on human health.[109]

[107] Mitsopoulos, G. et al. (2019) Annual performance of a supermarket refrigeration system using different configurations with CO2 refrigerant. *Energy Conversion and Management: X.* https://www.sciencedirect.com/science/article/pii/S2590174519300042.
[108] https://climate.emerson.com/documents/commercial-co%E2%82%82-refrigeration-systems-en-us-1800328.pdf.
[109]: https://www.cnn.com/2023/05/04/business/tyson-ammonia-leaks-invs/index.html.

- F-gas heat pumps can be up to 22% more energy efficient than standard propane (R-290) heat pumps
- HFC-32 (non-PFAS F-gas) has limited success and applicability in high temperature conditions and is not a viable alternative.
- The reports used by the DSs admit themselves that alternatives have shortfalls.

2. Use derogations

The DSs make statements on numerous occasions which contradict the general proposal of no use derogations beyond the transition period of 18 months after EiF (Annex 1). However, nothing in these statements points to the possibility of the industry being able to transition to a wide use of non-fluorinated alternatives in new equipment within this time period.

This is further demonstrated by the time that the industry has needed in the past to introduce alternatives, which in Chemours' experience has taken as long as 16 years, as shown by the time taken for the identification, screening (technical, safety and environmental evaluations), production and commercialization of new molecules, for example in the development of HFO-1234yf:
[Confidential]

Given the significant performance deficits between F-gases and the alternatives, and the time it has taken in the past to develop alternatives, it is clear that a ban on the use of F-gases 18 months after EiF would not permit cost-effective substitution to take place and hence would have disproportionate costs on society.

3. Safety considerations

The DSs state in numerous places that some of the disadvantages of flammable hydrocarbon-based systems could be overcome if codes and standards were relaxed, so that the charge sizes could be increased (see in Annex B.3 of this application).

As described in Attachment 1, section 3.4 safety standards are mainly based on calculations of Lower Flammability Limits (LFL), Oxygen Deprivation Limits (ODL) and Acute Toxicity Exposure Limits (ATEL) which are physical properties of a substance. Such properties cannot change. Constraints will always exist and will always be more restrictive for more dangerous substances and handled appropriately through international and European Standards, which require thorough review and consideration at the international level before an amendment can be considered.

<u>The market penetration of flammable non-fluorinated alternatives in heat pumps is a good example:</u>
Within domestic heat pump applications, there are currently two main technologies: air to air and air to water. In section 6.5 p92 of the latest working group report of the Technology and Economic Assessment Panel (TEAP) under the Montreal Protocol (UNEP, 2022), it is stated that for "air-to-air" air conditioners and heat pumps, HFC-410A is still the dominating refrigerant, HFC-32 is coming second and "enterprises within all regions continue to evaluate and develop products with various HFC/HFO blends, such as those

comprising HFC-32, HFC-125, HFC-134a, HFC-1234yf and HFC-1234ze. Products are being introduced with lower GWP alternatives, R-454A, R- 454B, R-452B and R-463A."[110]

When examining air-to-air HP technologies, the use of non- fluorinated alternatives such as hydrocarbons (R-290) have not been developed at all due to safety concerns, therefore holding near zero market share as shown in Figure B.2 from PAC&CLIM INFO[111] below.

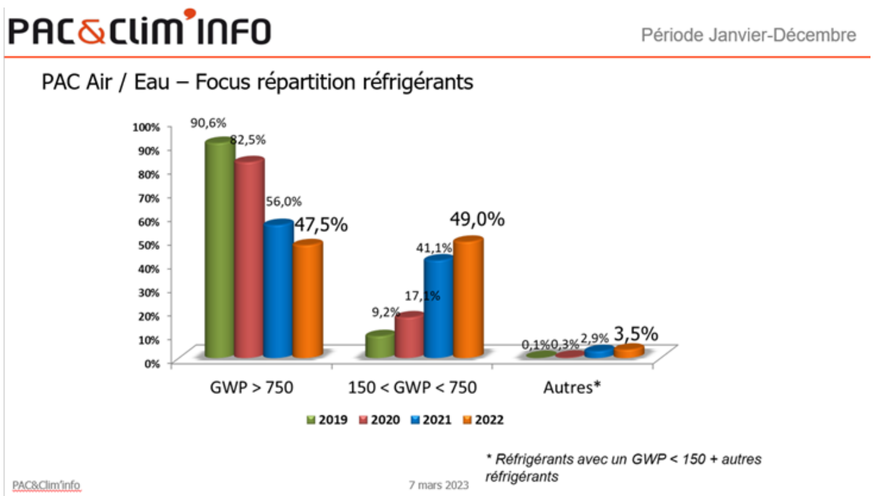


Figure B.2 PAC&CLIM INFO: Air water heat pump market split by GWP. Hydrocarbons will be included in the last group, called "Autres" since their GWP is below 150.

In other EU countries the market penetration of propane heat pumps is low single digit (estimated at 2% to 3% according to EHPA and between 2% and 4% according to a Deutsche Kälte und Klimatagung study[112]).

This is repeated in the case of China and India as R-290 has a limited market introduction in China due to safety concerns, despite its growing adoption in India for air-air heat pumps.[113]

In Section E2.8.4.2 of Annex E, concerning industrial refrigeration, the DSs admit that "there may be applications where alternatives are not appropriate because of the location of the industry or specific operating conditions". Despite this, there are no use derogations for this segment beyond refrigerants in

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[110] Maranion, B., Pizano, M. and Woodcock, A. (2022) Montreal protocol on substances that deplete the ozone layer report. *UN Environment Programme Ozone Secretariat*. https://ozone.unep.org/system/files/documents/TEAP-Decision-XXVIII-2-HFC-%20Alternatives-report-sept2022.pdf.

[111] France: Association professionnelle du chauffage et de la climatisation thermodynamique crée en 1996.

[112] Haberstroh, C. (2022) Deutsche Kälte- und Klimatagung 2022*, Fraunhofer*. https://publica.fraunhofer.de/entities/mainwork/992bcb99-b877-41b1-9444-b38919679a1b/details.

[113] Yan, H. et al. (2022) The role of heat pump in heating decarbonization for China carbon neutrality. *Carb Neutrality 1, 40* https://link.springer.com/article/10.1007/s43979-022-00038-0#:~:text=The%20maximum%20decarbonization%20potential%20from,CO2%20emission%20in%20China.

low temperature refrigeration below -50 Deg C (until 6.5 years after EiF). This (lack of) derogation is not representative of the DSs' comment, or of the situation in commercial refrigeration, with the need for a "toolbox" of refrigerants to be available to meet the complex and diverse requirements of this segment. For example, in smaller industrial applications, the use of ammonia is cost prohibitive or, in certain areas, prohibited by local ordinances. For hydrocarbons, the charge sizes needed in these applications are often too high to be compliant with building codes or permits for example.

For complex custom-built equipment, such as industrial process refrigeration, it is also the case that alternatives cannot be used in certain environments or situations. An example is the custom-built industrial process refrigeration (IPR) equipment operating on many industrial sites around the EU, such as the Chemours site in Dordrecht, Netherlands. Optimizing system efficiency, equipment size, environmental impact (i.e. refrigerant GWP), and other key design parameters, the most viable refrigerant solutions when the project started in 2013 were HFC-410A and HFC-134a for the two types of system required. Chemours IPR machines are installed in general purpose electrically classified areas, where propane and other highly flammable hydrocarbons cannot be used for safety reasons. Other options were also evaluated and discarded. The two industrial refrigeration machines at the Chemours Dordrecht site have very large charges (several tonnes). Ammonia was found to be reactive with some of the chemicals used in the manufacturing facility, and a significant safety concern was raised due to the proximity of the surrounding neighbourhood and the related consequences in a leak event, where the loss of a full charge would cause an unacceptable toxicity and flammability risk, even when considering including an ammonia/CO2 cascade system to reduce the required ammonia charge.[114]

The DSs state that research is continuing, that certain alternatives have deficiencies in hot climates or that certain applications are not beyond the trial stage. The indications above of:

- The performance limitations of non-fluorinated alternatives over the broad range of applications and climatic conditions that exist in the European Union;
- The time to develop a solution that can meet the requirements of the industry, and;
- The limited market penetration of non-fluorinated alternatives linked to safety considerations.

These examples point to the inadequacy of alternative solutions to cover efficiently and safely the full spectrum of requirements within the stationary HVACR industry and demonstrate that to ensure a smooth transition to viable alternatives, a time limited derogation of at least 12 years with a review period is needed for all stationary HVACR applications.

4. Maintenance derogation

A number of points were raised by the DSs which directly challenged their proposal of a 13.5 year derogation for the maintenance of HVACR equipment, and pointing to the need for a much longer derogation period (see Annex B.1 of this application). A 13.5-year derogation is also unrealistic for the custom IPR equipment operating on many industrial sites around the EU, including Chemours site in Dordrecht, mentioned above under point 3. Such equipment can also be found in a variety of industries such as plastics and rubber, chemicals, pharmaceuticals and biotechnology manufacturing industries, which require explosion-proof refrigeration equipment (chillers).[115] IPRs are custom designed and manufactured systems built for high reliability and equipment life operating in manufacturing

[114] https://www.cnn.com/2023/05/04/business/tyson-ammonia-leaks-invs/index.html.
[115] https://scychiller.com/what-is-explosion-proof-chillers/.

environments that may be toxic and or flammable. Chemours' IPR machines in Dordrecht are large, custom-built, high capacity, precision engineered machines cooling chemical manufacturing processes. They took over one year to manufacture and are designed for a minimum of two years continuous operation without downtime, with an expected life of 50 years (Chemours demonstrated with other IPR assets that their expected lifetime is 50 years through maintenance practices and investment). A 30 million Euro project installed the two new refrigeration machines.

Chiller reliability is key to plant operations in part due to the cost of lost production. However, many industrial process refrigeration systems are also used to ensure temperature-sensitive process material and waste streams are in the appropriate state to be safely handled and/or disposed. Loss of refrigeration could lead to the potential loss of process material which poses both safety and environmental concerns. Given the critical importance, high investment cost and extended lifetime of such equipment it is imperative that this equipment is allowed to be serviced and maintained until the end of their useful life.

However, the proposed maintenance should not be time-limited, since this would inevitably mean that some existing equipment would lose its value and, in the limit, be retired earlier than necessary.

Based on this evidence in the DSs proposal (Annex B.1 of this application) and the Chemours example above, an unlimited maintenance derogation is required for all HVACR equipment to avoid that fully functioning equipment, ready to serve for decades to come, would be unnecessarily replaced, creating enormous environmental and economic costs. This Derogation is proposed in our conclusion.

COST-EFFECTIVENESS OF NON-FLUORINATED SYSTEMS IN STATIONARY HVACR

A switch to non-fluorinated refrigerants in stationary HVACR from the result of the proposed restriction is expected to result in a disproportionate cost impact on society in the following areas:

1. Higher equipment costs due to stricter engineering requirements associated with high-pressure systems;
2. Higher energy use due to lower efficiency;
3. Higher maintenance costs associated with high-pressure systems;
4. Higher carbon and other emissions associated with higher energy use;
5. Lower refrigerant costs;
6. Other costs associated with reduced reliability (e.g. food waste)

We will demonstrate in Attachment 1, Chapter 2 that there are more appropriate measures that can significantly reduce emissions, and result in a much lower cost to society.

Chemours has made calculations of these impacts to obtain a more complete estimate of the cost-effectiveness of the proposed restriction. These calculations are presented in this section.

1. Additional initial purchase costs

In comparison to alternatives such as CO2, F-gas-based systems are less complex, and therefore consume fewer raw materials for construction, potentially reducing their cost and environmental footprint. Elements that need to be added for a CO2 system include a gas cooler pressure control valve, a flash tank (that decouples the flow in this valve from that in the expansion valve), and a third valve (that bleeds the gaseous refrigerant into the tank when the work done independently by the other two valves causes the pressure to rise too high).[116]

To counter the poor thermodynamic performance of CO2, Mitsopoulos et al. (2019) highlight some of the different engineered solutions for CO2 in a supermarket and how the coefficient of performance (COP) of those engineered solutions compare to a baseline R-404A system with no additional performance benefits. Figure B.3 below has the following different types of CO2 designs:[117]

- BS – Booster System
- BS + MS – Booster System with Mechanical Subcooling
- PC – Booster system with parallel compression
- PC + MS – Booster system with parallel compression and mechanical subcooling
- MT OVF – booster system with parallel compression and overfed evaporator in medium temperature
- MT OVF + MS – booster system with parallel compression medium temperature overfed evaporator and mechanical subcooling
- MT/LT OVF – booster system with parallel compression and overfed evaporators in medium and low temperature refrigeration
- MT/LT OVF + MS - booster system with parallel compression and overfed evaporators in medium and low temperature refrigeration and mechanical subcooling
- MT/LT OVF + IC - booster system with parallel compression and overfed evaporators in medium and low temperature refrigeration and an intercooler
- MT/LT OVF + IC + MS - - booster system with parallel compression and overfed evaporators in medium and low temperature refrigeration, an intercooler and mechanical subcooling

[116] https://www.carel.com/blog/-/blogs/carbon-dioxide-co2-cycles-in-the-hvac-r-sector.

[117] Mitsopoulos, G. et al. (2019)*:* Annual performance of a supermarket refrigeration system using different configurations with CO2 refrigerant. *Energy Conversion and Management: X*. https://www.sciencedirect.com/science/article/pii/S2590174519300042.

G. Mitsopoulos, et al.

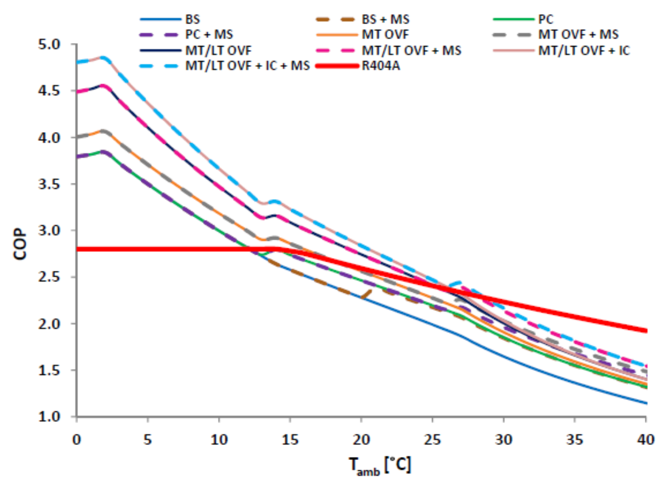

Fig. 20. Comparison of the COP for all the cases.

Figure B.3: Comparison of the Coefficient of Performance for all the different types of design

R-404A with a standard vapour compression cycle is highlighted with a solid red line. All the other architectures are for different variations of engineered CO2 systems for supermarkets, which would require additional investment. Below 15 Deg C ambient temperature these architectures showed superior energy performance to R-404A given the minimum condensing temperature for R-404A but as it gets warmer, even when highly engineered, the energy efficiency of CO2 systems struggles against the base R-404A case. While not considered by Mitsopoulos et al. (2019), many of the energy efficiency improvements required to make CO2 competitive could also have been applied to R-404A to further increase the energy efficiency delta between the two refrigerants. Furthermore, many of the newer HFO blends such as R-454C with a GWP of less than 150 have superior energy performance to R-404A, which also would further validate the value of the energy efficiency of an F-gas in comparison to CO2 and their cost effectiveness. Meeting the performance of an F-gas based system required additional investment which has the potential to impact the purchase cost of a CO2 system.

Safety features needed for Hydrocarbon (HC) systems also add costs to the system, as described by the DSs. For instance, in Section 2.8.2.2 Annex E, it is stated that the Infinitus Energy Solutions and Entropy Cooling Solutions study notes, “safety measures do increase the purchase costs of heat pumps and often the maintenance costs too (more inspections/maintenance).” In Section 2.8.2.1 of Annex E, the DSs state that “In some cases of commercial refrigeration, a secondary/indirect loop (glycol or water) can be used to reduce risk with flammable alternatives – however this will be less energy efficient and more expensive.” Finally, in Section 2.8.2.2 of Annex E, they state, “However, flammability when using hydrocarbons and costs may be barriers for full substitution of fluorinated gases.”

Although the additional initial purchase cost increase cannot be estimated, system design to counter the inefficiencies of CO2 (R-744) or safety measures to allow the use of hydrocarbons all add initial purchasing costs to systems, making these options less cost efficient to the system owners.

2. *Higher energy consumption costs of alternatives*

Available research shows the cost impact of transitioning the current commercial refrigeration and heat pump systems to non-fluorinated alternatives would result in additional energy consumption in both sectors.

Commercial refrigeration

European commercial refrigeration energy consumption in 2025 can be calculated at being approximately. 119TWh[118] (growing at 3.35% per year from 2007, equivalent to the growth of the use of energy consumption in the tertiary sector between 1990 and 2007[119]), reaching 320 TWh in 2055. The average store consumes between 126 and 270 MWh (average across all store sizes)[120], representing approximately 600k stores in 2025. Between 15% and 34% of energy savings could be achieved with F-gases versus R-744[121] [122], or an average saving of 25%. This would result in the following savings assuming an average equipment life of 20 years and that 1/20th of the equipment is replaced every year until fully converted:

- Energy savings between 2025 and 2055: 1,267 TWh (or 25% energy saving for the new installed and replaced equipment)
- 2055 energy savings: 25% * 320TWh = 80TWh
- At 28.4 Euro cents[123] / kWh this would equate to EUR 360 bn between 2025 to 2055 and EUR 22.7 bn in 2055 saving using F-gases compared to R-744.

Heat Pumps

With the European heating carbon neutrality being driven by heat pumps, the stock of heat pumps is expected to grow to 60 million (M)[124] units in 2030 and represent 611TWh energy consumption by 2050.[125] Up to 22% lower indirect emissions can be achieved by using F-gas based heat pumps:[126] This would result in the following savings assuming an average equipment life of 15 years and that 1/15th of the equipment is replaced every year until fully converted:

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118 Bertoldi, P. and Atanasiu, B. (2009) Electricity consumption and efficiency trends in European Union*, Topten, pp. 64.* https://www.topten.ch/sites/default/files/flyer%20pdfs/058_JRC_Report.pdf.

119 Bertoldi, P. and Atanasiu, B. (2009*)* Electricity consumption and efficiency trends in European Union*, Topten, pp. 64.* https://www.topten.ch/sites/default/files/flyer%20pdfs/058_JRC_Report.pdf.

120 Karampour, M., Sawalha, S. and Arias, J. (2016) Expertise hub for a market uptake of energy-efficient supermarkets by awareness raising, knowledge transfer and pre-preparation of an EU Ecolabel. rep*. Royal Institute of Technology.* https://cordis.europa.eu/project/id/696076.

121 Roberts, A.N. et al. (2020) Performance, cost and emissions comparison of refrigeration systems for supermarkets using refrigerants with a GWP below 150 *, International Institute of Refrigeration*. https://iifiir.org/en/fridoc/performance-cost-and-emissions-comparison-of-refrigeration-systems-142461.

122 Saab, S. et al. (2021) Theoretical study using low-GWP blends in various refrigerant subcooling designs suitable for commercial refrigeration systems *, International Institute of Refrigeration*. https://iifiir.org/en/fridoc/theoretical-study-using-low-gwp-blends-in-various-refrigerant-144302

123 https://www.euronews.com/next/2023/03/29/energy-crisis-in-europe-which-countries-have-the-cheapest-and-most-expensive-electricity-a.

124 https://www.ehpa.org/press_releases/europe-to-add-over-43-million-heat-pumps-by-2030-providing-heat-to-half-its-buildings/#:~:text=The%20total%20heat%20pump%20stock,will%20also%20provide%20renewable%20cooling.

125 https://www.woodmac.com/press-releases/europe-to-install-45-million-heat-pumps-in-the-residential-sector-by-2030/#:~:text=Heat%20pumps%20represent%20one%20of%20the%20most%20significant,to%20five%20million%20a%20year%20in%20the%202030s.

126 https://www.opteon.com/en/support/resource-center/leading-efficiency-in-heating.

- Energy savings between 2025 and 2055: 2,572 TWh (or 22% energy saving for the new installed and replaced equipment)
- 2055 energy savings: 22% * 611TWh = 134TWh
- At 28.4 Euro cents[127] / kWh this equates to EUR 730.5 bn between 2025 to 2055 and EUR 38.2 bn in 2055 saving using F-gases heat pumps.

In summary, using non-fluorinated alternatives would result in higher energy costs of EUR 60.1 bn in 2055. These are only two segments of the HVACR industry but show the extent of the cost impact of additional energy consumption of moving to non-fluorinated alternatives.

3. *Additional service requirements*

In addition to CO2 refrigeration systems' comparatively low energy efficiency, they are also very sensitive to leakage and less reliable than systems running with F-gases. In the case of a depressurization of a CO2 refrigeration system, the remaining liquid CO2 will instantly transform into dry ice, blocking the entire system for a long period and sometimes irremediably damaging it.[128] In commercial refrigeration, such failure of CO2 refrigeration systems also leads to a loss of goods, and to mitigate these risks, some retailers are using enormous amount of water, attempting to use dry gas coolers in a wet mode which is damaging the equipment.[129] This sensitivity to leaks could require additional maintenance costs to ensure that the system remains tight despite its high pressure.

Cost implication:
Cost of additional maintenance: one additional maintenance intervention per quarter (2 hours on average at 50 EUR/hour) or 400 EUR per system per year. If we estimate the number of systems being replaced and newly installed, this could represent EUR 10.1bn from 2025 to 2055, or EUR 640M in 2055.

4. *CO2e costs*

Heat pumps optimized for the latest generation of F-gas HFO blends (R-454C) can enable up to 29% higher energy efficiency and up to 49% higher capacity, while reducing emissions by up to 22% compared to standard R-290 (Propane) equipment.[130]

As already mentioned, in commercial refrigeration, the primary alternative being studied is CO2 and, even at ambient temperatures around 15-20 Deg C, the energy efficiency of CO2 is inferior to that F-gases.[131] Figure B.*3* compared the COP of a CO2 condensing unit compared with those of units using different F-gases.

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[127] https://www.euronews.com/next/2023/03/29/energy-crisis-in-europe-which-countries-have-the-cheapest-and-most-expensive-electricity-a.

[128] Trædal, S.; Stang, J.H.G.; Snustad, I.; Johansson, M.V.; Berstad, D. (2021). CO2 Liquefaction Close to the Triple Point Pressure. *Energies, 14, 8220*. https://doi.org/10.3390/en14248220

[129] http://www.frigoristes.fr/article.php?sid=391#.ZBj_kt3MLD4.

[130] https://www.opteon.com/en/support/resource-center/leading-efficiency-in-heating.

[131] Mitsopoulos, G. et al. (2019) Annual performance of a supermarket refrigeration system using different configurations with CO2 refrigerant. *Energy Conversion and Management: X.* https://www.sciencedirect.com/science/article/pii/S2590174519300042.

Overall, across all tested temperatures, the CO2 condensing unit COP was considerably lower than the F-gas COP (approximately 25% lower, and the COP of F-gases was at least 32% higher than R-744). This is expected based on the thermodynamic properties of CO2 vs typical F-gases used in refrigeration conditions.

Shilliday (2012) highlights that the standard vapour compression cycle for CO2 is inferior to F-gases across a temperature range of 20-40 Deg C in Figure B.4 below.[132]

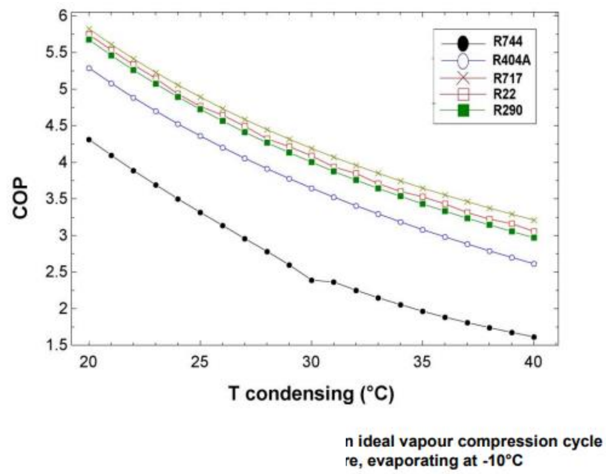

Figure B.4: Comparison of calculated coefficient of performances for an ideal vapour compression cycle with increasing condensing temperature, evaporating at -10^{o} C.

Particularly in warmer ambient climates, the relatively low critical temperature of CO2 versus F-gases will force the CO2 refrigeration cycle to operate in transcritical mode. Attempting to efficiently run a transcritical cycle for commercial or industrial cooling or heating greatly increases costs and complexities of the refrigeration systems while decreasing its energy efficiency. Such a decrease in energy efficiency increases the indirect emissions from electricity generation and, in some cases, these emissions even can supersede potential emissions in the rare case of a system leak, particularly over time.[133] Moreover, to run CO2 cooling systems in warmer climates, the systems require specific add-ons, complex cycles, and more materials, components, and controls, making them more complex, yet, they still deliver poor energy efficiency and must be considered unreliable even for the most highly engineered systems.

The higher energy consumption of non-PFAS alternative based systems described under point 2 can be translated into increased CO2 emissions. At an estimated CO2 intensity of 238g/KWh[134], and a cost of carbon permits of 95 €/CO_{2e}[135] /Tonne, using the same transition rate assumption as above, this equates to EUR 86.8 bn between 2025 and 2055 and EUR 4.8 bn in 2055.

5. Refrigerant costs

[132] Shilliday, J. (2012) Investigation and optimisation of commercial refrigeration cycles using the natural refrigerant CO2. *Brunel University Research Archive: Home*. https://bura.brunel.ac.uk/handle/2438/7454/.
[133] https://www.opteon.com/en/-/media/files/opteon/case-studies/opteon-asda-casestudy.pdf?la=en&rev=3709edb1eee141c39f9dee2137fdbeba.
[134] https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-13#tab-googlechartid_chart_11.
[135] https://tradingeconomics.com/commodity/carbon.

The DSs refer in a number of places to the benefits of switching to non-F-gas alternatives as a result of the cheaper cost of these gases. However, depending on the type of equipment, the refrigerant can represent only a small part of the total system cost, so a switch to cheaper substances will not generate a large saving. For example, in the case of heat pumps, the refrigerant cost can represent less than 1% of the overall cost of the system, without including the installation costs. This is based on the purchase price of a heat pump[136], a charge size of 1.5kg[137], and an estimated market price of refrigerant of EUR 30/kg. This demonstrates that in certain cases, although the cost of a non-fluorinated alternative might be cheaper, the impact on the total cost to the user is likely to be negligible in comparison with other sources of cost.

6. Other costs associated with reduced reliability

As described under point 3 above, CO2 systems are also very sensitive to leakage and less reliable than systems running with F-gases. This sensitivity to leaks could require that an additional charge be stored on site for rapid maintenance intervention. In the case of the formation of dry ice due to the depressurization of a CO2 system, there is a risk of a total loss of the food that the equipment is supposed to preserve. Although both of these costs are not quantified, they should be captured as a measurable impact.

Summary of cost effectiveness of non-fluorinated systems in stationary HVACR

The cost effectiveness of non-fluorinated stationary HVACR systems can be summarized as follow:

1. Higher equipment costs due to stricter engineering requirements associated with high-pressure systems;
2. Higher energy use due to lower efficiency;
3. Higher maintenance costs associated with high-pressure systems;
4. Higher carbon and other emissions associated with higher energy use;
5. Lower refrigerant costs;
6. Other costs associated with reduced reliability (e.g. food waste)

This results in an additional cost to society of the proposed bans of:

- €1,090 bn additional energy costs
- €10.1 bn additional services costs
- €86.8 bn in additional CO_{2e} emissions

Total: € 1,187 bn between 2025 and 2055 and € 66.4 bn in 2055.

As these figures do not cover the entire application range, it can be expected that it is probably an underestimation of the actual cost to society cost.

136 https://gigatek.be/fr/stiebel-eltron-hpa-o-4-cs-plus-compact-set-s--sel238993.
137 https://www.stiebel-eltron.fr/fr/produits-et-solutions/energies_renouvelables/pompes_a_chaleur/pompes_a_chaleuraerothermiquesair-eau/hpa-o-plus-compact-set-1-1/hpa-o-4-cs-plus-compact-set-s-1-1/caracteristiques-techniques.product.pdf.

Emission reduction and cost of a ban to reduce emissions:

The emission reduction and cost of a ban to reduce emissions can be estimated as follows:

Emission reduction:

- Using current average emission level from the Dossier Submitters 2025-2055: 33,542 tonnes per year as shown in Table B.3
- Chemours suggested estimate emission level 2025-2055: 16,333 tonnes per year

Costs of a ban:

- EUR 2.3M on average between 2025-2055 per tonne of emission reduction using the Chemours suggested emissions
- in 2055: EUR 3.2M per tonne of emission reduction using the Chemours suggested emissions (EUR 1.5M per tonne of emissions using the DSs emissions baseline)

Table B.3: Emission projection in tonnes

Emissions with dossier baseline

	2025	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
PFAS emissions per year	23,780	26,255	28,988	32,005	35,336	39,014	43,074
PFAS Emissions over the 5-year period	123,753	136,633	182,859	166,555	183,890	203,029	
Total emissions over the period 2025-2055	1,039,792						

Emissions with Chemours suggested leak rates

	2025	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
PFAS emissions per year	11,580	12,785	14,116	15,585	17,207	18,998	20,975
PFAS Emissions over the 5-year period	60,262	66,534	89,044	81,105	89,546	98,866	
Total emissions over the period 2025-2055	506,333						

In summary these calculations demonstrate that a switch to non-fluorinated alternative in stationary HVACR applications right after the transition period would result in significantly higher costs in terms of direct resource use, and also total EU energy requirements and impacts of carbon emissions and that the socio-economic cost of the emissions reduction would be disproportionate.

COST-EFFECTIVENESS OF ADDITIONAL F-GAS-BASED STATIONARY HVACR MEASURES

Stationary HVACR systems using F-gases are extremely high-performing, versatile and durable, and are also a key part of the EU's decarbonisation strategy (such as RePower EU). F-gases can be used safely, in a circular manner, with high rates of recovery and hence low emissions to the environment. However, emissions of F-gases from stationary HVACR systems do occur during the course of use and at end of life, so it is important to try and reduce these as far as is reasonable.

The previous analysis has demonstrated that a ban on the use of F-gases in stationary HVACR would be extremely costly, both in itself and in terms of the amount of PFAS emissions which it would save. However, Chemours believes that further emission reduction can be achieved more cost-effectively through the mandating of simple good-housekeeping measures into stationary HVACR system maintenance and recovery regimes. These conditions could be included in the proposed REACH restriction or form part of an extension to some other relevant legislation. In this section, we will demonstrate how such measures could be a cost-effective way of reducing PFAS emissions to a fraction of what they are today by 2055. These measures fall under five headings:

1. Reclaim end-of-life/circularity
2. Leak-testing
3. Leak rate certification
4. Technician certification
5. System architecture

In the remainder of this section, we will describe how these measures could be designed and implemented and provide our first estimates of their likely cost.

1. Reclaim end of life, circularity

All F-gases like HFC-134a, HFC-1234yf and blends are already recycled during servicing and can be re-used again and again at end of life of the equipment once reclaimed by a certified technician. The EU Council proposal on F-gas revision[138] recognizes the opportunity to reclaim these refrigerants at end of life. Often F-gases undergo a very basic cleaning process on-site and can be reinjected directly into a system without entering into the reclamation statistics.

There are national schemes that have promoted recovery, reclamation and destruction: In Denmark, an instrument of voluntary commitment is in place to incentivize proper recovery reclamation and destruction: an upfront fee is charged together with the price for the virgin refrigerant by the operator and is used to cover for expenses related to recovery, reclamation, and destruction.[139] This is also the case in France and has shown success since the system has been successful in place since 1993. A study carried out by Armines, a branch of the Ecole des Mines de Paris, calculated that the amount of greenhouse gas emissions avoided between 1993 and 2015 thanks to this measure amounted to 45 million tonnes of CO2 equivalent (association of distributors, fillers, recoverers & reclaimers of refrigerants, n.d.).

With the F-gas regulation revision and the proposed increased phase-down, the value of recovered F-gases will increase and this measure will be revenue generating for the contractors, which should further incentivise its application.

We recommend that upfront fees be compulsory in all Member States to promote recovery, reclamation, and destruction. This measure comes at no cost to the value chain.

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[138] Birchby, D. et al. (2022) Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases. *Oko-Institut for Applied Ecolocy and Oko-Recherche*. Pp. 57. https://www.consilium.europa.eu/media/63509/st08162-en23.pdf.

[139] Birchby, D. et al. (2022) Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases *Oko-Institut for Applied Ecolocy and Oko-Recherche*. Pp. 57. https://www.consilium.europa.eu/media/63509/st08162-en23.pdf.

This reclaim activity is already part of the F-gas regulation and its review and could be monitored through electronic logbooks such as those available in Poland and used by the industry today: www.bds.ichp.pl

2. Leak-testing

The current F-gas regulation already contains provisions for leak testing depending on the size of the equipment, and the F-gas regulation review is further strengthening these requirements by including Annex II gases. These requirements could be strengthened even further to ensure that system tightness is improved to the standards shown in Table B.4 below describing the current Commission proposal for leak checks in article 5 of the F-gas regulation review and our proposal for this article:

Table B.4: Leak check frequency, current and new proposal

		leak check frequency (months)				
Equipment that contains		Commission proposal		New proposal		
Annex I Fgas (CO_2 EqT)	Annex II, Section I Fgas (kg)	without leak detection system	with leak detection system	without leak detection system	with leak detection system	installation of a Compulsory remote monitoring system
2-50	1-10			6	12	
5-50	1-10	12	24			
50-500	10-100	6	12	3	6	no need for leak checks
500+	100+	3	6	1	3	no need for leak checks

Additional leak testing will be required for all equipment with a charge size above 2 CO EqT of Annex I F-gas and 1kg of Annex II section I F-gas based on Table B.4 above. The additional cost implications of these measures would be:

Heat pumps:

- Assuming that a leak check would cost EUR 100 on the 33M HP systems installed in 2025 growing to 133M in 2055;
- This would represent EUR 187.9 bn between 2025 and 2055;
- This would represent EUR 8.9 bn in 2055.

Commercial refrigeration

- Assuming that an average leak check for commercial refrigeration systems across all sizes would cost EUR 500 on the 600K commercial refrigeration systems installed in 2025 growing to 1.6M systems in 2055;
- This would represent EUR 52.7 bn between 2025 and 2055;
- This would represent EUR 2.7 bn in 2055.

Total estimated cost of additional leak test measures: EUR 240.6 bn between 2025-2055 and EUR 11.6 bn in 2055.

Leak testing provisions are already part of the F-gas regulation and its review and could be monitored through electronic logbooks such as those available in Poland and used by the industry today: www.bds.ichp.pl

3. Leak rate certification of components and equipment

To enable further emissions reduction, maximum leak rates need to be certified at the component level enabling the systems to meet the leak rate certification requirements, with reduction targets over time. There is evidence that leak rates have been reducing and that the industry is already implementing leak reduction strategies:

As the Commission's impact assessment[140] attests, the leakage rates of F-gases decreased following the introduction of improved containment measures with the current F-gas regulation in force since 2015 (European Commission, 2022, p. 68). Moreover, the progressive substitution of old equipment with newer less leaky equipment, is already leading to declining equipment lifetime emission rates (European Commission, 2022, p. 122).

In commercial refrigeration centralized systems, "The change to flammable lower GWP alternatives is giving rise to innovations in system architecture with a focus on charge reduction strategies, with fewer or better joints, variable speed technology, and better control, leak detection and isolation valves, all with the goal of reducing risk, cost, and complexity."[141]

- These trends and efforts should be translated into system maximum leak rate certification requirement by certification bodies (TUV for ex) and the following leak rate requirements should be introduced at EiF:
    - Comm ref centralized: 3%
    - Industrial refrigeration: 2%
    - Split AC and heatpumps: 0.9%
    - Centralized AC and VRF: 1.3%
    - Other applications 2.5%

These leak rates are aligned with leak rate results presented by VDKF in their July-August 2022 publication.[142]
Some system tightness requirements are included in standards such as IEC EN 60335-2-40 for monoblock heat pumps for example.

4. Certification of technicians

[140] European Commission (2022). *IMPACT ASSESSMENT REPORT: Accompanying the document Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014*. https://climate.ec.europa.eu/system/files/2022-04/f-gases_impact_assessment_en.pdf.

[141] Abdelaziz, O. et al. (2022) Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee: 2022 Assessment Report*. UN Environment Programme Ozone Secretariat, pp. 114*. https://ozone.unep.org/system/files/documents/RTOC-assessment -report-2022.pdf.

[142] https://www.vdkf.de/download/vdkf-verbandszeitung-juli-august-2022/

Good HVACR system and refrigerant handling practices are essential in reducing unintended emissions during system maintenance. The EU Council proposal for the F-gas revision[143] recognizes this need and defines a certification requirement for technicians.

- To further strengthen the current proposal certification training shall be followed by all technicians before being able to perform critical leak minimization activities and should not be allowed to work without training, and certificates delivered demonstrating the assimilation of best practices in the fields of:
    - Jointing (soldering and braising)
    - Leak detection
    - Leak reduction optimization
    - Certification on end-of-life management best practice
- An annual certification refresher course will also be dispensed to mitigate the risk of unintended emissions during system maintenance. The training can be combined with other maintenance certificates.
- Cost implications:
    - Required training/ annual refresher: 8 hours once. Annual refresher 2 hours per year: 345K RACHP contractors[144];
    - One off cost of EUR 400 or EUR 138M, and annual cost of EUR 100/yr or 34.5M total per year;
    - Or a total cost from 2025 to 2055 of EUR 1,2bn, or EUR 39M per year.

We therefore request to implement the EU Council proposal on technician certification for F-gases including proposed additional measures.

5. System architecture

Leakage rates have been reduced significantly over the years as demonstrated by the leak rate trends shared by VDKF in Figure B.5 below. The usage of non-brazen joint techniques that are much quicker to install and are leak free due to usage of double sealing, e.g. made up of O-ring and V-seal to prevent refrigerant from escaping (zero leakage) can be used to improve system tightness and further reduce leak rates. In addition, for more difficult areas to reach, Pair Coil can be used omitting additional joints and installation time.[145,146] The additional material costs incurred by the use of this equipment are in general compensated by the reduced installation time.

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[143] Birchby, D. et al. (2022) Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases. *Oko-Institut for Applied Ecolocy and Oko-Recherce*, pp. 57. https://www.consilium.europa.eu/media/63509/st08162-en23.pdf.
[144] https://www.area-eur.be/news/mandatory-certification-alternative-refrigerants-time-now.
[145] https://www.daikin-solutions.com/resources/ck/files/Daikin%20HVAC%20Installation%20Materials%20Catalogue%20(FA).pdf:
[146] https://www.ashrae.org/news/esociety/completed-research-september-2019.

Using existing data, it is possible to demonstrate that best in class leak rates in commercial refrigeration can be as low as 3%.[147] Other application can have even lower leak rates such as the ones shared by VDKF in their July-August 2022 publication[148] and described in Table B.5:

Table B.5: Average leak rates by application in third column of the table. Source: VDKF (translated from German)

Application	Average total refrigerant charge 2017-2021 in tonnes	Average total amount of refilled refrigerant 2017-2021 in tonnes	Average Leak Rate 2017-2021 in tonnes
Split A/C	231.4	2.0	0.89%
Commercial Refrigeration	862.9	26.9	3.15%
Industrial Refrigeration	543.2	11.3	2.08%
Centralized A/C	318.9	3.7	1.15%
VRF A/C	172.5	2.1	1.34%
Special installations	91.0	2.3	2.51%

Industry efforts to reduce leak rates have been successful as shown by the historical leak rate trend below published by the VDKF[149], where industry leak rates have come down from 3.2% in 2017 to 1.35% in 2021 or a 59% reduction in 4 years as shown in Figure B.5. This suggests that a further leak rate reduction trajectory is feasible and possible if stringent design, manufacturing, and installation procedures are implemented and monitored throughout the value chain, such as:

- Leakage reduction criteria as a compulsory requirement in system design;
- Requirement for system integrators to optimize the charge size (thus minimizing the leaks);
- Connections and component integration certification;
- Leak rate improvement at component level (compressor, condensers, heat exchangers, valves).

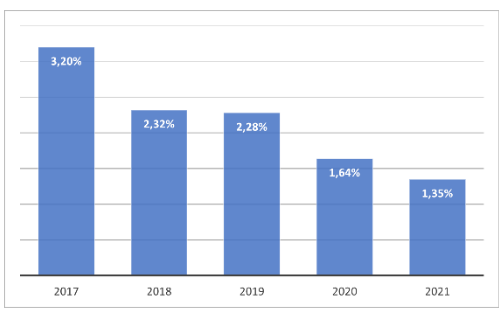

Figure B.5: VDKF industry leak rate trend

We therefore request to implement the following leak rate reduction targets:

- Current emission rates published by VDKF (as above) at EIF +18 months (transition period);

[147] https://www.opteon.com/en/-/media/files/opteon/case-studies/opteon-asda-casestudy.pdf?la=en&rev=3709edb1eee141c39f9dee2137fdbeba.
[148] https://www.vdkf.de/download/vdkf-verbandszeitung-juli-august-2022/.
[149] https://www.vdkf.de/download/vdkf-verbandszeitung-juli-august-2022/.

- 40% leak rate reduction at EIF + 4.5 years;
- 60% leak rate reduction at EIF + 6.5 years (based on the historical reduction trend);
- 80% leak rate reduction at EIF + 8.5 years (based on the historical reduction trend).

Cost implication: EU 242bn between 2025 and 2055 and 11.6bn in 2055

We request that it be certified at system handover and in system maintenance logs that the refrigerant leakage rate complies with the targets set out to reduce emissions (as defined above) for the systems built after EIF and the transition period of 18 months.

Impact on emissions

The current emissions rate of 3.5% would result in average annual emissions of 16,333 MT in EEA between 2025-2055 as shown in Table B.6. These emissions can be further deceased by the measures implemented above to:

- 0.4% per year 9 years after EiF, for the entire stationary HVACR sector or approximately 2 328 tonnes in 2055 assuming the market continues to grow as predicted in the DS proposal at 2% per year.

Table B.6: Emissions projections in tonnes

Emissions with dossier baseline

	2025	2030	2035	2040	2045	2050	2055
PFAS emissions per year	23,780	26,255	28,988	32,005	35,336	39,014	43,074
PFAS Emissions over the 5-year period	123,753	136,633	182,859	166,555	183,890	203,029	
Total emissions over the period 2025-2055	1,039,792						

Emissions with Chemours suggested leak rates

	2025	2030	2035	2040	2045	2050	2055
PFAS emissions per year	11,580	12,785	14,116	15,585	17,207	18,998	20,975
PFAS Emissions over the 5-year period	60,262	66,534	89,044	81,105	89,546	98,866	
Total emissions over the period 2025-2055	506,333	saved	333,478				

Emission estimates based on alternative Restriction Option based on RMMs

	2025	2030	2035	2040	2045	2050	2055
PFAS emissions per year	11,580	10,050	6,714	4,303	1,910	2,108	2,328
PFAS Emissions over the 5-year period	56,270	43,581	33,045	16,722	9,937	10,972	
Total emissions over the period 2025-2055	172,855						

Emission reduction and cost to reduce emissions:

- Total cost of the Chemours proposed emission reduction measures: €7.8 bn per year from 2025 to 2055;
- Projected emission reduction 2025-2055: 10,757 tonnes per year on average or 333,478 tonnes for the period;

- Projected emission reduction in 2055: 18,648 tonnes equivalent to an 89% reduction of suggested estimated leak rates;
- Cost per tonne of emission reduction 2025-2055: EUR 0.7M on average per tonne of emissions prevented;
- Cost per tonne of emission reduction 2055: EUR 0.6M per tonne of emissions prevented.

In summary the emissions of F-gases can be better handled by alternative RMMs at a lower cost to the European society:

- DSs proposal in 2055: EUR 3.2M per tonne of emission reduction based on our estimated emission calculation.
- Chemours proposal in 2055: 89% emission reduction at a cost of EUR 0.6M per tonne of emission reduction.

SUMMARY AND CONCLUSIONS

- Attachment 1, Chapter 1 demonstrates that All F-gases (current and future) fulfilling the PFAS definition used by the Dossier Submitters should be exempted from the scope of this restriction because there is no risk to be addressed at EU level. This consideration also applies to the persistent degradation products of F-gases, such as TFA, for which the risks for both human health and the environment are de minimis.
- Even if this is not accepted. The cost of a ban would be disproportionate. Additional risk management measures, such as enhanced inspection intervals, technician training and system design improvements, should be implemented to further minimize emissions. Emissions can be reduced by as much as 89% by 2055 at an estimated cost of EUR 0.6M per tonne of emission reduction.
- If the DSs still wish to pursue their derogation-based approach, the derogations are too short and the socio-economic consequences of a ban would be disproportionate compared to the environmental benefit of a restriction:
    - The total additional cost of a ban to the European society equates to €1 187 bn between 2025 and 2055;
    - Alternatives require at least 214TWh of additional energy generation in the EU in 2055 which is more than 5 times the total amount of renewable energy generated in France in 2020 (52TWh);
    - Without the use of HFOs, many European sustainability objectives could be at risk;
    - Historically the industry has required up to 16 years to transition to an alternative when this one was a close drop in;
    - Cost per tonne of emissions saved in 2055 is disproportionate:
        - EUR 3.2M per tonne of emission reduction based on Chemours estimated emission calculation;
        - Or more than 5 times higher than the alternate restriction option based on RMMs proposed by Chemours.

Therefore, the following derogations will be required to avoid disproportionate socio-economic impacts on society.

- Existing equipment using F-gas technologies:
  Existing stationary HVACR and transport refrigeration equipment which uses F-gases cannot be retrofitted to use alternative refrigerants. Therefore, a ban on F-gases would prevent this equipment being serviced and maintained, and lead to premature retirement. **A permanent derogation** is therefore justified to avoid the unnecessary costs of replacing this equipment. (This justification was used by the Dossier Submitters for their proposed derogation 5i, although this derogation was time-limited and restricted to existing HVACR equipment only.);

- Stationary HVACR and transport refrigeration applications
  There are significant specific performance limitations associated with the alternatives to F-gases across the different applications in stationary HVACR and in transport refrigeration. It might be possible to overcome these problems through engineering developments, but this will take time and resources. **A minimum 12-year derogation** is suggested to allow this to happen.

  A review should be undertaken before the end of the derogation period, to ensure that the necessary substitution activity has been successful. If not, a further extension of the derogation would be justified to avoid disproportionate costs in future.

ANNEX B.1: SUMMARY OF ANNEX E CLAIMS

Use derogations quoted comments from the proposal that go against the current proposal of no derogation beyond the transition period of 18 months after EiF:

- **Annex E p242 2.8.2.1:** "However, in certain specific cases, finding alternatives may be more challenging." "In some cases of commercial refrigeration, a secondary/indirect loop (glycol or water) can be used to reduce risk with flammable alternatives – however this will be less energy efficient and more expensive."
- **Annex E p248 2.8.2.2:** "the assumption that the sector is fully ready to replace them with alternatives may be premature." "For CO2 high working pressures and poor performance in hot climates makes its uses in small/mid-size commercial chillers/refrigerators less efficient." "However, it has been noted by stakeholders that drawbacks with CO2 as a refrigerant include high working pressures that require solid equipment design and lower energy efficiency in warm climate." "However, flammability when using hydrocarbons and costs may be barriers for full substitution of fluorinated gases."
- **Annex E p249 2.8.2.2:** "VFR systems in commercial air conditioning and heat pumps may be challenging to build with natural refrigerants due to flammability." And for transport refrigeration: "Alternatives may have lower energy efficiency, and safety is of concern as people are carried together with the goods to be cooled. Specific barriers affect the sector, for example, size limitations are problematic for the use of active CO2 systems given the layout of existing trucks. Further design work would be needed to provide viable alternatives that are widely applicable across the market."
- **Annex E p263 2.8.4.2:** "Medium-sized systems with refrigerating capacities between 1 kW and 20 kW can use condensing units, featuring several display cases linked to a small machine room. Fluorinated

gases are commonly used as the refrigerant […]. Use of propane is growing more slowly […]. There is research on the use of CO2 but so far these have not extended beyond the trial stage. (UNEP, 2019a)."

- **Annex E p263 2.8.4.2:** "Available data, and information gained through the CfE and the 2nd stakeholder consultation, indicate limited options for commercial AC systems at the present time, though research on the use of CO2, especially in cooler climates, is continuing."
- **Annex E p264 2.8.4.2**: Commercial AC: "UNEP (2019a) refers to a number of applications of ammonia, hydrocarbons and CO2 in Europe, though these do not extend to the full range of chiller sizes."
- **Annex p 269 2.8.4.2.** Commercial HVACR: "There is growing acceptance of the use of alternatives using particularly CO2 and hydrocarbons in the commercial sector. However, the sector is still dominated by using fluorinated gases, and the assumption that alternatives are ready to replace them is premature. Further research is being conducted in several areas."
- **Annex E table E.98 p292**, "There is growing acceptance of the use of alternatives in this sector [Commercial Air Conditioning (AC) and Heat Pumps (HP)], particularly CO2 and hydrocarbons, or CO2 in cascade systems with other gases such as ammonia." Growing acceptance can be challenged on the base of equipment standards limitations (e.g. EN 60335-2-40 and building standards limiting AC/HP residential use, or large size chillers natural refrigerants not being available).

Safety considerations, quoted from the submission stating erroneously that the charge sizes of flammable non-fluorinated alternatives can be increased, and standards can be relaxed:

- **Annex E p246 E2.8.2.2:** "It was suggested that the safe application of higher charge limits is possible, and that future applications of safety measures will result in charge limits that enable a far greater and wider application of hydrocarbon refrigerants without resulting in a significant risk increase for users."
- **Annex E, p.253 claims**, "There is progress to amend the standards and allow for the use of some flammable alternative refrigerants. Therefore, it is expected that equipment based on alternatives become safer and more widely used."
- **Annex E p 247 2.8.2.2** discussed the Infinitus Energy Solutions and Entropy Cooling Solutions.[150] When reviewing this report, on page 8 referring to heat pumps, there is a disclaimer stating that hydrocarbons are only successful "if adequate risk management measures can be put in place." Page 8 further notes that "HC are less suitable for larger multi-split and VRF systems due to the high costs and constraints of the required safety measures" and that "safety measures do increase the purchase costs of heat pumps and often the maintenance costs too (more inspections/maintenance)".

Points raised by the Dossier Submitters, directly challenging their proposal of a 13.5 year derogation on the maintenance of HVACR equipment and pointing to the need for a much longer maintenance derogation. These quotes can be found at the end of this document:

- **Annex E p263 2.8.4.2:** "From the stakeholder consultation information was gathered to indicate that the lifetime of medium and large equipment is in the order of 15 to 25 years, and that it would take 10 to 12 years to develop new products and take them to market. On this basis, there is a significant lifetime remaining, in the order of decades, for equipment that is already in place."

[150] *Redefining waste (2013) Infinitus Energy*. Available at: http://infinitus-energy.com/.

- **P264:** "Chillers tend to operate for many years and have been reported to last worldwide 'not uncommonly for over 40 years' (UNEP, 2019a)."
- **P266:** Electronic cooling of data centers: "On time scales, stakeholders commented that the existing stock would need to rely on HFOs and HFCs for the next 20 years at least. Accepting that existing alternatives are not compatible with these systems, this time scale does not look unrealistic."

ANNEX B.2: DETAILED PERFORMANCE INFORMATION OF HFC-32 DEMONSTRATING:

Detailed performance information of HFC-32 demonstrating its limitations:
Comparison for supply of water at 55°C with fluctuating ambient temperature (A7: 7 Deg C, A2: 2 Deg C, A-7: -7 Deg C, A-15: -15 Deg C)

Figure B.6 below shows the coefficient of performance (COP) calculation results from the NIST Refprop 10.6. thermodynamic model. For the non-PFAS HFC-32, the COP drops considerably from high to lower ambient temperature conditions.

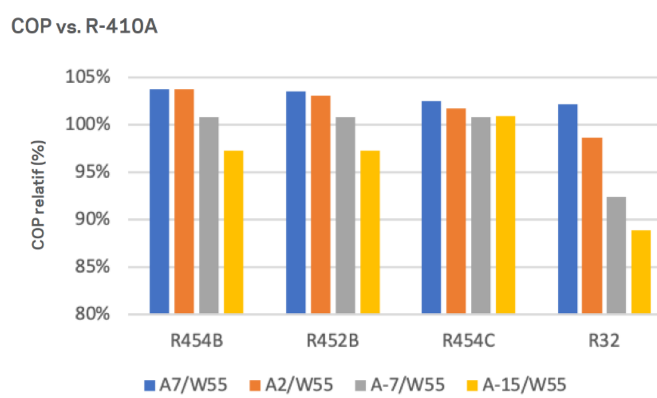

Figure B.6: COP calculation results from NIST Refprop 10.6[151] (thermophysical property model)

Furthermore, Figure B.7 below[152] demonstrates that HFC-32 generates a higher compressor discharge temperature than all F-gases in the study, resulting in a limited operating map, which reduces the application flexibility[153] and demonstrating that HFC-32 is not a suitable alternative contrary to what is pointed out on page 244 of the proposal.

[151] National Institute of Standards and Technology (2022). *NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP): Version 10* https://www.nist.gov/srd/refprop.
[152] Abdelaziz, O. *et al.* (2022) Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee: 2022 Assessment Report. *UN Environment Programme Ozone Secretariat, pp. 108*.
https://ozone.unep.org/system/files/documents/RTOC-assessment -report-2022.pdf.
[153] https://trane.eu/uk/about-trane/blog-post.html?Id=11.

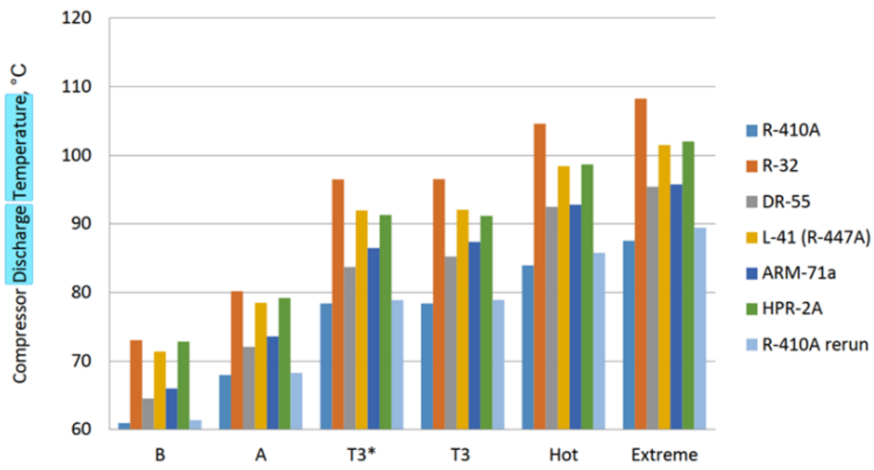

Figure E.7. Compressor discharge temperature for R-410A and its alternatives at each test condition.

Figure B.7: Compressor discharge temperature for R-410A and its alternatives at each test condition

C. Foam blowing agents application submission

INTRODUCTION

F-gases serve as highly effective blowing agents in foam production for insulation materials, buildings, refrigerators and other appliances. F-gases can be used to produce a large variety of foams, depending on the desired properties and application requirements.

In residential homes and commercial buildings, the use of **F-gas blown spray foams** effectively insulates new buildings, renovates old buildings and reduces energy consumption through insulation. Alternatives such as fiberglass or mineral wool have lower insulating power and thus must be installed in greater thicknesses to achieve the same thermal resistance – which may not be feasible when renovating existing housing units. Closed cell spray foams that use hydrofluoroolefin (HFO) or hydrochlorofluoroolefin (HCFO) blowing agents like HFO-1336mzzZ, HFO-1336mzzE and HCFO-1233zdE are the only insulation that can perform multiple functions: air sealing, vapor barrier and insulation – all with a single product installed by a single contractor.[154]

In unventilated attic designs in particular, the sealing capability and high thermal resistance provided by HFO blown spray foam provides a unique monolithic layer of insulation, sealing the attic, extending the climate-controlled space to the roof deck. This greatly improves the energy efficiency of the entire home. Spray foam is the best solution for this design. In some cases, spray foam can even be applied over an existing roof to repair and improve the building. This allows for the existing roofing materials to be reused in-situ and reduces waste generation.[155]

In **industrial applications**, HFO blown spray foam is used to insulate process storage tanks, LNG tanks and heat exchangers, condensers, distillation columns and other process equipment. It is applied directly to the process equipment, conforming to smooth or irregular shapes without leaving air gaps, completely adheres to surfaces and will not sag or settle over time.[156]

In the Dossier Submitters' (DS) proposal, there is a proposal for a 6.5 year derogation after entry into force (EiF). This is a proposal since the DSs state that they have weak evidence of a low substitution potential for F-gas foam blowing agents and are seeking additional evidence. We will demonstrate in our submission why we disagree with the DSs' claim that this short derogation "would permit more opportunity to research and introduce cost-effective alternatives" and that fluorinated fluids are critical in supporting the EU's effort to reach its environmental objectives such as Fit for 55 and smart and sustainable mobility.

Performance benefits of HFO blown spray foam:

HFO blown foams have exceptional thermal resistance, and low density. This minimizes the thickness of foam needed by 50% compared to a foam blown with water or CO2. As a result, less polymer is required per unit area (e.g. typically closed cell HFO spray foams have a free rise density as low as 28 kg/m^3 vs 43 kg/m^3 for closed cell water/CO2 blown foams).[157] Because of the superior insulating power resulting from

[154] https://www.whysprayfoam.org/spray-foam/types-spray-foam/

[155] Spray Polyurethane Foam Alliance (SPFA) (2019*). Spray Polyurethane Foam in Cathedral Ceilings and Unvented (Conditioned) Attics*. https://www.naylornetwork.com/spf-nwl/pdf/SPFA-141_-_Mar_2019.pdf

[156] https://www.americanfoamexperts.com/spray-foam-insulation-tanks/

[157] https://icc-es.org/acceptance-criteria/ac377/

the use of HFOs, the insulation also takes up very little space. Therefore, spray foam can be used to remediate or renovate existing buildings and homes with highly energy efficient insulation in the existing space where wall thicknesses cannot accommodate the required thickness of water blown or CO2 blown foam. The same applies to fiberglass or mineral wool, as these have lower insulating power and require greater insulation thicknesses to be installed to achieve the same thermal resistance. Water-blown or CO2-blown foams are neither sustainable nor economically viable when it comes to insulating older homes and buildings during renovations. There are no non-flammable alternative blowing agents that can match or approximate the thermal resistance and density reductions provided by HFO blowing agents.[158] An example of resource efficiency using a laboratory scale sample of spray foam blown with different blowing agents is shown below (Chemours own calculations), where a foam blown with water or CO2 will need to have a mass more than 2.5x higher than an HFO blown foam to achieve the same thermal resistance:

For a Spray Polyurethane Foam (SPF) blown with HFO:

- Density = 32 kg/m^3
- Thermal Conductivity (lambda value)= 20 mW/m-K (lower is better)
- Installed Thickness = 8.9 cm
- Installed Area = 892 m^2
- Installed Mass of Foam = 2540 kgs

For a SPF blown with Water or CO2:

- Density = 43 kg/m^3 (density must be at least this or greater to achieve dimensional stability requirements)
- Thermal Conductivity (lambda value) = 36 mW/m-K[159]
- Installed Thickness = 15.6 cm (to achieve the same thermal resistance as the HFO example)
- Installed Area = 892 m^2
- Installed Mass of Foam = 6675 kgs

Closed-cell SPF is used to create stronger walls and increase resistance against wind uplift in high wind events. Testing has shown that 5 cm of closed-cell SPF will increase the racking strength of a wall by up to 300%.[160] It is a Class 5 flood damage-resistant material, as defined by the USA Federal Emergency Management Agency (FEMA). For this reason, FEMA recommends the use of closed-cell insulation where water contact is likely – like under floors, or on basement or crawlspace walls – to mitigate losses in a flood event and reduce the risk of mold growth.[161] Closed cell spray foam is moisture resistant, so if the process equipment is cold, it will prevent condensation. It is durable and does not lose its effectiveness if it gets wet.

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[158] Center for the Polyurethanes Industry (2016). *The Spray Polyurethane Foam (SPF) Advantage*. https://www.whysprayfoam.org/wp-content/uploads/2017/05/SPF_Advantage_Brochure.pdf

[159] Santiago-Calvo, M., Tirado-Mediavilla, J., Rauhe, J.Chr., Jensen, L.R., Ruiz-Herrero, J.L., Villafañe, F. and Rodríguez-Pérez, M.Á. (2018). Evaluation of the thermal conductivity and mechanical properties of water blown polyurethane rigid foams reinforced with carbon nanofibers. *European Polymer Journal*, 108, pp.98–106. https://doi.org/10.1016/j.eurpolymj.2018.08.051

[160] National Association of Home Builders. *NAHB Building Wall Test*. https://www.tigerfoam.com/PDF-FILES/NAHBBUILDINGWALLTEST.pdf

[161] Federal Emergency Management Agency (FEMA) (2008). *Flood Damage-Resistant Materials Requirements*. https://www.fema.gov/sites/default/files/2020-07/fema_tb_2_flood_damage-resistant_materials_requirements.pdf

SAFETY & SUSTAINABILITY BENEFITS

Since HFOs used in spray foam have no flash point, foams blown with HFOs have lower flammability ratings than foams blown with hydrocarbons (HCs). These spray foams are thus able to meet more stringent building codes for fire and life safety. Non-flammable blowing agents may also be safely used in spray foam without fear of explosions or fires due to the blowing agent, which is not the case of other flammable blowing agents such as hydrocarbons, which cannot be used for spray foam due to the safety risk. Another alternative, methyl formate is classified under the regulation on the registration, evaluation, authorization and restriction of chemicals (REACH) as harmful if swallowed, causes serious eye irritation, is harmful if inhaled and may cause respiratory irritation.[162]

Using non-flammable HFOs is technically straight forward and does not require the use of high-pressure chemicals such as supercritical CO2 that introduce unnecessary hazards. Non-flammable HFOs are processed with two-component proportioning systems that are easy to use and contractor-friendly. This system with two components ensures that the foam material is of consistent quality and applied evenly to provide effective insulation. The formulations used are tightly controlled by the chemical manufacturers. Thus, the blowing agent amounts are controlled and delivered with one of the components (B-component).

HFO-1336mzzZ, HFO-1336mzzE and HCFO-1233zdE are the next generation blowing agents replacing Hydrofluorocarbons (HFCs) and offer a significant contribution to reducing energy consumption and CO2 emissions due to their exceptional insulating power. HFO blowing agents improve the insulating power of polyurethane (PU) foam by 5% versus HFCs and by 20% versus hydrocarbons (HCs). Additionally, HFOs improve the insulating power of foams when blended with other blowing agents by 10-20%. This minimizes the cost impact of HFOs, while enabling foam manufacturers to meet current and future energy efficiency standards.[163]

THE CURRENT REGULATIONS EFFFECTIVELY MANAGE F-GASES AND MINIMIZE THEIR EMISSIONS

The Dossier Submitters conclude that the F-gas Regulation (FGR) is insufficient to manage the risks associated with F-gases. The conclusion appears to be based on two arguments: that the FGR "does not per se restrict the use of the substances but rather aims for a reduction of their use" and that the current FGR does not regulate all fluorinated gases fulfilling the DSs' PFAS definition. Rather, they argue a REACH restriction is required because that would limit as many uses as practically possible and thereby minimize F-gas emissions (and hence exposures), cover current and future F-gases, and prevent regrettable substitution. Derogations are proposed for "some key applications of fluorinated gases [where] alternatives are not yet available."

[162] https://echa.europa.eu/nl/substance-information/-/substanceinfo/100.003.166

[163] 2017 CPI Paper and 2018 UTECH Paper – Reference can be made available to ECHA upon request

We believe this conclusion is unfounded. F-gases are already strictly regulated under the current Regulation 517/2014 (FGR)[164]. It establishes a phasedown schedule for HFCs – consistent with a substitution objective of the proposed REACH restriction – as well as stringent provisions to require training and certification of technicians and to minimize leakages throughout the lifecycle of the F-gases. The Commission Proposal to review the F-gas Regulation ("Commission Proposal")[165] currently under discussion extends the containment, training and certification, and recovery measures to Annex II – Section I F-gases (HFOs and HCFOs). The Commission Proposal therefore addresses the principal concerns expressed by the Dossier Submitters about the suitability of using the FGR to manage F-gases and the risks associated with them. As a result, Chemours considers that the F-gas regulation is the best tool to manage F-gases and reduce their emissions and has the necessary measures in its current version and the revision proposals by the commission and council to achieve this. Further details are presented in Attachment 1 section 1.5. The rest of this submission will focus on other issues raised by the proposed restriction.

EMISSIONS ESTIMATE

The Annex XV report highlights the use of F-gas blowing agents in spray foam applications but does not provide an emissions estimate. Chemours estimates emissions from spray foam applications to be the following:

- The amount of spray foam (rigid polyurethane foam)[166] in the European market is estimated to be 222 000 tons in 2024 with a Compound Annual Growth Rate (CAGR) of 3.6%.[167]
- A typical spray foam application contains 5% blowing agent in the formulation.[168]
- According to current practices, 50% of blowing agent consumed in the production of the formulation is eventually emitted over the lifetime of the foam and its end of life: 10% released during installation, 24% released during lifetime in building (via diffusion), and 16% released during end-of-life.[169]
- Estimated trifluoroacetic acid (TFA) yield [170] [171]:
    - HFO-1234ze: up to 2%
    - HFO-1336mzzZ: up to 4%
    - HFO-1336mzzE: up to 4%

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[164] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006;

[165] Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014;

[166] One component systems, spray foam and other systems including pipe insulation as well as automotive and other smaller end uses

[167] Chemours internal assessment

[168] Thinkstep (2018). *Spray Polyurethane Foam Insulation Products EPD Background Report*. https://www.sprayfoam.org/files/SPFA_EPD%20Background%20Report%2020181029_signed(1).pdf

[169] Spray Polyurethane Foam Association (SPFA) (2022). *Environmental Product Declaration: Spray Polyurethane Foam Insulation (HFO)*. ASTM International. https://pcr-epd.s3.us-east-2.amazonaws.com/451.EPD_for_SPFA_EPD_20181029_HFO_excl_2K-LP.pdf

[170] European FluoroCarbons Technical Committee (EFCTC) (2021). *EFCTC Position Paper: Published evidence supports very low yield of TFA from most HFOs and HCFOs.* https://www.fluorocarbons.org/wp-content/uploads/2021/08/2021_08_EFCTC_Position-Paper_Published-evidence-supports-very-low-yields-of-TFA-from-most-HFOs-and-HCFOs_F.pdf

[171] https://www.fluorocarbons.org/news/eeap-2022-tfa-yields-from-hfcs-and-hfos/

- HCFO-1233zd (E/Z): up to 2%

Based on import data, in 2022, between 620-840 tons of HFO-1336mzzZ and HFO-1336mzzE were imported into the EU27/European Economic Area (EEA) representing <8% of the total HFO blowing agent consumption. This ratio will change in the future but is assumed to be 25% to remain conservative.[172] The average TFA yield across the HFO blowing agents in use is therefore 2.5% maximum. As discussed in Chapter 1, from an environmental risk perspective we consider that the relative contribution to the overall TFA budget from these substances is negligible.

Using the information above, the estimated emissions of blowing agent and resulting TFA are shown in the Table C.1 below: Please note that the emission figures are not yearly values, but emission estimate values over the lifetime of the foam installed.

Table C.1: estimated emissions of blowing agent and resulting TFA

	2025	2030	2035	2040	2045	2050	2055
Rigid foam tons	229,992	274,481	327,575	390,939	466,560	556,809	664,516
Blowing agent tons (5%)	11,500	13,724	16,379	19,547	23,328	27,840	33,226
TFA tons (avg yield: 2.5%)	287	343	409	489	583	696	831
Blowing agent emissions (50%)	5,750	6,862	8,189	9,773	11,664	13,920	16,613
TFA Emission (50%)	144	172	205	244	292	348	415
2025-2055	7,959						

The emissions of TFA of foam are extremely low, and in this submission, we will demonstrate the high value of the contribution of spray foam to meeting the European policy objectives.

THE PROPOSED DEROGATIONS ARE INADEQUATE

On the basis that the FGR is deemed insufficient to manage the risks of F-gases, the DSs propose a general ban on the use of F-gases, except in a limited number of "key" applications where they conclude alternatives are not yet available and hence derogations are required. In the foam domain specifically, the DSs propose the following derogation marked FOR CONSIDERATION: "Foam blowing agents in expanded foam sprayed on site for building insulation until 6.5 years after EiF)". In light of uncertainty regarding the precise circumstances under which alternatives would be unavailable, such a derogation is not proposed at this point but marked for reconsideration. A derogation might be proposed at a later stage if additional information on alternatives becomes available".

Based on the available data, we consider that the derogations proposed by the dossier submitters are not sufficient to avoid a disproportionate impact to society. In addition, the derogations which are suggested are too short to allow substitution to take place in a cost-effective manner. These conclusions are based on an assessment of the technical feasibility of alternative foam-blowing agents, the technical feasibility

[172] Chemours internal analysis

of alternative insulating materials/technologies, and the costs of these alternatives. These issues are considered in the following sections.

TECHNICAL FEASIBILITY OF ALTERNATIVES

Technical feasibility of alternatives blowing agents in spray foam

The alternatives analysis below will demonstrate that there are no non-flammable alternative blowing agents that can match or approximate the thermal resistance and density reductions provided by HFO blowing agents.

High Pressure Spray Foam requires the use of a physical blowing agent that has the following properties:

- Low Global Warming Potential (GWP) and Ozone Depleting Potential (ODP).
- Boiling point in the range of 15 to 35 Deg C for high pressure spray foam to be able to operate at around room temperature.
- Non-flammable, because flammable blowing agents are not safe for this application due to risk of fire and explosion.
- Low toxicity, because these products are used in habitable spaces.
- High thermal resistance, to meet sustainability and energy objectives.
- Chemical compatibility with other polyurethane ingredients, because blowing agents are preblended with other ingredients and stored for up to 12 months.
- Low solubility and low permeance in polyurethane foam, as the blowing agent must remain inside the polymer to give the foams long term thermal resistance.
- Surface tension and ability to form closed cells, as a uniform closed cell network is necessary for the foam to perform as a highly efficient insulation.

In Annex E, section 2.8.2.3, p 251 of the REACH dossier, the United Nations Environmental Programme (UNEP) is cited stating that “for PU spray foam the major challenge relates to the safe processing of these systems under in-situ conditions within a building. The potential for the accumulation of blowing agent in ‘pockets’ creates the risk of fire or explosion if flammable materials are used. Water-blown foam is also used, but there are challenges with dimensional stability (including density which increases costs) and insulating capability.”
The use of flammable blowing agents in spray foams is not safe due to the potential for flammable vapors to accumulate in the application area creating the risk for an explosive atmosphere. This is also stated in the FTOC 2018 report: “flammable blowing agents including hydrocarbons have broadly been ruled out for polyurethane spray foam”[173] Methyl formate, methylal, water, or supercritical CO2 cannot be used as alternatives in spray foam for the reasons explained in the following sections.

<u>Methyl Formate</u>:

[173] https://ozone.unep.org/sites/default/files/2019-04/FTOC-assessment-report-2018.pdf

Methyl formate is flammable and has a flash point of -32 Deg C.[174] It is therefore unsafe for this application. The extreme solubility of this chemical in the polyurethane polymer also makes it unsuitable for use in spray foam applications and causes problems with the dimensional stability of the foam.[175] Foams made with methyl formate shrink when exposed to hot humid environments[176] as demonstrated by the data below.

Data for a SPF blown with HFO-1336mzzZ:

- Density: 36 kg/m^3
- Initial Lambda: 25 mW/m-K
- 30 days Aged Lambda: 25.4 mW/mK
- Dimensional Stability 14 day: -3.5% volume change (PASS)

Data for a SPF blown with methyl formate:

- Density: 32 kg/m^3
- Initial Lambda: 27.3 mW/m-K (aged lambda cannot be measured due to shrinkage)
- Dimensional stability 7 day: -64% Volume Loss (failed must be less than 10% change[177])

The dimensional stability results for methyl formate-blown foam support the conclusion that it is not a viable blowing agent for rigid polyurethane spray foam. In addition, the thermal resistance of foams made with this chemical is much lower than of foams made with HFO-1336mzzZ, HFO-1336mzzE, and HCFO-1233zdE; requiring much greater thickness of foam to reach the desired thermal resistance.

Methylal: Methylal suffers from the same analogous weaknesses as methyl formate. It is equally flammable and thus not safe, with a flash point of -18 Deg C.[178] The thermal resistance of foams with methylal as blowing agent is also low. It is also extremely soluble and thus dimensionally unstable, as the following data shown.[179]

Data for a SPF blown with methylal blown:

- Density: 37 kg/m3
- Initial Lambda: 27 mW/m-K (aged lambda cannot be measured due to shrinkage)
- Dimensional stability 7 day: -57% Volume Loss (failed must be less than 10% change)

Water or CO2:

In Annex E, section 2.8.4.3, p 270, it is stated that *"*for spray or dispensed foam, the alternative is to go to polyurethane open-cell products (with CO2 or water blown system). This would not meet the needs of customers looking for better energy efficiency, insulating performance, strength, rigidity and water

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174 ThermoFisher Scientific (2021). *Safety data sheet: Methyl formate*. https://www.fishersci.com/store/msds?partNumber=AC414345000&productDescription=METHYL+FORMATE%2C+SPECTRO+500ML&vendorId=VN00032119&countryCode=US&language=en

175 Chemours (2023). *Chemours Technical Report: Comparison of Spray Foam Blowing Agents*. l

176 Chemours (2023). *Report: Evaluation of methyl formate and Methylal in SPF*

177 Building code % volume loss standard requirement in the US for spray foam, ICC-ES AC377. Internal Standards for many spray foam manufacturers are even more restrictive, imposing <5% change

178 ThermoFisher Scientific (2021). *Safety data sheet: Methylal.* https://www.fishersci.com/store/msds?partNumber=M222500&productDescription=METHYLAL+CERTIFIED+500ML&vendorId=VN00033897&countryCode=US&language=en

179 Chemours (2023). *Report: Evaluation of methyl formate and Methylal in SPF*

absorption resistance." For closed cell spray foams with a density of less than approximately 43 kg/m^3, there are no suitable alternatives to HFO blowing agents that are non-flammable. Water blown or CO2 blown foams suffer from defects that prevent them from being adopted as the sole blowing agent.

In Annex E, section 2.8.3, p 257, a possible derogation is proposed for foam blowing agents in foam that is sprayed on site for building insulation. The justification given is that although "water-blown foam can also be used, there are challenges with dimensional stability and insulating capability". In our view, there are also other challenges in using water as a blowing agent, as explained in the following paragraphs.

Water reacts with isocyanate to form CO2, urea, and heat. These foams are brittle and suffer from poor adhesion to substrates when sprayed on surfaces that have a temperature of ~20 Deg C and less, due to the relatively high urea concentration that often forms on the surface of these foams.[180] This gives them a limited application window. Foams made with water are also dimensionally unstable, due to a relatively high diffusion coefficient of the carbon dioxide through the cell walls.[181]

The high viscosity of the polyol blend is also problematic for water-blown foams (a direct result of the removal of the fluorinated blowing agent). The isocyanate component has a pressure of about 180 centipoise (cP) at 20 Deg C, whereas a typical water-blown polyol component can range from 1500cP to 3000cP. If the component pressures do not match, this will result in an uneven/defective foam.

Water or CO2 blown foams have 30% to 50% lower thermal resistance than HFO blown foam. This requires much greater foam thickness to reach the desired insulating power.[182] The lower thermal resistance of water or CO2 blown foam requires a 75% greater thickness to achieve the same thermal resistance as HFO blown foams, thus the mass of the foam is increased by 235%.[183]

HFO blowing agents absorb the heat of reaction during the application of a foam. Without the HFO present, a water blown foam will have an increased risk to auto ignite due to the exothermic heat generated in the core of the foam. Water blown foams require spraying multiple applications of a thin layer of foam to mitigate this particular risk, greatly increasing the installed density, further reducing the insulating power, and increasing the installation time and cost.[184]

For closed cell spray foams with a density of less than approximately 43 kg/m^3, there are no suitable alternatives to HFO blowing agents that are non-flammable. If water or CO2 is used as blowing agent, the foams suffer from defects that prevent them from being adopted as the sole blowing agent. Water reacts

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[180] Rao, R.R., Mondy, L.A., Long, K.N., Celina, M.C., Wyatt, N., Roberts, C.C., Soehnel, M.M. and Brunini, V.E. (2017). The kinetics of polyurethane structural foam formation: Foaming and polymerization. *AIChE Journal*, 63(7), p.5. https://doi.org/10.1002/aic.15680

[181] Santiago-Calvo, M., Tirado-Mediavilla, J., Ruiz-Herrero, J.L., Villafañe, F. and Rodríguez-Pérez, M.Á. (2019). Long-term thermal conductivity of cyclopentane–water blown rigid polyurethane foams reinforced with different types of fillers. *Polymer International*, 68(10), p.3. https://doi.org/10.1002/pi.5893

[182] Randall, D. and Lee, S. (2002). *The Polyurethanes Book*. [Huntsman Polyurethanes] ; Distributed by John Wiley & Sons, [Everberg, Belgium], pp.234, fig. 15-5

[183] Calculation based on Example of resource efficiency of using a SPF blown with HFO on page 2 of this submission

[184] https://poliuretanos.com.br/Ingles/Chapter2/23blowing.htm

with isocyanate to form CO2, urea, and heat. These foams are brittle and suffer from poor adhesion to substrates due to the relatively high urea concentration that often forms on the surface of these foams.[185] Water blown spray foams with a density of approximately 43 kg/m^3 and greater, while possible, still have similar defects and shortcomings that only the use of HFOs can solve, for example brittleness, poor adhesion, and poor thermal resistance. Additionally, the use of only water or CO2 as a blowing agent requires the use of up to two times the amount of polyurethane, doubling the cost of the installation vs. using a lower density HFO blown spray foam.[186]

HFO blown foams do not have the limitations and flaws of supercritical CO2. Annex E, section 2.8.2.3, p 250 states that “CO2 is also used as a blowing agent in many applications. Already in 2009, it was stressed that pentane or CO2 can be used as blowing agents in all types of rigid XPS foam, rigid PUR foams and flexible PUR foams, and the technology has been successfully used by several large manufacturers.” We agree that CO2 can be used in several of these applications – however, this does not include high- or low-pressure spray foam. To produce commercially acceptable insulation, a blowing agent needs to be liquid for high pressure spray foam. In low pressure spray foam the blowing agent needs to be soluble in the polyol and isocyanate components so as to function as a propellent and a blowing agent. Supercritical CO2 is not able to meet the necessary requirements for these applications.

While spray foams have been produced with supercritical CO2, they have serious flaws due to properties of CO2. Due to the low boiling point (-78 Deg C) of the supercritical CO2[187], the exotherms of these foams are greatly reduced. This slows the curing process, that heightens during and after application. This results in foams having a very friable (crumbly) surface that has difficulty adhering to substrates, resulting in installation failures. This flaw has resulted in very limited adoption of supercritical CO2. CO2 is not viable as the sole blowing agent in lower pressure spray foam due to its low solubility in the polyol and isocyanate components. HFOs have the advantage of being soluble in both components, allowing it to function as both a blowing agent and propellant.

The use of supercritical CO2 in spray foam produces foams that have thermal conductivities far inferior to spray foam with HFOs. CO2 blown foams have thermal conductivities of 36 mW/m-K[188] vs as low as 20 mW/m-K for an HFO blown foam. This technology also lacks versatility. Spray foams are applied in outdoor climates throughout the year, so substrates may have a range of temperatures, such as -20 Deg C, 0 Deg C or 20 Deg C. Supercritical CO2 also produces foams that are more permeable and have a larger open cell content. This is a direct result of its low boiling point for this application, which causes over pressure inside the cells, resulting in cell window rupture.[189]

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[185] Rao, R.R., Mondy, L.A., Long, K.N., Celina, M.C., Wyatt, N., Roberts, C.C., Soehnel, M.M. and Brunini, V.E. (2017). The kinetics of polyurethane structural foam formation: Foaming and polymerization. *AIChE Journal*, 63(7), p.5. https://doi.org/10.1002/aic.15680

[186] Honeywell International (2018). *HFO-and HFC-based Spray Foam Compared to Water-blown Systems*. https://prod-edam.honeywell.com/content/dam/honeywell-edam/pmt/oneam/en-us/blowing-agents/documents/pmt-am-solstice-lba-enovate245fa-cost-effective-solutions-brochure.pdf

[187] https://www.sciencedirect.com/topics/chemistry/carbon-dioxide#:~:text=Carbon%20dioxide%20(CO2)%20is,is%20slightly%20soluble%20in%20water

[188] Santiago-Calvo, M., et al., (2018). Evaluation of the thermal conductivity and mechanical properties of water blown polyurethane rigid foams reinforced with carbon nanofibers. *European Polymer Journal*, 108, pp.98–106. https://doi.org/10.1016/j.eurpolymj.2018.08.051

[189] United Nations Development Programme (UNDP) (2013). *UNDP Report: Supercritical Co2 Technology For Poyurethane Spray Foam*. Available at: https://ozone.unep.org/sites/default/files/2019-04/FTOC-assessment-report-2018.pdf

The use of supercritical CO2 in high pressure foams also requires the introduction of a third component, which is a pressurized gas. This necessitates new equipment and gives a contractor control over the dosing of the blowing agent. Past attempts at adopting third stream technology in high pressure spray foam have led to an increase in misapplication and incorrect dosing of blowing agents by the contractors in attempts to reduce foam density lower than their design criteria.

Hydrocarbons:
Hydrocarbons and other flammable blowing agents cannot be used in in-situ spray foam for safety reasons. Flammable vapors could accumulate in the application area and create the risk of an explosive atmosphere. Polyurethane foams blown with hydrocarbons are more combustible due to the flammability of the blowing agent, which contributes to the overall flammability of the polymer. For these reasons, flammable blowing agents have been excluded from polyurethane spray foam.[190] Unlike hydrocarbons, HFOs such as HFO-1336mzzZ are not flammable.

In Annex E, section 2.8.2.3, p 250, a report by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) is quoted,[191] according to which "hydrocarbons are the preferred blowing agent in the manufacturing of refrigeration appliances in many regions." This was indeed the case, but only until the commercialization of HFO-1336mzzZ, HFO-1336mzzE, and HCFO-1233zdE from 2010. Since then, it has been shown that HCs cannot meet new energy efficiency ratings without the incorporation of a blend of HFO/HCs to enhance insulation performance.[192] The energy efficiency of refrigerators and air conditioners is increased by their insulation, which reduces the heat flow into or out of the appliance.

In Annex E, section 2.8.4.3, p 270 it is stated, that "switching to hydrocarbons has also occurred in the phenolic foam sector, where hydrocarbon blown foams are used in less demanding applications where there is scope for increased thicknesses of insulation to compensate for the reduced thermal performance and where fire performance is less critical." Switching to hydrocarbons has indeed resulted in lower thermal performance and thus a loss of market share to polyurethane foam products that use HCFO or HFO blowing agents (despite the increase in blowing agent cost). Phenolic foam manufacturers have developed new products with greatly improved thermal insulation ability (10 to 20% better thermal resistance) using HCFO and HFO blowing agents. [Confidential].[193]

In Annex E, section 2.8.2.3, p 251, it is argued that "the insulating properties of foam blown with natural gases are slightly reduced, and therefore that in order to reach the same insulating effect, a thicker layer of foam will need to be used with the alternatives." This is an understatement in our view. The insulation properties of foams blown with HFOs are at least 20% better than with hydrocarbons. As it is also stated in Annex E, section 2.8.4.3, p 270 that "customers were moving back to HFOs because of superior performance on insulation, by up to 20% than either hydrocarbons or CO2 (water) systems." Furthermore, HFOs can be blended with hydrocarbons and/or CO2 to produce foams having even better insulating

[190] United Nations Development Programme (UNDP) (2018). *Montreal Protocol on substances that deplete the ozone layer: 2018 report of the Rigid and Flexible Foams Technical Options Committee*. https://ozone.unep.org/sites/default/files/2019-04/FTOC-assessment-report-2018.pdf
[191] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (2009). *Natural Foam Blowing Agents: Sustainable Ozone- and Climate-Friendly Atlernatives to HCFCs.* https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/giz2009-en-natural-foam-blowing-agents.pdf
[192] 2017 CPI Paper and 2018 UTECH Paper – Reference can be made available to ECHA upon request
[193] [Confidential]

properties. Research shows that an additional 20% improvement in thermal resistance is attainable when using blends of HFOs and HCs. If we use products with lower insulating power, this will mean that the insulation thickness would need to be increased by 10 to 25% with hydrocarbons and as much as 100% vs foams using CO2 as a blowing agent. Increasing the thickness of foam insulation will also increase the weight of the foam needed by at least 20% and will for example require the redesign of appliance shells to accommodate the insulation by reducing the usable volume of the refrigerator. If the volume space is not reduced, then the overall width and depth of the appliance will be increased. Increased foam thickness results in reduced productivity and a corresponding increase in the cost per unit.[194]

In Annex E, section 2.8.4.3, p 271, it is stated that “there was no evidence in either the CfE or 2nd stakeholder consultation that industry has taken steps to make a transition from HFOs for high specification applications, which should not be considered surprising given that the migration from HFCs to HFOs is ongoing and there is no regulatory pressure to go further, although there is pressure linked to the high price of HFOs. A major manufacturer cited a period of 7-10 years for developing future alternatives.” To our knowledge, no non-flammable alternative blowing agents exist for spray foam that can meet current or future performance requirements or energy efficiency regulations. Should the energy efficiency requirements increase in the appliance segment, HCs alone will not be able to keep up with regulatory requirements. HFOs are needed now and in the future due to their ability to improve thermal resistance by up to 20% when used in combination with hydrocarbons.[195]

Technical feasibility of alternative insulating technologies

As is the case for alternative foam blowing agents, no alternate insulating technology can match or approximate the thermal resistance provided by HFO blown spray foam, as explained in the following section.

Fiberglass and rockwool*:*
Fiberglass and rockwool have a thermal resistance of about 0.65 m^2K/W at a thickness of 25mm. HFO blown spray foam has a thermal resistance of about 1.14 m^2K/W at 25mm.[196] This means that to achieve the same insulating power, fiberglass or rockwool will require 75% greater thickness to match the HFO blown spray foam insulation. It should also be noted that fiberglass and rockwool cannot support much weight and will sag and settle overtime due to its own weight. In the case of horizontal installations, simply adding additional layers of fiberglass or rockwool will compress the underlying layers of insulation and reduce the overall thermal resistance. In the case of vertical installations, fiberglass and rockwool will sag overtime, leaving areas at the top of wall sections uninsulated.

Closed-cell spray foam is the only insulation that provides multiple functions – insulation, air barrier and vapor barrier. Fiberglass, rockwool, and open cell foams are not able to provide the complete range of functionality at once. Fiberglass, rockwool and open cell foam allow air and vapor to move through them

[194] 2017 CPI Paper and 2018 UTECH Paper – Reference can be made available to ECHA upon request
[195] 2017 CPI Paper and 2018 UTECH Paper – Reference can be made available to ECHA upon request
[196] Australian Modern Building Alliance (2021). *Comparison of polyurethane insulation with other insulants*. https://australianmodernbuildingalliance.org.au/images/amba/resources/Compare_Polyurethane_Insulation-6.v1.pdf

(meaning they cannot be used to create an unventilated attic, for instance).[197] Builders using closed cell SPF can avoid using multiple products during construction and reduce the time and cost of the building.

In industrial applications, alternatives like fiberglass require fasteners or another means to adhere to the substrate, resulting in compression of the insulation, which further reduces thermal resistance. Fiberglass will also not stop air moving through it and can allow for condensation on the surface, resulting in wet insulation. Once the insulation is wet its ability to insulate is compromised and it must be replaced completely.

Other applications with no suitable alternatives include polyurethane foam insulation for cryogenic refrigeration, aerospace vehicles and rockets. These applications require insulation with exemplary physical properties to withstand the harsh environmental and use conditions while maintaining their insulating and structural integrity.

Conclusion

The previous discussion demonstrates that there are no alternatives that can match or approximate the overall performance and universal applicability of HFO blown spray foam, whether alternative blowing agents or alternative insulation materials. Characteristics like flammability prohibit the use of some alternatives in certain situations. In other cases, alternatives are much less effective at providing insulation, meaning a loss of space (to allow more material) or higher heating and cooling costs, both of which result in higher costs. Alternatives also have other problems (e.g. structural integrity, water resistance).

COST-EFFECTIVENESS OF NON-FLUORINATED FOAM BLOWING AGENTS

A switch to non-fluorinated refrigerants in foam blowing agents or alternative insulating materials if the proposed restriction was implemented would be expected to result in a disproportionate cost impacts on society in (*inter alia*) the following areas:

- Higher energy consumption due to lower energy efficiency;
- Higher carbon emissions associated with higher energy use.

In this section, monetary estimates of these costs are generated.

Higher energy consumption

The Spray Polyurethane Foam Alliance has undertaken a modelling comparison of energy requirements in residential homes using F-gas-blown in-situ spray foams versus glass wool. The results showed that homes using F-gas-blown spray foams have a potential total energy saving of 2,515 kWh/year[198] compared

[197] Spray Polyurethane Foam Alliance (SPFA) (2019). *Spray Polyurethane Foam in Cathedral Ceilings and Unvented (Conditioned) Attics*. https://www.naylornetwork.com/spf-nwl/pdf/SPFA-141_-_Mar_2019.pdf
[198] Spray Polyurethane Foam Alliance. *Counting Carbon: Demand a Better Insulation in Your Next Home.* https://www.sprayfoam.org/files/Demand%20a%20Better%20Insulation.pdf

to non-fluorinated alternatives. Here we extend this calculation to estimate what energy savings would be across the EU of using F-gas-blown spray foams instead of fiberglass wool.

The average size of a new build property in Europe was estimated to be 327 square meters.[199] To calculate the number of "equivalent virtual new builds" (which includes spray foam used for renovation purposes) using F-gas blown spray foam, it is assumed spray foam will be installed in the ceiling and internal walls. An average floor plan size of 327 m2 results in an average wall length of just over 18 meters. The average height of internal residential property walls in Europe is between 2.2 and 2.73 meters, so a midpoint height of 2.45 meters was applied. This results in 44.3 m2 of foam being required per internal wall. Insulating an average one-story home with ceiling and wall insulation means 504.21 m2 of spray foam will be required, and to insulate a two-story home with top ceiling and wall insulation will require 681.43 m2 of foam. Weight in kg/m2 for cavity and roof applications is 5.76 kg/m2.[200] Hence, 118kg of spray foam are used per house. Given the previously mention estimate of the volume of spray foam to be used in the EU in 2024 (approximately 222,000 tons), this implies that around 1.88 million (M) houses (either newly built or renovated) would be insulated in 2024. Assuming the previously mentioned growth rate, an insulation lifetime of 70 years, and an annual energy saving per house of 2,515 kWh from F-gas-blown spray foam compared with fiberglass, the energy costs per year of a ban entering into force on 1 January 2025 until 2055 are as shown in Table C.2.

Table C.2: Cumulative energy savings and additional energy cost of houses that cannot be insulated with spray foam

	2025	2030	2035	2040	2045	2050	2055
Rigid foam in tons	229,992	274,481	327,575	390,939	466,560	556,809	664,516
Number of houses added [M]	1.95	2.33	2.78	3.31	3.95	4.72	5.63
Cumulative houses [M]	1.95	12.80	25.75	41.20	59.64	81.65	107.92
TWh/yr (2,515kWh/house)	4.9	32.2	64.8	103.6	150.0	205.4	271.4
Cost Euro m (0.28 E/kWh)	1,392	9,142	18,390	29,428	42,601	58,322	77,083

Thus, a ban on HFO spray foam which forced building owners to use alternatives such as fiberglass to insulate their homes would result in additional cumulative energy costs of 3,590 TWh over the period 2025-2055, equal to EUR 1,019bn in additional energy costs, at an average of EUR 32.9bn per year (271 TWh and EUR 77.1bn additional energy costs in 2055).

CO_{2e} COSTS

The increased energy consumption associated with the use of alternatives to HFO blown foam can be translated into increased CO_2 emissions. At an estimated CO_2 intensity of 238g/KWh[201] and cost of carbon

[199] European Commission, Directorate-General for Energy, (2019) Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU: final report. *Publications Office, pp. 295-296.* https://data.europa.eu/doi/10.2833/14675

[200] Federation of European Rigid Polyurethane Foam Associations (2014). *Life Cycle Environmental and Economic analysis of polyurethane insulation in low energy buildings*. https://www.pu-europe.eu/fileadmin/documents/Factsheets_public/Factsheet_15_Life_Cycle_Environmental_and_Economic_analysis_of_Polyurethane_Insulation_in_Low_Energy_Buildings__fin_.pdf

[201] https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-13#tab-googlechartid_chart_11

permits of EUR 95/ton CO_{2e}[202], this equates to EUR 81.2bn over the period 2025 – 2055, or EUR 2.7bn per year (EUR 6.1bn in 2055).

Summary of the cost-effectiveness of non-fluorinated foam blowing agents

A ban on F-gas-based foam blowing agents would be expected to increase energy consumption and carbon emissions, resulting in additional costs to society of EUR 1,101bn over the period 2025-2055, or EUR 35.5bn on average per year, and an additional cost of EUR 83.2bn in 2055.

Emission reduction and cost of a ban to reduce emissions

Table C.1 presented Chemours' estimates of the emissions of TFA from the use of F-gas-blown spray foam and these are reproduced in Table C.3. It can be seen that TFA emissions would be expected to be 257 tons per year on average over the period 2025-2055, or 7,959 tons in total over the same period. This gives an average cost of preventing the emission of 1 ton of TFA through a ban on F-gas-blown spray foams of EUR 138m between 2025-2055, with a cost of EUR 200m per year in 2055.

Table C.3: Chemours emission projections from F-gas-blown spray foam (tons)

	2025	2030	2035	2040	2045	2050	2055
TFA Emission per year	144	172	205	244	292	348	415
Emissions over the 5-year period	772	922	1,100	1,313	1,567	1,870	
Total emissions over the period 2025-2055	7,959						

In summary, these calculations demonstrate that a switch to non-fluorinated alternatives in spray foam applications immediately following the transition period or following a time-limited derogation period would result in significantly higher costs in terms of total EU energy requirements and impacts of carbon emissions. Given the extremely high costs per ton of TFA prevented from entering the environment, the socio-economic costs of a ban on the use of F-gases as foam-blowing agents would be disproportionate.

COST-EFFECTIVENESS OF ADDITIONAL F-GAS-BASED FOAM BLOWING AGENT MEASURES

The previous section estimated the cost of banning F-gas foam-blowing agents and forcing a switch to alternative blowing agents or insulation materials. These estimates exclude some sources of cost and are therefore likely to underestimate the true cost. Compared with the quantity of TFA which would be prevented from entering the environment, the costs of a ban appear disproportionate. In this section, we estimate the cost-effectiveness of other measures which could be used to reduce the emissions of TFA from the use of F-gas-blown spray foam.

Closed-cell spray foam is manufactured on-site by combining isocyanate and resin. The resin contains a blowing agent that expands the mixture to create a foam with closed cells. Blowing agents are essential

[202] https://tradingeconomics.com/commodity/carbon

ingredients in spray foam insulation. They create tiny bubbles of trapped gas that slow the movement of heat, making foam a good insulator and air and vapor barrier. HFO blowing agents reduce the amount of air leakage in buildings and hence increase energy efficiency. In addition, the choice of blowing agent formulation offers the opportunity to optimize the thermal efficiency and overall performance of the foam (bigger and smaller air enclosures with low water absorption and resistance to mold). Emissions from closed cell foam are typically less than 2% annually.[203]

Table C.1 indicates that emissions of TFA from the use of F-gas-blown spray foam are already low compared with other sources of PFAS into the environment. However, emission reductions are still possible, and the following regulatory framework is proposed to reduce emissions to a fraction of what they are today by 2050:

- Certified installers;
- Enhanced F-gas recovery at end of life.

Certification of installers

This would ensure installers have undergone training and install according to industry standards.[204] Di-isocyanates are a key component in polyurethane foam blowing systems, the most used being polymeric MDI (pMDI). Occupational exposure is a concern for industry sectors using these compounds due to their volatility, aerosolization, skin sensitization and the hot processes that are required when handling these compounds. As an amendment to Annex XVII of REACH, the Commission Regulation (EU) 2020/1149[205] was introduced to ensure that training is provided for workers in sectors that use di-isocyanates. All training must be in place by 24 August 2023 and is expected to reduce workers' exposure to di-isocyanates by 50% to 70%. Consequently, exposure to polyurethane foams made with F-gases as their foam blowing agent is also expected to decrease. Therefore, the use of trained personnel to apply spray foams is likely to reduce both exposure and emissions to the environment.

Enhanced F-gas recovery at end of life

The 2014 F-gas regulation requires operators of products and equipment that contain F-gases to arrange for the recovery of the gases, "to the extent that it is technically feasible and does not entail disproportionate cost." Special facilities for processing foam from domestic appliances exist today and are also used where foam can be separated easily (e.g. foam blocks from insulating pipes and vessels).[206] Some countries such as Sweden, Switzerland, Denmark, and Germany transform practically all PU waste, which cannot be recycled or recovered otherwise, into energy. On average, it can be estimated that about half of the PU insulation waste is treated in this way in Europe.[207] Further progress can be made to ensure

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[203] https://www.constructioncanada.net/sprayfoam-to-hfo-the-blowing-agents-shift-explained/2/
[204] https://www.foamcomfort.ca/what-is-a-foam-master
[205] https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e180876053
[206] Gluckman Consulting (2015). *EU F-Gas Regulation Guidance Information Sheet 7: Foam Insulation Products.* http://www.gluckmanconsulting.com/wp-content/uploads/2015/02/IS-7-Insulating-Foam-v3.pdf
[207] PU Europe (2013). *Waste management and polyurethane insulation in the context of resource efficiency.* http://highperformanceinsulation.eu/wp-content/uploads/2016/08/Polyrethane_insulation_and_waste_management.pdf

foam recycled or as a minimum incinerated instead of disposed of in landfills at limited amount of additional costs.

Page 272 of the REACH dossier states that "the low density and correspondingly high volume of the foams may be a deterrent to establishment of an efficient collection network for low value recyclate". In fact, low density flexible foams are widely recovered and recycled today. Examples include mattresses and carpet underlay. Rigid foams are also recycled, and recycling is commercially viable.[208] Recycling of waste from construction activities, including refrigeration appliances, and insulation waste must be carried out in accordance with EU Regulation EN 50574; this is therefore a legal requirement for fluorocarbons or hydrocarbons.[209]

Incineration is more expensive than landfilling, and the additional cost to incinerate 1 ton of foam can be estimated at €14.8/ton.[210] Using the foam volumes in Table C.1 and the assumption above that approximately 50% of the PU waste is already incinerated, this represents a cost of € 94M between 2025-2055 and € 4.9M in 2055.

The European end of life directive should therefore prohibit land fill of PU foam and mandate incineration in case recycling is not possible, therefore reducing the emissions at end of life from 16% to 0%, as shown in Table C.4.

Table C.4: Lifetime emissions in tons with enhanced F-gas recovery at end of life

	2025	2030	2035	2040	2045	2050	2055
Emissions installation	29	34	41	49	58	70	83
Emissions lifetime	69	82	98	117	140	167	199
emissions at end of life	0	0	0	0	0	0	0
TFA Emission per year	98	117	139	166	198	237	282
Emissions over the 5-year period	525	627	748	893	1,065	1,272	
Total emissions over the period 2025-2055	5,412						

Emission reduction and cost to reduce emissions

- The current emissions would result in estimated average TFA emissions of 257 tons per year between 2025-2055. These emissions can be further deceased by the measures implemented above to 175 tons per year on average between 2025-2055.
- These measures result in estimated emissions of 282 tons in 2055 as shown in Table C.5.
- Projected emission reduction 2025-2055: 82 tons per year on average or 2,547 tons for the period.
- Projected emission reduction in 2055: 133 tons equivalent to a 32 % reduction in emission.
- Estimated cost per ton of emission reduction 2025-2055: EUR 0.04M per ton of emissions prevented.

[208] Emery Oleo Chemical have several products available made with recycled rigid foam: www.emeryoleo.com
[209] https://freonatervinning.se/
[210] https://www.energyjustice.net/incineration/expensive-waste using the average USD 2019 exchange rate of 0.8931 (US Dollar to Euro Spot Exchange Rates for 2019)

- Estimated cost per ton of emission reduction 2055: EUR 0.04M per ton of emissions prevented.

In summary, the emissions of F-gases can be better handled by alternative risk management measures (RMMs) at a lower cost to the European society:

- DS proposal in 2055: EUR 200M per ton of emission reduction based on our estimated emission calculation.
- Chemours proposal in 2055: 32% emission reduction at a cost of EUR 0.04M per ton of emission reduction.

Table C.5: Emission projection in tons
Chemours emission estimate

	2025	2030	2035	2040	2045	2050	2055
TFA Emission per year	144	172	205	244	292	348	415
Emissions over the 5-year period	772	922	1,100	1,313	1,567	1,870	
Total emissions over the period 2025-2055	7,959	saved	2,547				

Emission estimates based on alternative Restriction Option based on RMMs

	2025	2030	2035	2040	2045	2050	2055
TFA Emission per year	98	117	139	166	198	237	282
Emissions over the 5-year period	525	627	748	893	1,065	1,272	
Total emissions over the period 2025-2055	5,412						

CONTRIBUTION TO POLICY OBJECTIVES

The European Green Deal, proposed in 2019, has promised to reshape the European Union (EU) into a resource sustainable economy and to be carbon neutral by 2050 while reducing greenhouse gas emissions by 55% in 2030. Furthermore, the Fit for 55 initiative has set binding targets at an EU level that require public sector buildings to be more energy efficient (3% of building floor space is due to be renovated every year to make them more energy efficient), while the Sustainable and Smart Mobility Strategy aims to have 100 European cities climate neural by 2030. On this same line, the Energy Performance of Buildings Directive (EPBD) promotes policies that aim to have a decarbonized building stock by 2050, within which the EU Renovation Wave Strategy aims to renovate and upgrade most of Europe's infrastructure to allow for more energy efficient buildings.
Therefore, making existing and new buildings more energy efficient is a centerpiece of these EU sustainability policy targets – and high-insulating spray foams play a pivotal role in this ambition. In this sense, to realize the goals of the European Green Deal, the contribution of F-gases (HFOs) is crucial.

THE USE OF F-GAS BASED SPRAYFOAM IN OTHER APPLICATIONS

F-gas based spray foam is used in a number of applications, some large, but others very niche. Below are some examples and the criticality of F-gas based spray foams in other applications than on-site for building insulation. The value brought by F-gas based spray foam demonstrates the need for a broad derogation of all F-gas based spray foam applications.

Integral Skin Foams

Historically, integral skin foams that are used to make parts for automotive interiors, shoe soles, bicycle seats, and office furniture were made using HFCs such as HFC-245fa. With the HFC phase down, HFC foam blowing agents were converted to low GWP alternatives. The blowing agent selected depends on the exact end use. For example, some high-density foams were converted to methyl formate for use in steering wheel covers. Other high-end applications, require the use of HFO-1336mzzZ, HFO-1336mzzE, and HCFO-1233zd-E because there are no other alternatives that match the performance required for these high-end applications. Integral skin foam is a dual-layer structure formed during the foam making process[211]. The foam is similar to a loaf of bread: it has an inner uniform open cell structure surrounded by a thick outer skin. This skin forming process is made possible by the condensation effect of the blowing agent near the foam/foam-mold interface. HFOs and HCFOs have a boiling point that make this interaction possible.

Integral skin foams must stand up to rigorous physical tests to prove their durability in the end use, such as hot to cold cycling, humid aging, abrasion resistance testing, resiliency testing, and compression set testing under load. The foams also must not break down physically or chemically in these end uses. HFO/HCFOs are the only alternatives to HFCs for integral skin intended for use in automotive, bicycle seats, office furniture, and shoe soles.[212]

Due to its high solubility, methyl formate is only suitable for use in thin, high-density applications such as steering wheel covers. Methyl formate is unable to form lower density integral skin foams due their tendency to shrink. It may also hydrolyze in hot-humid conditions to formic acid, which could present a skin contact health issue, and is also highly flammable.

Hydrocarbons are more difficult to work with, and produce integral skin foams that are softer than those made with HFCs/HCFOs. Due to their flammability, they may not be used unless the process is made explosion proof.

Chemours has converted several integral skin manufacturers away from HFC-245fa and HFC-134a that now use HFO-1336mzzZ. Additionally, we have identified HFO-1336mzzE as particularly effective in these applications, producing foams with aesthetics that cannot be produced with other blowing agents. Since HFO-1336mzzZ and E are non-flammable they provide a low volatile organic compounds (VOC), a non-flammable alternative to pentanes, and a low GWP alternative to HFC-245fa and HFC-134a. The quantity of blowing agent used for these applications is very small, often ~6 wt% or less, therefore, allowing their continued use should be permitted.

[211] https://knowledgecenter.mearthane.com/integralskinfoam

[212] https://knowledgecenter.mearthane.com/integralskinfoam

Appliance Applications

The insulating properties of foams blown with HCs are at least 20% lower than foams blown with HFOs. Furthermore, HFOs can be blended with hydrocarbons and/or CO2 to produce foams, having even better insulating properties. Research shows that an additional 20% improvement in insulating power versus hydrocarbons is attainable when using blends of HFOs and HCs. If we accept a lower lambda product, this will mean that the insulation thickness would need to be increased by 10 to 25% with pure hydrocarbons and as much as 100% with CO2[213]. It should also be noted that increasing the thickness of foam insulation will also increase the weight of the foam needed by at least 20%, and will require the redesign of appliance shells to accommodate the insulation by reducing the usable volume of the refrigerator. If the volume space is not reduced, then the overall width and depth of the appliance will be increased. In sum, increased foam thickness results in reduced productivity and a corresponding increase in the cost per unit.

A typical household equipped with Energy Star-certified products can reduce CO2 emissions by about 32,660 kg and save about US 8,200 in utility costs over the lifespan of these products. Through HFO technology, we can reduce CO2 emissions by up to 20% through reduced energy use and improved insulating power.[214]

SUMMARY AND CONCLUSIONS

- Attachment 1, Chapter 1 demonstrates that all F-gases (current and future) fulfilling the PFAS definition used by the Dossier Submitters should be exempted from the scope of this restriction because there is no risk to be addressed at EU level. This consideration also applies to the persistent degradation products of F-gases, such as TFA, for which the risks for both human health and the environment are *de minimis*.
- In case the abovementioned conclusion is not accepted, the cost of a ban would be disproportionate. Additional risk management measures, such as technician training and enhanced F-gas recovery at end of life, should be implemented to further minimize emissions. The TFA emissions (which are already at a low level) can be reduced by approximately 30% by 2055 at an estimated cost of EUR 0.04m per ton of emission reduction.
- If the DSs still wish to pursue their derogation-based approach, the derogations are too short and the socio-economic consequences of a ban would be disproportionate compared to the environmental benefit of a restriction:
    - The total additional cost of alternatives to the European society equates to € 1,101bn between 2025 to 2055;
    - Alternatives require 116 TWh of additional energy generation in the EU per year between 2025 to 2055, which is more than 2x the total amount of renewable energy generated in France in 2020 (52 TWh);

[213] 2017 CPI Paper and 2018 UTECH Paper – Reference can be made available to ECHA upon request

[214] https://www.epa.gov/archive/epa/newsreleases/energy-star-collaboration-aims-increase-sales-energy-efficient-products.html

- With no viable alternative as today, the short term (10 years) socio-economic impact caused to the European society of an entry into force by 1 January 2025 would in additional cost between € 10.6-13.4bn;[215]
- Without the use of HFOs, many European sustainability objectives could be at risk;
- The cost per ton of emissions saved in 2055 is disproportionate;
  - EUR 200M per ton of TFA emission reduction based on Chemours estimated emission calculation; or
  - More than 400x above the alternate restriction option based on RMMs proposed by Chemours.

Therefore, the following derogations will be required to avoid disproportionate socio-economic impacts on society.

- Foam-blowing agents (Foam-blowing agents in expanded foam sprayed on site for building insulation; Foam-blowing agents in expanded foam for all applications where the foam is not sprayed on site for building insulation):
  HFO-blown spray foam exhibits exceptional thermal resistance and low density compared with alternative blowing agents and materials, and hence provides much better insulation in a given amount of space. The fundamental disadvantages of alternatives will never be overcome. **A derogation** for F-gases in this application is therefore justified.

  It is not possible to specify a meaningful (evidence-based) time-limited derogation/transition period because it is not clear that alternatives can ever be economically competitive. Hence the costs of a ban are expected to remain disproportionate for the foreseeable future.

[215] Report for Chemours Thermal Specialized Solutions (TSS), 2022: *Socio-Economic Analysis and Impact Assessment of a potential REACH Restriction on F-gases as PFAS.* Attachment 3 Annex IV [attached in confidential version]

D. Immersion cooling application submission

INTRODUCTION

In the DS proposal, immersion cooling is barely considered and there is very limited information presented concerning the use of fluorinated substances in immersion cooling. The European data centre market is forecast to grow from € 15.7bn in 2023 to € 29.1bn in 2028.[216,217] With the development of new technological trends such as artificial intelligence, the internet of things (IoT) or autonomous driving, the need for highly effective data centre cooling is forecast to grow in the coming years and the uptake of immersion cooling will become a vital building block of European policy objectives to support the digital transformation and help deliver the EU Green Deal. We will explain in our submission why we disagree with the DS claim that "Mineral oils, synthetic oils, natural oils, hydrocarbon fluids [can be used] as alternatives in heat transfer fluids for immersion cooling", and demonstrate that fluorinated fluids are critical in delivering superior performance and allowing for the development of new computing technology within the EU.

Immersion cooling technologies

In immersion cooling applications, heat is removed from electrical equipment by submerging them in a thermally but electrically non-conductive (dielectric) fluid. A dielectric fluid possesses unique and non-replicable properties that enable electronics ranging from servers, cables, and batteries to be in direct contact with the fluid while enhancing their normal functions (e.g. longer battery life and greater processing capability). This, in turn, allows for significantly more effective heat removal than experienced with other cooling technologies, such as air-cooled systems. There are two types of immersion cooling systems: single phase immersion cooling (1-PIC) and two-phase immersion cooling (2-PIC). A simplified representation can be found in Figure D.1 below:

216 https://www.mordorintelligence.com/industry-reports/europe-colocation-market-industry
217 at the USD-EUR exchange rate of 31/08/23

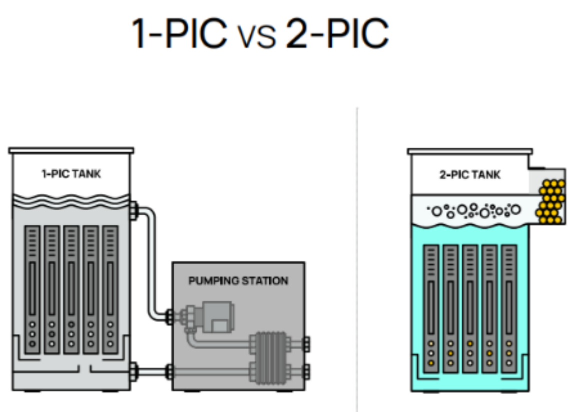

Figure D.4 Schematic of immersion cooling technologies. LiquidStack & Chemours.[218]

In 1-PIC, the dielectric fluid is heated by the electronics or electrical equipment, pumped to, and cooled by an external water-cooled heat exchanger before returning to the tank. Fluids used in 1-PIC are typically oils which are combustible and very viscous, increasing fire risk while reducing total system efficiency. In the 2-PIC system, on the other hand, the dielectric liquid boils when in direct contact with hot server parts and turns into vapour. Vapour rises and condenses on a heat exchanger (condenser) above the liquid surface, returning to a liquid state in a passive cycle that takes place inside a closed tank. There is no need for pumps to circulate the liquid during the cooling process. 2-PIC takes advantage of highly effective heat transfer performance by boiling the dielectric fluid, which is several orders of magnitude greater than those demonstrated by air cooled systems and superior to 1-PIC systems using oils. The dielectric fluids used in 2-PIC are exclusively fluorinated, non-flammable, non-ozone depleting, many of them with low global warming potential, and safe to handle when used according to the manufacturer's recommendations, such as the Opteon™ 2P50 new specialty fluid development for 2-PIC immersion cooling announcement by Chemours[219]. Table D.1 below by Raniwala (2022) from Microsoft summarizes the key attributes of two-phase immersion cooling:[220]

Table D.1 Benefits of two-phase immersion cooling according to Raniwala (2022)

Lower TCO	**Improve Sustainability**	**Enable Innovation**
Simplified climate-agnostic rapidly-deployable infrastructure Reduce hosting costs via efficient cooling and smaller DCs Increase reliability by preventing oxidation/contaminants	Enable smaller land parcels DC Reduce GHG emissions and Energy per VM Enable water-less cooling Enable energy recovery	Enable higher-performance and higher-power CPUs (>500W), FPGAs, GPGPUs and ASICs Enable stable operating temperatures for components Simplify and improve interconnect Enable physical disaggregation

[218] LiquidStack & Chemours (2022). Two-Phase vs Single-Phase Immersion Cooling Fluids: Deconstructing Myths with Science. *LiquidStack.* https://liquidstack.com/white-papers/fluorinated-cooling-fluids-101

[219] https://www.chemours.com/en/news-media-center/all-news/press-releases/2023/chemours-announces-development-of-new-specialty-fluid-for-two-phase-immersion-cooling-opteon-2p50

[220] Raniwala, A. (2022). Bringing 2-Phase Immersion Cooling to Hyperscale Cloud. *2022 Optical Fiber Communications Conference and Exhibition (OFC)*. https://ieeexplore.ieee.org/document/9748792

Table D.2 below summarizes the key advantages of 2-PIC which include:

- Lower total cost of ownership due to high energy efficiency, smaller buildings and simplified mechanical infrastructure with no chillers;
- Ease of maintenance due to low viscosity of fluorinated fluids;
- High flexibility as new servers with upgraded chips can be immersed in the same tank with no need for redesign;
- No fire hazards as fluorinated fluids used in 2-PIC are non-flammable as opposed to non-fluorinated hydrocarbon-based oils;
- 2-PIC's best in class energy efficiency.[221]

Table D.2: Key advantages of 2-phase immersion cooling

	Power/ Rack	Total Cost of Ownership	Ease Maintenance	Flexibility	Fire Hazard	Energy Efficiency
Air Cooled Applications	<30 kW	✓	✓	✓	✓	★☆☆
Direct Cooling (Cold Plate)	75-100 kW	✗	✓	✗	✓	★★☆
Oil Based Single Immersion Cooling	100 kW	✓	✗	✓	✗	★★☆
Two Phase Immersion Cooling	500 kW	✓	✓	✓	✓	★★★

Source: www.Liquidstack.com, adapted by Chemours internal information

2-PIC's superior cooling performance, in comparison with other technologies, helps to keep chips cooler and make them last longer. The article "Cost-Efficient Overclocking in Immersion-Cooled Data centers" shows that immersion-cooled chips can last two to four times longer than air cooled chips, which also leads to a reduction of electronic waste.[222]

2-PIC technology provides the lowest CO_2 equivalent emissions and overall energy consumption. In fact, 2-PIC can reduce total cost of ownership by 50% with as much as 60% power savings.[223]

Cold plate Technology

In addition to the segmentation of immersion cooling, we ask that ECHA recognize an additional trend involving the utilization of secondary loop systems in data center cooling (as shown in Table D.2). Cold

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221 https://liquidstack.com/immersion-cooling

222 Misra, P. A., Manousakis, I., Choukse, E. et al. (2022). Overclocking in immersion-cooled datacenters. *IEEE Micro, 42(4), 10–17*. https://doi.org/10.1109/mm.2022.3163107

223 Kimball, M. & Moor Insights and Strategy. (2023). Addressing The Power Issue With Mears Advanced Technology Group. *Forbes*. https://www.forbes.com/sites/moorinsights/2023/02/23/addressing-the-power-issue-with-mears-advanced-technology-group/?sh=6dd318077da7

plate technology has been identified as a solution that can support chips up to 600 Watt (W), which makes it an ideal interim solution while the industry develops two phase immersion cooling capabilities. This solution is ideal for supporting the next step in chip capacity and does provide some benefits to end users in the form of energy savings vs. air cooled technologies. In this architecture a secondary fluid is cooled using active (by means of a chiller) and passive (by means of a cooling tower) means. The fluid is then circulated through piping to static evaporators or cold plates that then cool IT components through near contact. The fluid is then circulated through the piping to reject the heat into a secondary fluid or to ambient conditions[224] as shown in Figure D.2. These systems are often referred to as cold plate or direct to chip cooling systems. Similar to immersion cooling technologies, cold plate architectures are relatively new to the market and there is little data to compare technologies, thus the following section will leverage publicly available comparison to highlight the benefits and limitations of the technology.

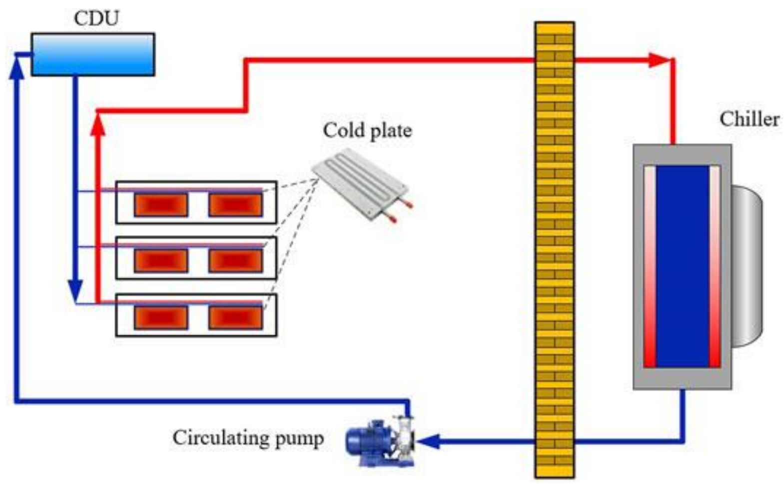

Figure D.2: Cold plate cooling technology architecture

Cold plate technologies are likely an interim (transitional) solution for data center IT component cooling, as several risks and limitations exist with this infrastructure. In a traditional system, a fluorinated or non-fluorinated fluid is used as the primary coolant in a traditional chiller application. In all cases the performance of fluorinated and non-fluorinated solution alternatives are different, as non-fluorinated alternatives solutions such as CO2, Hydrocarbons, and Ammonia have performance, technical and charge size limitations that are described in Attachment 1 Section 3.3 and 3.4, when compared to systems using F-gases, i.e. HFC, HFO, and HFO blend-based solutions. The secondary cooling fluid can be either single-phase or two-phase in nature, where single-phase fluids offer diminished performance due to the loss of capacity from a lack of heat absorption through evaporation. Fluorinated solutions are most commonly used in the secondary loop but in some cases substances such as pure water or a water glycol mix can be used in place of a fluorinated substances. The use of a fluorinated fluid vs. a substance such as water limits the potential risk to the IT equipment due to leaks. Leaks are a major barrier for this technology as water in direct contact with IT equipment will create a short circuit, equipment failures and subsequently increased IT waste.

While cold plate is an option for data centers, three major challenges exist with this technology:

1. The technology is viewed as an interim solution: As noted by Intel on their technology roadmap (in Figure D.3 below), liquid only or direct to chip cooling may only be able to support chip

[224] Zhang, Y., Fan, C. and Li, G. (2022). Discussions of Cold Plate Liquid Cooling Technology and Its Applications in Data Center Thermal Management. *Frontiers in Energy Research, 10.* https://doi.org/10.3389/fenrg.2022.954718

capacities up to 600W. Meanwhile companies like Nvidia and Intel have already begun commercializing chips greater than 700W, a trend that is expected to continue.

2. Cold plate technologies are expensive: Although Chemours was not able to locate a total cost of ownership comparison several papers have articulated the complexity and cost associated with piping a secondary cooling fluid to each individual processor. Additionally, air cooled systems are still required when using cold plate applications as the cold plate system is only responsible for cooling critical components.[225,226]
3. Leaks- Leaks from cold plate systems are prevalent. The use of very small pipes and the volume of piping leads to leaks over time. These leaks run the risk of corroding critical components or in the worst-case scenario, create an immediate short circuit within the system[227]. While fluorinated fluids can help to resolve this challenge, Chemours does not advocate for their use in systems with high leak rate potentials, rather manufactures of the system must utilize mitigation technologies to ensure low leak rates.

Automotive electric powertrain and battery cooling applications:

Immersion cooling is not limited to data center cooling. It is also considered for automotive electric vehicle powertrain and battery cooling applications. In all cases, batteries and other electronic components submerged in an immersion cooling fluid will support improving the efficiency, range, and safety of these growing applications. For automotive applications a range of options exist similar to data center immersion cooling. The volume of publicly available information is limited as this is a new application that is expected to gain traction as electric vehicles increase in use and manufactures change focus from model commercialization to system optimization. More information on this application can be found in the Annex 1 at the end of the Mobile air conditioning and heat pump application submission in this attachment (Information on battery electric vehicles (BEV) electric component immersion cooling thermal management).

2-PIC, AN ESSENTIAL TECHNOLOGY FOR THE FUTURE OF THE EU'S COMPETITIVENESS

2-PIC – which only works with fluorinated fluids – is necessary for the next generation data centers required to meet datafication and the increased needs for computational power and storage. As stated in the paper "Approaching the Heat Limit with Liquid Immersion Cooling":[228] "When it comes to pushing the heat limit, two-phase cooling addresses the data center needs of the future". When compared to single-

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[225] Green Revolution Cooling. *Cold Plate Versus Single-Phase Immersion Cooling*. https://www.grcooling.com/wp-content/uploads/2020/04/grc-blog-library-tech-comparison-%E2%80%94-cold-plate-vs-single-phase-immersion-cooling.pdf

[226] Zhang, Y., Fan, C. and Li, G. (2022). Discussions of Cold Plate Liquid Cooling Technology and Its Applications in Data Center Thermal Management. *Frontiers in Energy Research, 10.* https://doi.org/10.3389/fenrg.2022.954718

[227] Zhang, Y., Fan, C. and Li, G. (2022). Discussions of Cold Plate Liquid Cooling Technology and Its Applications in Data Center Thermal Management. *Frontiers in Energy Research, 10.* https://doi.org/10.3389/fenrg.2022.954718

[228] https://www.datacenterfrontier.com/data-center-cooling/whitepaper/21437208/tmgcore-approaching-the-heat-limit-with-liquid-immersion-technology

phase cooling, two-phase cooling primarily offers better heat dissipation as demonstrated by Intel[229], stating that above 700W of heat per chip, only two-phase heat transfer can provide effective cooling, which is also demonstrated in Figure D.3, in the top right-hand corner, where the next gen chips with a power above 700W can only be cooled by two-phase cooling:[230]

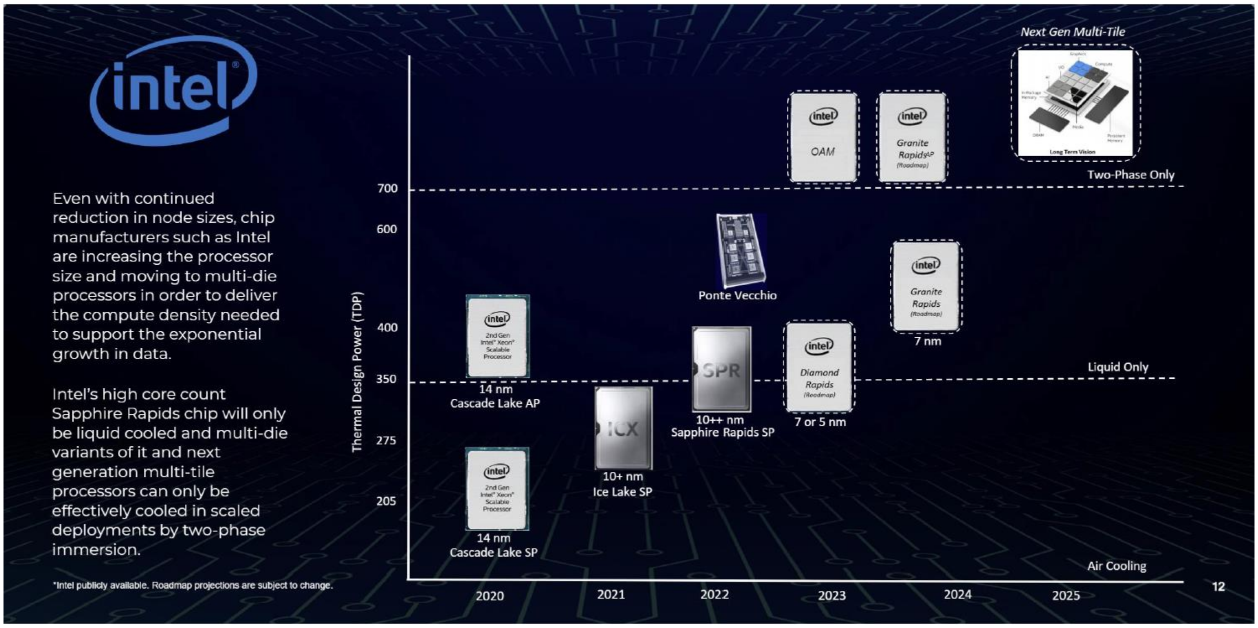

Figure D.3 Source: Dara Center Frontier Webinar series: The State of Data Center Cooling, page 5

According to a major immersion cooling server provider (for both two-phase and single-phase immersion cooling), two-phase immersion cooling achieves two times more heat rejection than single-phase."[231] In fact, representatives from Microsoft-Azure line out that "2*PIC can support a higher thermal flux than 1PIC. Thus, we argue that 2PIC is the most promising technology."*[232] An immersion tank manufacturer of both two-phase and single-phase immersion cooling tanks states that: "While single-phase immersion cooling is still considered a good option for cooling high-performance computers and hot data center environments, dual-phase immersion cooling systems are the number one solution.*"*[233] Another tank manufacturer also states the advantages of single-phase immersion cooling over air cooling, but also the more superior attributes of two-phase immersion over single-phase immersion.[234]

ANNEX E Section E2.12.1 p411 highlights the status of the market today noting that "Immersion cooling (Most likely no PFAS-use in EEA but potentially in the future)". The DSs also recognise in the same section

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229 https://www.datacenterfrontier.com/data-center-cooling/whitepaper/21437208/tmgcore-approaching-the-heat-limit-with-liquid-immersion-technology
230 https://www.datacenterfrontier.com/ai-machine-learning/video/11435139/the-state-of-data-center-cooling
231 https://2crsi.com/immersion-cooling
232 Misra, P. A., Manousakis, I., Choukse, E., Jalili, M., Goiri, I., Raniwala, A., Warrier, B., Alissa, H., Ramakrishnan, B., Tuma, P., Belady, C., Fontoura, M., & Bianchini, R. (2022). Overclocking in immersion-cooled datacenters. *IEEE Micro,* 42(4), 10–17. https://doi.org/10.1109/mm.2022.3163107
233 https://tmgcore.com/single-phase-vs-two-phase-immersion-cooling
234 https://www.datacenterfrontier.com/data-center-cooling/whitepaper/21437208/tmgcore-approaching-the-heat-limit-with-liquid-immersion-technology

the importance of the data centre market, its projected growth and the growth of immersion cooling over the coming years: “Globally, data centre market is expected to grow by 10% in the coming years. Several factors are driving this growth, including the datafication and the increased needs for computational power and storage drove up by technological trends such as Internet of Things (IoT), Data & Analytics, Artificial Intelligence (AI) and – particularly – blockchain and video streaming. In 2019, data centres immersion cooling market was valued at US$177 million (M), but the market is expected to grow at a Compound Annual Growth Rate (CAGR) of 23.2% in the reference period 2019-2024 and reach an estimated market size of US$500 million by 2024.”

We agree with the statement by the DSs that immersion cooling is not a technology which is currently developed in the EU, but 2-PIC is necessary for next generation data centres and is required to promote the use of next generation computing technologies in the EU. Alternate technologies such as 1-PIC are suitable today but they are inferior to 2-PIC, which makes them unsuitable for the next generation computing technologies.

Therefore, banning the fluorinated gases on which 2-PIC solutions depend will risk restricting investment in the EU in this fast-growing strategic industry, as data centre providers will choose to locate their future data centres where the best available technology is accessible, such as the US and China. Currently, the top five global computing hyperscalers have future capacity under development which will more than double their installed capacity of 10 070 megawatts (MW).[235] Banning fluorinated gases will not only exclude strategic investment in this future technology in Europe, impacting the European economy but also European sovereignty, as storage and processing of European data is shifted to countries outside of the EU. For data centres which are unable to move (e.g. because they have low signal latency requirements and hence must be local to their customers), banning F-gases will simply prevent them from participating in the transition to next generation computing technology.

This is especially relevant when additional regulation, such as the EU Code of Conduct on Data Centre Energy Efficiency will set clear requirements for data centres forcing energy efficiency improvements to curb growing consumption.[236]
Note that if data centres relocate outside of the EU, emissions will still take place. Computing power will still be needed, but in countries with potentially less stringent environmental policies, maintenance practices and emission controls as in the EU despite using the newest cooling technology.

One of the top data center providers in the world, Microsoft, made public announcements on its support for immersion cooling as a way to reach their sustainability goals: “This year we achieved a major milestone in liquid cooling R&D, making Microsoft the first cloud provider that is running two-phase liquid immersion cooling in a production environment, demonstrating viability for broader use in our data centres. Our latest research in liquid cooling addresses the concept of overclocking, which is to operate chip components beyond their pre-defined voltage, thermal and power design limits to further improve performance. Based on our tests, we’ve found that for some chipsets, the performance can increase by 20% through the use of liquid cooling. This demonstrates how liquid cooling can be used not only to support our sustainability goals to reduce and eventually eliminate water used for cooling in datacenters, but also generate more performant chips operating at warmer coolant temperatures for advanced artificial intelligence (AI) and machine learning workloads. Because of the efficiencies in both power and

[235] https://www.datacenterknowledge.com/manage/2023-these-are-world-s-12-largest-hyperscalers#close-modal
[236] https://joint-research-centre.ec.europa.eu/scientific-activities-z/energy-efficiency/energy-efficiency-products/code-conduct-ict/code-conduct-energy-efficiency-data-centres_en

cooling that liquid cooling affords us, it unlocks new potential for datacenter rack design. In short, liquid cooling paves the way for more densely packed servers in smaller spaces, meaning increased capacity per square foot in a datacenter – or the ability to create smaller datacenters in more strategic locations in the future. This adds to the benefits of waterless cooling design."[237]

As 2-PIC is the **only technology** enabling the development of the next generation computing technology and data centres in the EU, it is a vital building block of European policy objectives to support the digital transformation.

2-PIC is also a key technology to support water policies by helping data centres dramatically reduce water usage. The white paper "2-Phase Immersion Liquid Cooling: How Data Centers Could Save 300 Billion Liters of Water Per Year" sheds light on the benefits of two-phase immersion cooling for water consumption and underlines that "When it comes to savings, there is simply no other solution that consumes less water and electricity than 2-PIC."[238] In fact, air cooled data centres consume hundreds of billions of gallons of water, while in many cases 2-PIC can nearly eliminate direct water consumption in data centres. Water usage in data centres was recently highlighted in an article which stated "With drought spreading around the globe, battles are emerging between data center operators and adjacent communities over local water" Many of these locations are in Europe including Spain, Italy, Ireland, where large data centres are being built but water may be scarce. The same article highlights that "every short conversation of 20 to 50 questions and answers with ChatGPT – an artificial intelligence tool – represents about 500 milliliters of water." Challenges with water use can be addressed by 2-PIC with fluorinated fluids which enables waterless or near waterless cooling.

Furthermore, 2-PIC allows higher computing power in a condensed space. 2-PIC data centers will also have a significantly smaller physical footprint,[239,240,241] which contributes to the goals of (EU) 2018/841 on the inclusion of greenhouse gas emissions and removals from land uses well as reducing resource consumption of building materials and embodied carbon in infrastructure.

THE CURRENT REGULATIONS ARE THE BEST TOOLS TO MANAGE F-GASES AND MINIMIZE THEIR EMISSIONS

The Dossier Submitters conclude that the F-gas Regulation (FGR) is insufficient to manage the risks associated with F-gases. The conclusion appears to be based on two arguments: that the FGR "does not per se restrict the use of the substances but rather aims for a reduction of their use" and that the current

[237] Walsh, N. (2023). Supporting our customers on the path to net zero: The Microsoft cloud and decarbonization. *The Official Microsoft Blog*. https://blogs.microsoft.com/blog/2021/10/27/supporting-our-customers-on-the-path-to-net-zero-the-microsoft-cloud-and-decarbonization/

[238] Liquid Stack & Data Tank. (2022). 2-Phase Immersion Liquid Cooling: How Data Centers Could Save 300 Billion Liters of Water Per Year. *Liquid Stack*. https://liquidstack.com/white-papers/data-centers-could-save-300-billion-liters-water

[239] Major J., Padilla F. & Slyziuk E. et al. (2022). Two-phase liquid immersion cooling 2022 case study. *LiquidStack*. https://liquidstack.com/case-studies/two-phase-liquid-immersion-cooling-2022-case-study

[240] LiquidStack & Chemours. (2022). Two-Phase vs Single-Phase Immersion Cooling Fluids: Deconstructing Myths with Science. *LiquidStack / Chemours*. https://liquidstack.com/white-papers/fluorinated-cooling-fluids-101

[241] https://www.opencompute.org/events/past-events/2018-ocp-global-summit

FGR does not regulate all fluorinated gases fulfilling the DSs' PFAS definition. Rather, they argue a REACH restriction is required because that would limit as many uses as practically possible and thereby minimise F-gas emissions (and hence exposures), cover current and future F-gases, and prevent regrettable substitution. Derogations are proposed for "some key applications of fluorinated gases [where] alternatives are not yet available."

We believe this conclusion is unfounded. F-gases are already strictly regulated under the current Regulation 517/2014 (FGR)[242]. It establishes a phasedown schedule for HFCs – consistent with a substitution objective of the proposed REACH restriction – as well as stringent provisions to require training and certification of technicians and to minimize leakages throughout the lifecycle of the F-gases. The Commission Proposal to review the F-gas Regulation ("Commission Proposal")[243] currently under discussion extends the containment, training and certification, and recovery measures to Annex II – Section I F-gases (HFOs and HCFOs). The Commission Proposal therefore addresses the principal concerns expressed by the Dossier Submitters about the suitability of using the FGR to manage F-gases and the risks associated with them. As a result, Chemours considers that the F-gas regulation is the best tool to manage F-gases and reduce their emissions and has the necessary measures in its current version and the revision proposals by the commission and council to achieve this. Further details are presented in Attachment 1 section 1.5. The rest of this submission will focus on other issues raised by the proposed restriction.

VERY LOW LEAK RATES OF TWO-PHASE IMMERSION COOLING SYSTEMS

2-PIC is an inherently low emission application. 2-PIC systems do not operate under pressure, but rather the pressure inside the tank is maintained near atmospheric levels, which drastically reduces the risk and the extension of vapour leaks. Typical evaporative losses in 2-PIC tanks are only about 1-2% (of the total fluid amount in the tank) per year,[244] while some OEM manufacturers claim values of 0.85% per year, thanks to well-sealed tanks and short maintenance intervals. 2-PIC tanks are maintained and operated by highly trained professionals, in industrial-like settings, so better operating practices and low evaporative losses are more likely. Two-phase immersion fluids also operate at relatively low temperatures of about 50°C to 80°C and are highly stable within the system, significantly increasing the longevity of the fluid.

Two-phase immersion fluids, like all F-gases, are highly recyclable and can be easily cleaned and repackaged - while also demonstrating a long lifetime and consequently potential for full circularity. Due to high cost and sensitivity of servers to contaminants, two-phase immersion fluids are kept in pristine conditions with filtration and desiccant systems, further increasing the fluid life and recyclability compared to other F-gas applications.

Assuming that at the end of the currently operating data centers' useful life (estimated at 12 years) the new constructions were to transition to 2-PIC technology, applying a current-technology leak rate of

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[242] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006;

[243] Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014;

[244] LiquidStack & Chemours. (2022). Two-Phase vs Single-Phase Immersion Cooling Fluids: Deconstructing Myths with Science. *LiquidStack / Chemours*. https://liquidstack.com/white-papers/fluorinated-cooling-fluids-101

0.85% for all installations would represent 556 tons annual emissions on average between 2025 and 2055 (and 1 111 tons in 2055).

NEED FOR DEROGATIONS FOR IMMERSION COOLING SYSTEMS AND MAINTENANCE

On the basis that the FGR is deemed insufficient to manage the risks of F-gases, the DSs propose a general ban on the use of F-gases, except in a limited number of “key” applications where they conclude alternatives are not yet available and hence derogations are required.

In the immersion cooling domain specifically, the DSs propose no derogations, in which case the use of PFAS in immersion cooling would be banned from 1.5 years after EiF in new systems.

We believe this would impose disproportionate costs on existing users of immersion cooling, such as data center providers. This is because the ban fails to take into account that F-gas-based immersion cooling systems which are already in use at this point could be expected to remain in use for many years afterwards. The ban would prevent the servicing and maintenance of existing F-gas immersion cooling systems, and potentially of the data centres themselves, with expected economic and environmental costs.

Derogation 5i proposed by the DSs explicitly relates to the servicing of existing HVACR equipment which uses F-gases:

- maintenance and refilling of existing HVACR equipment put on the market before [18 months after EiF] and for which no drop-in alternative exist until 13.5 years after EiF.

The DSs propose this derogation because of “the lack of drop-in alternatives means that equipment that would currently need servicing including some top up of refrigerant levels could not be repaired. Added costs would arise from the premature retirement of existing equipment, the early purchase of replacement equipment and added environmental burdens from disposal of equipment.”

It is not clear why the same argument was not recognized for immersion cooling (which is considered as an “other application” under the applications for fluorinated gases, E.2.8.2.8). We agree with the DSs’ view on the need to allow the maintenance and refilling of existing HVACR equipment but argue that it applies equally to other F-gas-based systems which are already installed such as immersion cooling.

However, in the next section we present analysis which demonstrates that F-gas-based 2-PIC immersion cooling is significantly cheaper than cooling using other substances and technologies. This performance difference is a fundamental result of the difference in properties between F-gases and other fluids and it will be extremely challenging to close this gap (and it might not even be possible). Hence it is argued the current ban on the future use of F-gases in immersion cooling would result in disproportionate costs to society.

COST EFFECTIVENESS OF NON-FLUORINATED IMMERSION COOLING SYSTEMS IN DATA CENTERS

The European Commission has noted that data centers alone will consume 5% to 9% of the global electricity consumption, and hence that data centres need to become more energy efficient. [245] Despite this, the DSs did not share any cost effectiveness calculations of the use of 2-PIC compared to a traditional air-cooling in data centres, or to the proposed 1-PIC alternatives, which are not suitable to enable the development of the next generation computing technology and data centres. But publicly available information demonstrates the high energy consumption of traditional air-cooled technology, resulting in terawatts of additional energy consumed if the best-in-class 2-PIC technology were to be banned.

In 2018, energy consumption by data centres in the EU was 76.8 TWh[246]. This is estimated 104.7 TWh by 2025, growing at an estimated growth rate (2010-2018) of 4.5% which will be further driven by the growth of AI with tools such as ChatGPT. As a result, the proportion of global energy supply dedicated to computing power is estimated to increase from 1-2% in 2018 to around 8-21% in 2030. Increases in energy efficiency will be vital to help mitigate the rise in energy consumption by data centers, which cannot be achieved by air cooling.

Power usage effectiveness (PUE) is the common standard for measuring the energy efficiency of data centers, with lower PUE indicating higher the energy efficiency. PUE has recently reached a plateau due to the efficiency limitation of air-cooling technologies, which is the predominant technology currently in most data centres. “For a decade, data centers made great progress reducing PUE levels. From 2007 to 2017, the average PUE in data centers fell from 2.5 to 1.58. Unfortunately, data center PUE has flatlined since. According to the Uptime Institute’s Global Data Center Survey 2021, the average data center PUE globally is now 1.57. This means facility functions add nearly 60% to the energy use of IT.”[247] The problem is getting worse as servers and chips become more and more powerful, rejecting more heat: “Even with optimized energy efficiency, the amount of power required to cool data centers with air-cooling is still increasing.”[248]

2-PIC has the best-in-class PUE compared to alternative technologies for data center cooling, as Table D.3 below outlines in detail.[249] An average PUE of 1.7 achieved by air cooling with chillers (see table below) means that for every 100 MW of power consumed by data centers, an additional 70 MW of power consumption is necessary for cooling. Other air-cooling technologies, such as water-side and direct evaporative cooling, result in a lower PUE factor (increase energy efficiency) but may increase water consumption. For cold plate technology, cooling power consumption is 8% (8 MW per 100 MW of heat from servers) for an average PUE of 1.08. For 1-PIC (single-phase immersion cooling), the cooling power is reduced to 5% (5 MW per 100 MW of heat from servers), but still more than double of what 2-PIC can achieve, at only 2% (2 MW per 100 MW of heat from servers) of cooling power or a PUE of 1.02. The Table D.3 below also shows that the maximum server cooling capacity - or the most heat that can be removed by the cooling technology - is greater than 4kW for 2-PIC. In case of 1-PIC, it is limited to 2kW, which means that a data center for 1-PIC would need at least twice as many immersion tanks as one designed

[245] https://digital-strategy.ec.europa.eu/en/policies/green-cloud
[246] https://www.ucc.ie/en/eri/news/data-centres-a-view-from-europe.html
[247] https://liquidstack.com/blog/why-data-center-efficiency-gains-have-stalled-since-2018
[248] https://liquidstack.com/blog/why-data-center-efficiency-gains-have-stalled-since-2018
[249] Misra, P. A., Manousakis, I., Choukse, E. et al. (2022). Overclocking in immersion-cooled data centers. *IEEE Micro, 42(4), 10–17*. https://doi.org/10.1109/mm.2022.3163107

for 2-PIC. The adoption of 2-PIC will play a critical role in dramatically increasing data centers' energy efficiency (decrease PUE) and reducing the size of data centre buildings.

Table D.3. Comparison of the Main Data Center Cooling Technologies' PUE.

Cooling Technology	Average PUE	Peak PUE	Server Fan Overhead	Max Server Cooling
Chillers (Air Cooled)	1.70	2.00	5%	700 W
Water-Side (Air Cooled)	1.19	1.25	6%	700 W
Direct Evaporative (Air Cooled)	1.12	1.20	6%	700 W
CPU Cold Plates	1.08	1.13	3%	2 kW
1-PIC	1.05	1.07	0%	2 kW
2-PIC	1.02	1.03	0%	>4 kW

The articles "Cost-Efficient Overclocking in Immersion-Cooled Data Centers", "Thermal Performance of Single-Phase and Two-Phase Immersion Cooling in Data Center", "Overclocking in Immersion-Cooled Datacenters", and "Bringing 2-Phase Immersion Cooling to Hyperscale Cloud" all show the energy efficiency and cooling performance advantages of 2-PIC over single-phase immersion cooling technologies. [250,251,252,253] Higher energy efficiency (lower PUE) will result in lower cooling energy consumption translating into lower indirect CO_2 emissions due to cooling.

Using the information above and assuming that at the end of the currently installed data centers' useful life (estimated at 12 years) the new constructions were not to transition to 2-PIC technology, the additional cooling power of the currently used cooling technology versus using 2-PIC would represent 1 753TWh between 2025-2055 and 112.9TWh in 2055 representing an additional energy cost of 498bn € between 2025-2055 and 32bn € in 2055.[254]

The increased energy consumption of the currently used cooling technology of a water-based immersion cooling systems versus a 2-PIC can be translated into increased CO2 emissions. At an estimated CO2 intensity of 238g/KWh[255] and cost of carbon permits of 95 €/CO_{2e}[256] /ton, using the same transition rate assumption as above, if the new constructions were not to transition to 2-PIC technology the estimates value of the increased emissions represent: 39.6bn € between 2025-2055 and 2.6bn € in 2055.

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[250] Majid, J., Manousakis, I. & Goiri, I. (2021). Cost-Efficient Overclocking in Immersion-Cooled Datacenters. *Microsoft*. https://www.microsoft.com/en-us/research/uploads/prod/2021/04/Zissou-Overclocking-ISCA21.pdf

[251] Misra, P. A., Manousakis, I., Choukse, E. et al. (2022). Overclocking in immersion-cooled datacenters. *IEEE Micro, 42(4), 10–17*. https://doi.org/10.1109/mm.2022.3163107

[252] Liu, C. K. & Chang, T. Y. (2022). Thermal Performance of Single-Phase and Two-Phase Immersion Cooling in Data Center.*17th International Microsystems, Packaging, Assembly and Circuits Technology Conference (IMPACT)*, doi: 10.1109/IMPACT56280.2022.9966684. https://ieeexplore.ieee.org/document/9966684

[253] Raniwala, A. (2022). Bringing 2-Phase Immersion Cooling to Hyperscale Cloud. *2022 Optical Fiber Communications Conference and Exhibition (OFC)*. https://ieeexplore.ieee.org/document/9748792

[254] https://www.euronews.com/next/2023/03/29/energy-crisis-in-europe-which-countries-have-the-cheapest-and-most-expensive-electricity-a

[255] https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-13#tab-googlechartid_chart_11

[256] https://tradingeconomics.com/commodity/carbon

Summary of the cost effectiveness of non-fluorinated immersion cooling systems in data centers

The total additional cost in the case of a ban on the use of F-gases in immersion cooling (2-PIC) can be summarised in the following way:
Current technology versus 2-PIC:

- 497.7 bn € additional energy costs
- 39.6M € CO_{2e} emissions
  Total: 537.3bn € additional costs between 2025-2055 and 34.6 bn € in 2055

Emission reduction and cost of a ban to reduce emissions

The emission reduction and cost of a ban to reduce emissions can be estimated as follow:

Emission reduction:

- Using Chemours suggested estimate emission level 2025-2055: 556 tons per year as shown in Table D.4

Costs of a ban:

- 31.2 M € on average between 2025-2055 per ton of emission reduction using the Chemours suggested emissions

Table D.4: Emission projection in tons
Emissions with Chemours suggested leak rates

	2025	2030	2035	2040	2,045	2050	2055
PFAS emissions per year	0	196	409	572	714	891	1,111
PFAS emissions over the 5-year period	385	1,398	2,436	3,132	3,907	4,875	
Total emissions over the period 2025-2055	17,245						

These calculations demonstrate that a switch to non-fluorinated data centre cooling systems would result in significant costs in terms of energy consumption, and also total EU energy requirements and impacts of carbon emissions and that the socio-economic cost of the emissions reduction would be disproportionate.

SAFETY CONSIDERATIONS OF 1-PIC

Single-phase immersion technologies primarily use hydrocarbon-based oils or, sometimes, fluorinated substances with high boiling points (usually above 130°C) as immersion fluids. Although section 2.11 on page 396 of Annex E, table E.128, notes mineral oils, synthetic oils, natural oils, & hydrocarbon fluids as alternatives to fluorinated fluids in immersion cooling, these alternatives have significant shortcomings such as flammability, high viscosity, combustibility, ignition risk, and potential safety issues if a system leaks. Along those lines, oils present a risk to the employees servicing and interacting with the systems, as they are difficult to clean up in the event of spills. Due to their high viscosity, they pose a slip hazard that is not easily mitigated in a data centre environment and makes for challenges in server maintenance. High viscosity fluids also impact energy consumption since they are harder to pump and, as a result, require more energy to circulate the oil that cools the chips.

Given that electronics themselves are an ignition source, the application of combustible immersion fluids, such as non-fluorinated oils, in cooling technologies for data centres can pose a significant fire risk, which makes them less than optimal for this application and could increase hazard insurance and fire protection/extinguishing costs.

The article "Approaching the Heat Limit with Liquid Immersion Cooling" discusses some of the shortcomings of the single-phase "non-fluorinated" oils in detail, such as combustibility (low flash point) as well as lower heat transfer coefficients.[257] More details regarding the shortcomings of oils, listed as alternatives, are explored in the white paper "Two-phase vs single-phase immersion cooling: Deconstructing myths with science".[258]

COST-EFFECTIVENESS OF ADDITIONAL F-GAS BASED IMMERSION COOLING SYSTEM MEASURES

Despite their low leak rates (between 1-2%), the proper maintenance of immersion cooling tanks is critical in enabling reduced leak rates and promoting circularity. This would require the implementation of mandatory leak checks on tanks and mandatory technician training and certification of immersion cooling tank maintenance technicians.

Adequate maintenance and handling of tanks during data center maintenance can support maintaining and improving the lows leak rate of immersion cooling applications. Furthermore, once systems are installed and as the technology matures and the fouling of components/fluids reduces, there will be virtually no reason to open the systems and the maintenance intervals will become longer and longer reducing the leak rates to a very low estimated number such as 0.1%.

The simplicity of the systems compared to legacy technologies will require few technician trainings and therefore result in a de minimis cost.

Impact on emissions

The current emission rate would result in emissions of 1111 tons in 2055. These emissions can be further reduced by the measures implemented above to 131 tons per year in 2055. These measures will come at no additional cost to the users.

[257] TMGcore. (2022). Approaching the Heat Limit with Liquid Immersion Technology. *Data Center Frontier*. https://www.datacenterfrontier.com/data-center-cooling/whitepaper/21437208/tmgcore-approaching-the-heat-limit-with-liquid-immersion-technology

[258] LiquidStack & Chemours. (2022). Two-Phase vs Single-Phase Immersion Cooling Fluids: Deconstructing Myths with Science. *LiquidStack / Chemours*. https://liquidstack.com/white-papers/fluorinated-cooling-fluids-101

In summary the emissions of F-gases can be better handled by alternative RMMs at a lower cost to the European society:

- DS proposal in 2055: EUR 31.2M per ton of emission reduction based on our estimated emission calculation.
- Chemours proposal in 2055: 88% emission reduction at no additional cost to the users.

SUMMARY AND CONCLUSIONS

- Attachment 1, Chapter 1 demonstrates that all F-gases (current and future) fulfilling the PFAS definition used by the Dossier Submitters should be exempted from the scope of this restriction because there is no risk to be addressed at EU level. This consideration also applies to the persistent degradation products of F-gases, such as TFA, for which the risks for both human health and the environment are de minimis.
- Even if this is not accepted, the cost of a ban would be disproportionate. Additional risk management measures, such as additional leak checks and technician training and system design improvements, should be implemented to further minimize emissions. Emissions can be reduced by close to 90% by 2055 at no additional cost.
- If the DSs still wish to pursue their derogation-based approach, the derogations are too short and the socio-economic consequences of a ban would be disproportionate compared to the environmental benefit of a restriction:
- The total additional cost of a ban to the European society equates to 537.3 bn € between 2025 and 2055;
    - Energy consumption of data centers can be reduced by more than 90% compared to the currently used technology;
    - Water consumption of data centers can nearly be eliminated with the implementation of immersion cooling technology;
    - Data center physical footprint can be reduced by 60% with the implementation of 2-PIC compared to air cooled technologies;
    - With a ban on 2-PIC, the competitiveness of the European data center sector is at risk.
    - Cost per ton of emissions saved in 2055 is disproportionate:
        - EUR 31.2M per ton of emissions reduction based on Chemours estimated emissions.

Therefore, the following derogations will be required to avoid disproportionate socio-economic impacts on society.

- Existing equipment using F-gas technologies:

  Existing two-phase immersion cooling equipment which uses F-gases cannot be retrofitted to use alternative refrigerants. Therefore, a ban on F-gases would prevent this equipment being serviced and maintained, and lead to premature retirement. **A permanent derogation** is therefore justified to avoid the unnecessary costs of replacing this equipment. (This justification was used by the Dossier Submitters for their proposed derogation 5i, although this derogation was time-limited and restricted to existing HVACR equipment only.)

- Two-phase immersion cooling applications:
  Two-phase immersion cooling based on F-gases is the technology which will support the next generation of data centers and electric vehicle powertrain thermal management. Alternatives are far less effective and would result in significant increases in energy use and cost. A ban on F-gases in these applications would also encourage investment in these key strategic technologies to divert to countries where they can still be used. **A derogation** for F-gases in this application is therefore justified.

  <u>It is not possible to specify a meaningful (evidence-based) time-limited derogation/transition period because it is not clear that alternatives can ever be economically competitive. Hence the costs of a ban are expected to remain disproportionate for the foreseeable future.</u>

- Cold plate technology:
  Although cold plate technology based on F-gases is an interim solution that will be required to support the data center market in transitioning from air cooled systems to immersion cooling systems, there are significant technical and cost challenges, which will force deselection long term. To allow an effective transition to alternative technologies such as 2-PIC, we defer to the recommendations of the sector experts.

ANNEX: IMMERSION COOLING COMMENTS ON ANNEX E

Referring to table E.90 on page 269 of Annex E concerning the use of ammonia as a refrigerant in chillers to produce cold air, the table notes that ammonia may be able to be used for large data center applications, however, ammonia is not a reasonable substitute for many locations due to toxicity and flammability considerations. Additionally, ammonia has additional requirements to be used due to the toxicity and the inherent nature of large ammonia leaks. The additional requirements can result in significant added costs and may be a driver to de-select European countries as an area to build future data centers.

The following health related risks are recurringly mentioned as limiting factors for the use of ammonia:

- Strong odor and irritant (make people panic due to water solubility on wet body parts (eyes, breathing ways…)
- Lighter than air, generating concerns related to propagation in case of leak
- Corrosive: Non-compatible with copper and zinc (+others)
- Toxicity: Even so-called “low-charge ammonia” systems, promoted as a safe alternative, have a charge that is high enough to trigger fatal consequences if they appear, and while reducing the charge does lower the potential impact of an incident, it does not eliminate it
- Machine rooms need to be construct following tough rules (EN378-3 chapter 5):
  - Atex mechanical ventilation
  - Atex leak detection with 2 thresholds coupled with a safety shut down system to disrupted energy feed to all non-atex materials inside the machine room
  - The floor needs to be sealed
  - The water waste collecting need to be monitored with automatic shut off valves to avoid environment contamination in case of leakage

    - Depending on quantities on site declaration/authorization's are required to operate delivered by authorities (ICPE in France)
    - Controls and strict follow up
    - Specific trainings for staff

Moreover, ammonia systems are constrained by several National and European regulations:

- As an example: the applicable regulation in France greatly limits Ammonia potential adoption across applications:
    - ICPE "code de l'environnement"
    - Working code
    - Public establishment regulation
    - Arrêté 20/11/2017
    - PED + CTP
- Similarly, the below regulation limits use of ammonia also in the EU:
    - EN378-1 to 4
    - PED 2014/68/UE
    - Machine directive 2006/42/CO
    - Low tension 2006/95/CE
    - Electromagnetique compatibility 2004/108/CE

When examining the Tyson plant as a case study for ammonia usage, where a pipe weld in the plant ruptured and filled the room with ammonia gas, it is evident that ammonia is not a feasible alternative as prolonged exposure has been proven deadly in high doses.[259]

Table E.90 on page 269 also notes low charge hydrocarbon systems as another viable technology. In this case, hydrocarbons could be used to some capacity, but low charge hydrocarbon-based systems may require more units and inevitably lead to higher electrical consumption than even traditional air-cooled systems utilizing fluorinated solutions fulfilling the OECD 2021 PFAS definition. Chillers used in air cooled data centers are large and hydrocarbons are not a refrigerant option due to significant risk of higher refrigerant charges. The table does not include the inherent benefits of immersion cooling technologies either single phase or two phase.

In both cases, Ammonia and hydrocarbons are only used in chiller for air-cooled systems which will not adequately address the energy efficiency and next generation computing challenges faced by the data center market. Chillers, however, are not required in 2-PIC systems.

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[259] https://www.cnn.com/2023/05/04/business/tyson-ammonia-leaks-invs/index.html

E. High Temperature Heat Pump and Organic Rankine Cycle application submission

INTRODUCTION

Heat pump technology is well-established for commercial and residential applications, district heating, and industrial processes with heat supply temperatures up to 70 to 80°C or slightly above.

High-temperature heat pump (HTHP) technology is much less established with limited commercially available units. For the 100–200°C heat supply range where 27% of industrial process heat demand exists[260], Arpagaus et al.[261] identified many promising HTHP applications, including drying, thermal separation and preservation in the food, paper, chemical, metal and plastic manufacturing sectors, that currently rely on steam heating from fossil fuel boilers.

According to the International Energy Agency (IEA), around 46% of the total energy used for heat is used by industry[262], which means approximately 17 EJ, and this is increasing year over year. Moreover, up to 2.8% of industrial energy consumption is wasted as low-grade heat below 100 °C[263]. HTHPs based on vapour compression cycles[264] are able to capture this waste heat and convert it into a high-grade, over-100 °C heat, useful for several industrial processes[265].

The value of a HTHP is to recover wasted heat from a low-temperature heat source and raise it to higher temperature level, where it can be re-used for valuable processes or electricity production. HTHPs provide much more than the direct conversion of electric power to heat by traditional heat pumps, by allowing to re-use heat which would otherwise be lost. HTHPs do this at a fraction of the operating costs of using fossil fuel to accomplish the same function.

High temperature heating applications, such as heating hot water, steam production, and various manufacturing processes (pasteurization, drying, sterilization, distillation, and many others) commonly utilize fossil fuels. This affects numerous industries, like chemical, paper, food, and manufacturing, which have temperature demands from 100 - 200 °C [266].

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[260] Adamson, C. *et al.* (2022) 'High-temperature and transcritical heat pump cycles and advancements: A review", Renewable and Sustainable Energy Reviews, 167. https://doi.org/10.1016/j.rser.2022.112798
[261] Arpagaus, C. *et al.* (2018) 'High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials', *Energy*, 152, pp. 985–1010. https://doi.org/10.1016/j.energy.2018.03.166.
[262] https://www.sciencedirect.com/topics/engineering/international-energy-agency
[263] https://www.sciencedirect.com/science/article/pii/S2213138822000418#b0010
[264] https://www.sciencedirect.com/topics/engineering/vapor-compression
[265] Arpagaus, C. *et al.* (2018) 'High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials', *Energy*, 152, pp. 985–1010. https://doi.org/10.1016/j.energy.2018.03.166.
[266] Hamid, K. et al. (2023) 'Potential evaluation of Integrated High Temperature Heat Pumps: A review of recent advances', Applied Thermal Engineering, 230, p. 120720. https://doi.org/10.1016/j.applthermaleng.2023.120720.

Organic Rankine cycle (ORC) also makes use of low temperature industrial waste heat but for electricity generation rather than converting this waste heat into a higher heat output, as in the case of HTHPs[267,268].

THE CURRENT REGULATIONS ARE THE BEST TOOLS TO MANAGE F-GASES AND MINIMIZE THEIR EMISSIONS

The Dossier Submitters conclude that the F-Gas Regulation (FGR) is insufficient to manage the risks associated with F-gases. The conclusion appears to be based on two arguments: that the FGR "does not per se restrict the use of the substances but rather aims for a reduction of their use" and that the current FGR does not regulate all fluorinated gases fulfilling the DSs' PFAS definition. Rather, they argue a REACH restriction is required because that would limit as many uses as practically possible and thereby minimise F-gas emissions (and hence exposures), cover current and future F-gases, and prevent regrettable substitution. Derogations are proposed for "some key applications of fluorinated gases [where] alternatives are not yet available."

We believe this conclusion is unfounded. F-gases are already strictly regulated under the current Regulation 517/2014 (FGR)[269]. It establishes a phasedown schedule for HFCs – consistent with a substitution objective of the proposed REACH restriction – as well as stringent provisions to require training and certification of technicians and to minimize leakages throughout the lifecycle of the F-gases. The Commission Proposal to review the F-gas Regulation ("Commission Proposal")[270] currently under discussion extends the containment, training and certification, and recovery measures to Annex II – Section I F-gases (HFOs and HCFOs). The Commission Proposal therefore addresses the principal concerns expressed by the Dossier Submitters about the suitability of using the FGR to manage F-gases and the risks associated with them. As a result, Chemours considers that the F-gas regulation is the best tool to manage F-gases and reduce their emissions and has the necessary measures in its current version and the revision proposals by the commission and council to achieve this. Further details are presented in Attachment 1, section 1.5. The rest of this submission will focus on other issues raised by the proposed restriction.

VERY LOW LEAK RATES OF HTHP AND ORC SYSTEMS

Industrial equipment such as HTHP and ORC are highly monitored and maintained systems that can achieve very low leak rates. The typical leak rate of HTHP is around 1% as described by Zielerbauer et al

[267] Ochoa, G.V., Isaza-Roldan, C. and Duarte Forero, J. (2020) 'Economic and exergo-advance analysis of a waste heat recovery system based on regenerative organic Rankine cycle under organic fluids with low global warming potential', Energies, 13(6), p. 1317. https://doi.org/10.3390/en13061317.

[268] Velanparambil Ravindran, R., Huang, M.J. and Hewitt, N. (2023) 'Design and modelling of a small-scale reversible high-temperature heat pump—organic Rankine Cycle System for industrial waste heat recovery', International Journal of Low-Carbon Technologies, 18, pp. 482–493. https://doi.org/10.1093/ijlct/ctad038.

[269] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006;

[270] Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014;

(Life cycle assessment and shadow cost of steam produced by an industrial-sized high-temperature heat pump[271]).

ALTERNATIVES FOR HTHP AND ORC

One of the most important factors to consider when designing a heat pump compression system[272] is the fluid employed. Not all refrigerants can be used in HTHPs due to their technical limitations, temperature ranges and safety considerations.

Key selection criteria are thermal stability, high critical temperature, low critical pressure, low pressure ratio, low GWP and safety (low flammability and toxicity). Other key factors include efficiency, cost, availability, oil suitability (and mixture properties) and material compatibility.

The thermodynamic properties of most fluids used in refrigeration systems and low temperature heating are not suitable for high temperature applications[273]. They are typically constrained by the required compressor technology given the very high pressure operating conditions.

HFC-245fa and HFC-134a, are still predominantly used in HTHPs and ORCs, but today the focus is shifting to lower GWP refrigerants such as R-718 (water), R-744 (CO2), R-717 (ammonia), hydrocarbons (isobutane R-600a, n-pentane R-601) and hydrofluoroolefins (HFOs and HCFOs) such as HFO-1336mzzZ, HFO-1336mzzE and HFO-1233zdE[274].

In Annex E p 248, the DS state: "For industrial heat pumps the main market is using fluorinated gases, but this could easily be replaced with natural refrigerant alternatives that provide higher efficiency. There may potentially be situations or processes, however, where the continued use of fluorinated gases is required." We disagree with the statement made by the DSs and, in this document, we will demonstrate that fluorinated gases cannot be easily replaced with natural refrigerants and that we estimate approximately 50% of the HTHP and ORC market can only be addressed with F-gas based HTHPs and ORCs.

Further on page 247, it is stated that "No universal non-PFAS refrigerant is suitable for all applications up to about 230 °C. However, the hydrocarbons butane (R600), iso-butane (R600a), pentane (R601) and heptane (R603) are applicable solutions..." However, hydrocarbons have large constraints linked to their inherent flammability , which limit their utilisation in specific industries and configurations.

HFOs are recommended as the substitute of HFCs in heat pumps due to their similar thermodynamic properties combined with negligible GWP. Some HFOs are drop-in substitutes for the existing HFCs (R245fa and R365mfc), allowing them to be used with existing technologically developed solutions without any modification.

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[271] Zeilerbauer, L. et al. (2023) 'Life cycle assessment and shadow cost of steam produced by an industrial-sized high-temperature heat pump', Sustainable Production and Consumption, 40, pp. 48–62. https://doi.org/10.1016/j.spc.2023.06.016.

[272] https://www.sciencedirect.com/topics/engineering/compression-system

[273] High Temperature Applications - an overview | ScienceDirect Topics

[274] Malavika, S. et al. (2021) 'Performance optimization of a heat pump for high temperature application', Materials Today: Proceedings, 46, pp. 5278–5285. https://doi.org/10.1016/j.matpr.2020.08.639.

HFOs enable high energy efficiency system operation. Mateu-Royo et al. compared eight advanced cycle configurations and nine refrigerants. HFO-1336mzzZ resulted in the highest COP increase compared to all other alternatives including R-601 (n-penthane)[275].

Water (R-718)

Though water (R-718) presents 100 times higher latent heat than HFC-134a, making it an attractive option for temperatures higher than 150 °C, the density of water vapour is relatively low when compared to other working fluids. Therefore, large compressors or high-speed compressors will be required to transfer the equivalent mass flow compared to what a smaller compressor would do with other working fluids.[276]

Water also has a high compressor discharge temperature for a given pressure lift, which limits the type of compressor, its material and lubricant. Since the compressor is typically a major contribution to the overall investment cost of the heat pump installation, this has a high impact on the economic performance of a water based HTHP.[277,278]

Ammonia (R-717)

R-717 (Ammonia) is a known refrigerant with good thermodynamic properties. But R-717 is toxic at even very low concentrations and the output temperature for HTHPs using ammonia is limited to below 100 Deg C, and coupled with a high pressure of 60 bars, hence limiting ammonia's range of application.

Aside from the high compressor discharge temperature and pressure, ammonia also has challenges in the type of materials used in the system, since ammonia reacts with copper in the presence of water. This limits the material type selection available for ammonia heat pumps.
All these factors limit the use of ammonia in HTHPs[279].

The use of ammonia and water in a 2-stage heat pump would provide an energy-efficient, but complex and therefore costly alternative to the operation of a 1-stage heat pump with a fluorinated refrigerant.

CO2 (R-744)

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[275] Hamid, K. et al. (2023) 'Potential evaluation of Integrated High Temperature Heat Pumps: A review of recent advances', Applied Thermal Engineering, 230, p. 120720. https://doi.org/10.1016/j.applthermaleng.2023.120720.
[276] Bamigbetan, O. et al. (2017) 'Review of vapour compression heat pumps for high temperature heating using natural working fluids', International Journal of Refrigeration, 80, pp. 197–211. https://doi.org/10.1016/j.ijrefrig.2017.04.021.
[277] Bamigbetan, O. et al. (2017) 'Review of vapour compression heat pumps for high temperature heating using natural working fluids', International Journal of Refrigeration, 80, pp. 197–211. https://doi.org/10.1016/j.ijrefrig.2017.04.021.
[278] https://doi.org/10.18462/iir.gl.2018.1367 Hlsdorf, B., Schlemminger, C. and Bantle, M. (2018) Design recommendations for R-718 heat pumps in high temperature... Available at: https://doi.org/10.18462/iir.gl.2018.1367.
[279] Jiang, J. et al. (2022) 'A review and perspective on industry high-temperature heat pumps', Renewable and Sustainable Energy Reviews, 161, p. 112106. https://doi.org/10.1016/j.rser.2022.112106.

Carbon dioxide R-774 does not have the required thermodynamic properties for being used in subcritical conditions, but researchers have found out its potential in the transcritical range. Transcritical HPs with R-744 as a refrigerant are more commonly used in the lower temperature ranges. There are few studies[280] that have investigated transcritical cycles with heat sinks above 100 °C, they are not commonly mentioned in the literature, and are still at the developmental stages. They are not commercially available today.

Technology readiness is at the early stages and needs to address several challenges relating to Transcritical HTHP technology, and most of which centre around the compressor before this technology could be commercialized:

- Requires the refrigerant to be compressed to extreme pressures, the high compression ratio making use of current compressor technology difficult;
- Requires identification of efficient refrigerants beyond CO2, as a refrigerant (blends) to maximise COP while keeping within pressure limits;
- Needs larger heat transfer surfaces[281] that impacts the compressor power and therefore the COP of the HTHP with higher cost of ownership;
- Requires a lubricant that is miscible with the refrigerant. A potential solution is oil-free compressors but this often comes with a sacrifice of isentropic efficiency (ratio of actual power to the power produced by the same equipment with 100% efficiency) [282], and therefore a higher cost of ownership.

From all above it can be concluded that R-744 is not a valid option for HTHP above 100°C, and there is no indication today that the technology will be able to develop to make CO2 a viable HTHP fluid.

Hydrocarbons

Some hydrocarbons (HCs) such as R-290, R-600, R-600a, and R-601 seem good candidates in HTHPs but with the limiting factor of high flammability which will restrict their field of application in large scale industrial applications. Based on safety concerns, the charge size of HCs will in many cases be a seriously limiting factor, making it impossible for many large-scale applications.[283]

This shows the importance of A1 refrigerants (no flame propagation) for reducing hazards. All flammability definitions and their use limitations and constraints are detailed in the ASHRAE Standard 34.

50% OF THE HTHP POTENTIAL MARKET CAN ONLY BE ADDRESSED BY F-GASES

All non-fluorinated alternatives have limitations, which are preventing their implementation especially in high temperature applications:

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[280] Adamson, K.-M. et al. (2022) 'High-temperature and transcritical heat pump cycles and advancements: A Review', Renewable and Sustainable Energy Reviews, 167, p. 112798. https://doi.org/10.1016/j.rser.2022.112798.

[281] https://www.sciencedirect.com/topics/engineering/heat-transfer-surface

[282] https://www.sciencedirect.com/topics/engineering/isentropic-efficiency

[283] Hamid, K. et al. (2023) 'Potential evaluation of Integrated High Temperature Heat Pumps: A review of recent advances', Applied Thermal Engineering, 230, p. 120720. https://doi.org/10.1016/j.applthermaleng.2023.120720.

- Hydrocarbons are classified as A3 fluids (highly flammable, potentially explosive), which limits the range of applications across the industry;
- Ammonia (R-717) can be **used up to 90 Deg C sink temperature** (for higher temperatures, existing compressor technology is limited due to high discharge pressures). Safety precautions must be implemented due to toxicity (B2L class), which is also limiting the application range;
- CO2 (R-744), is **common in smaller sizes**. The nature of the refrigerant (the low critical temperature of 31C and high critical pressure of 73.6 bar) limits CO2 heat pumps to a narrow range of applications;
- Water (R718), due to its **low density requires expensive/complex equipment** (several compressor stages / large compressor stages / high-speed oil-free turbo compressors with high flow rate and low-pressure ratio). For the above reasons It has only been applied in limited application.

These limitations prevent the alternatives to offer universal solutions for HTHP, especially when it come to the high temperatures, above 150 Deg C.

Real applicability of alternatives to F-Gases to different applications can also be drawn from the studies conducted by OST, Arpagaus et al. (2018[284], 2020[285]).
For example, Propane is not included since its critical temperature is too low for the chosen application (evaporation temperature: 60 Deg C, condensation temperature: 130 Deg C).

Figure E.1 from the Ost submission to the REAH restriction (#3975), which displays a benchmarking of the volumetric heat capacity of the heat pump and the coefficient of performance. The higher the COP, the higher the energy efficiency and performance. The higher the Volumetric heat capacity and the lower the system cost.

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[284] Arpagaus, C. *et al.* (2018) 'High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials', *Energy*, 152, pp. 985–1010. https://doi.org/10.1016/j.energy.2018.03.166
[285] Mateu-Royo, C. et al. (2021) 'Advanced high temperature heat pump configurations using low GWP refrigerants for Industrial Waste Heat Recovery: A Comprehensive Study', Energy Conversion and Management, 229, p. .

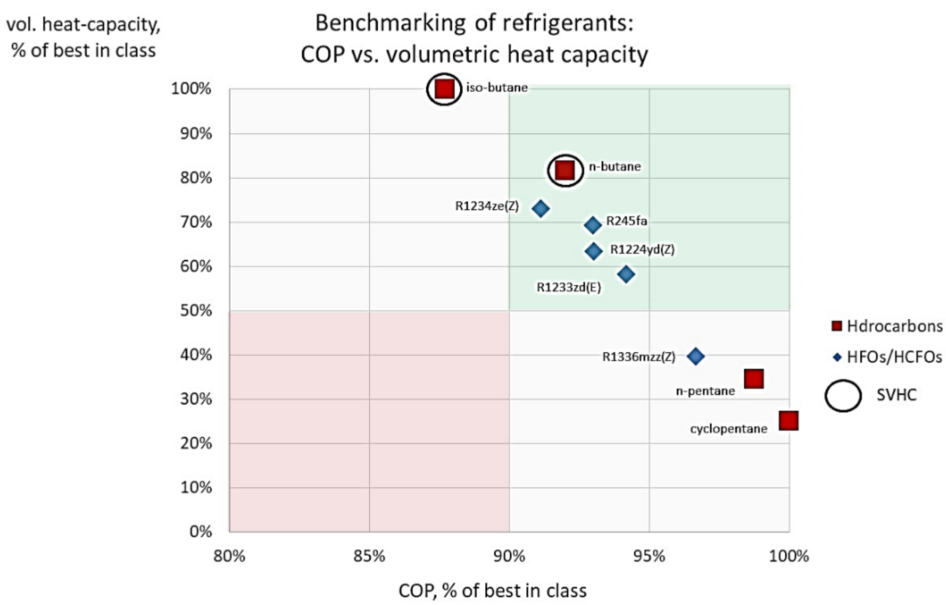
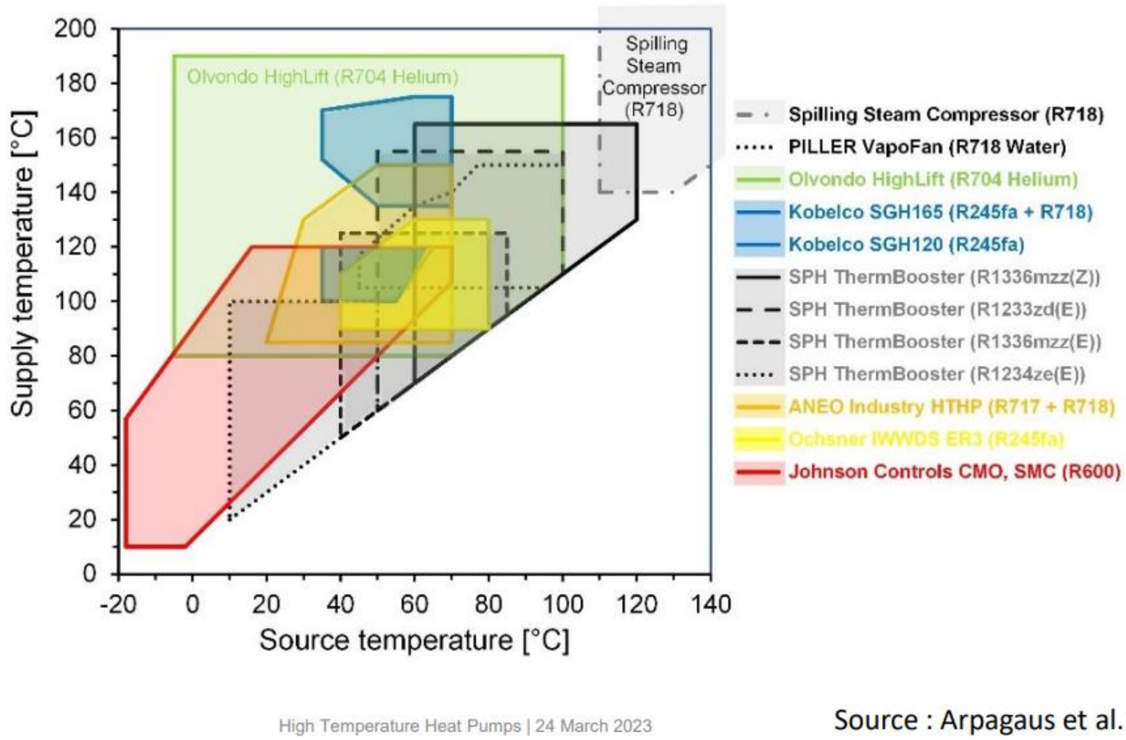


Figure E.1: benchmarking of the volumetric heat capacity of the heat pump and the coefficient of performance

Although hydrocarbons cover a range of capacities and COPs, in each case a trade-off is introduced between performance and cost (n-butane has only an acceptable performance, but a low cost and cyclopentane has a high performance but a high cost).

Figure E.2[286] shows the uniqueness of HFOs for HTHPs when the high temperature of the source is considered and how the operating range (determined by the physical limits of the components) of HFOs (grey boxes) is broader than the other existing technologies (Olvondo Helium HTHP is early stage developmental, limited and the economics have not yet been demonstrated).

[286] https://www.sweet-decarb.ch/fileadmin/downloads/Presentations_File/04_Overview_of_HTHP_technologies_24_March_2023.pdf



Source : Arpagaus et al. 2023

Figure E.2: Operating ranges of potential HTHP fluids

Considering all the refrigerant selection criteria that are discussed above: high efficiency (COP), safety (low flammability, low toxicity), low GWP, technology readiness and attractive economics, F-gases and HFOs today and in the future are the best suited choice for HTHPs. Looking at the balance of properties between COP and volumetric heating capacity[287], Frate et Al demonstrate in their study that HFOs "resulted as the best compromise fluid in all configurations"[288] compared to any alternatives.

HFOs exhibit the best balance of properties and cost, they also offer a retrofit solution for existing HTHP and ORC equipment presently containing HFC-245fae. This is critical to allow the use of the currently developed technology without incurring development costs to transition to non-flammable ultra-low GWP solutions. The implementation can also be faster using the existing technology when a non-flammable solution is required.

HTHP is an emerging application, which is still in flux in the choice of the mainstream technology. It is therefore difficult to evaluate the size of the market that is only addressable by F-gases. Given the excellent performance of F-gases, the incumbent position of F-gases in the current HTHP technology, level of technological uncertainty of certain alternatives and the industry expert statements that HFOs offer the best compromise fluid, in our expert judgment, we estimate the market share that is only addressable by HFOs to be approximately 50% of the total market.

[287] https://www.sciencedirect.com/topics/engineering/volumetrics

[288] Frate, G.F., Ferrari, L. and Desideri, U. (2019) 'Analysis of suitability ranges of high temperature heat pump working fluids', Applied Thermal Engineering, 150, pp. 628–640. https://doi.org/10.1016/j.applthermaleng.2019.01.034.

JUSTIFICATION FOR DEROGATIONS FOR HTHP AND ORC SYSTEMS AND MAINTENANCE

On the basis that the FGR is deemed insufficient to manage the risks of F-gases, the DSs propose a general ban on the use of F-gases, except in a limited number of "key" applications where they conclude alternatives are not yet available and hence derogations are justified. In the stationary HVACR domain and HTHP and ORC specifically, the DSs propose no derogations.

Therefore, the DSs submitters propose to ban the use of PFAS in HTHP and ORC from 1.5 years after EiF (HVACR applications).

Derogation 5i proposed by the DSs explicitly relates to the servicing of existing HVACR equipment which uses f-gases:

- maintenance and refilling of existing HVACR equipment put on the market before [18 months after EiF] and for which no drop-in alternative exist until 13.5 years after EiF

Based on the available data we consider that the derogations proposed by the dossier submitter are not sufficiently wide to avoid disproportionate impacts to society. In addition, the derogations which are suggested are too short to allow substitution to take place in a cost-effective manner.

However, in the next section we present analysis which demonstrates that F-gas-based HTHP (which we are using as a proxy for ORC which is based on the same fundamental principles) is significantly cheaper than using other substances and technologies. The performance gap between F-gases and non-fluorinated alternatives requires trade-offs that technological advancements might, in certain cases be able to bridge (technology in flux). However, achieving this is likely to be extremely difficult, or extremely costly, and there may remain fundamental limits which prevent the gap from being closed completely. Hence it is argued the current ban on the use of F-gases in HTHPs (and also ORCs) would result in disproportionate costs to society which are unlikely to be reduced by technical innovation.

COST-EFFECTIVENESS OF NON-FLUORINATED HTHP SYSTEMS

A study estimates that the total potential latent heat that could be utilized and upgraded by industrial heat pumps is 28.37 TWh/yr in the EU in 2023. This corresponds to about 15% of the heat consumption within the two temperature bands (100-150 and 150–200 Deg C), and about 1.5% of the total heat consumption.[289] This market is forecasted to grow at 5.4% per year[290]. The potential in 2025 will be 31.5 TWh and in 2055, the total potential market is estimated to be 152.5 TWh for the 100-200 Deg C HTHP bands.

[289] https://www.sciencedirect.com/science/article/pii/S1359431118376087#:~:text=The%20results%20of%20this%20analysis,of%20the%20total%20heat%20consumption.

[290] https://www.gminsights.com/industry-analysis/industrial-heat-pump-market

With an assumed 50% of the market that cannot be addressed by non-fluorinated alternatives in the case of a ban, in 2025 an estimated 15.7 TWh/yr of potential available latent heat will be wasted without F-gas HTHP systems, and 76.3 TWh in 2055.
The performance of this technology allows to estimate the net return of a HTHP to be 75% of the available energy (it requires the equivalent of 25% of the energy used to operate the heat pump). With an average cost of electricity at 28.4 Euro cents[291] / kWh the estimated energy cost of a ban would be EUR 254.9bn between 2025-2055 and EUR 16.2bn in 2055.

Emission reduction and cost of a ban to reduce emissions:

The emission reduction and cost of a ban to reduce emissions can be estimated as follow:

Emission reduction:

- Using the Chemours suggested estimate emission level 2025-2055: 25 tonnes per year as shown in Table E.1, which is already a very low level of emissions.

Cost of a ban:

- EUR 326.3 million (M) on average between 2025-2055 per tonne of emission reduction using the Chemours suggested emissions;
- in 2055: EUR 326.3M per tonne of emission reduction using the Chemours suggested emissions.

Table E.1: Emission projection in tonnes

Emissions with Chemours suggested leak rates

	2025	2030	2035	2040	2045	2050	2055
Installed volume in HTHP	1,028	1,337	1,739	2,262	2,942	3,827	4,978
PFAS emissions per year	10	13	17	23	29	38	50
PFAS Emissions over the 5-year period	57	74	97	126	164	213	
Total emissions over the period 2025-2055	781						

These calculations demonstrate that a ban of F-gases in HTHP and ORC applications right after the transition period would have a significant cost in terms of energy consumption and result in foregone energy savings due to the lack of alternatives to address about 50% of the HTHP market, and that the socio-economic cost of the emissions reduction would be disproportionate. The level of emissions of the HTHP systems is very low, which result is a very high cost of a ban due to the large energy saving that can be generated through the use of HTHP and ORC systems. This would also have a negative impact on the European sustainability objectives of reaching climate neutrality by 2050 and supports the decarbonization of the energy sector.

291 https://www.euronews.com/next/2023/03/29/energy-crisis-in-europe-which-countries-have-the-cheapest-and-most-expensive-electricity-a

COST-EFFECTIVENESS OF ADDITIONAL F-GAS-BASED HTHP AND ORC MEASURES

The previous analysis has demonstrated that a ban on the use of F-gases in Stationary HVACR would be extremely costly, both in itself and in terms of the amount of PFAS emissions which it would save. Although the current level of emissions in HTHP and ORC is very low, Chemours believes that further emissions reduction can be achieved more cost effectively through the mandating of simple good-housekeeping measures into HTHP and ORC system maintenance and recovery regimes. These conditions could be included in the proposed REACH restriction or form part of an extension to some other relevant legislation. In this section, we will demonstrate how such measures could be a cost-effective way of reducing PFAS emissions to a fraction of what they are today by 2055. These measures fall under five headings:

1. Reclaim end-of-life/circularity
2. Leak-testing
3. Leak rate certification
4. Technician certification
5. System architecture

The DSs consider industrial heat pumps, which include HTHP as an HVACR application (mentioned in section 2.8.2.2 Annex E). The measures proposed above are detailed in the Attachment 2, Stationary HVACR application submission and we will only share a summary of the impact on emissions and the cost to reduce emissions for HTHP and ORC applications. The detailed measures can be found in the Attachment 2, stationary HVACR application submission.
In fact, given a relatively small number of systems in the market, we estimate the actual cost to implement these measures will be de minimis.

Impact on emissions

The current emissions rate of 1.0% would result in average annual emissions of 25 tonnes in EEA between 2025-2055 as shown in Table E.1 above. These emissions can be further deceased by the measures implemented above. In the Attachment 2, Stationary HVACR application submission, we request to implement leak rate reduction targets from a 40% leak rate reduction 4.5 years after EiF to an 80% leak reduction 8.5 years after EiF resulting in an average leak rate of 0.4% for Stationary HVACR. Since HTHP and ORC are highly monitored and maintained systems, we estimate that the HTHP and ORC industry will be able to achieve the average stationary HVACR leak rate of 0.4% per year, 9 years after EiF . This is estimated to approximately represent emissions of only 20 tonnes in 2055 at no additional cost.

In summary the emissions of F-gases can be better handled by alternative RMMs at a lower cost to the European society:

- DS proposal in 2055: EUR 326.3M per tonne of emission reduction based on our estimated emission calculation.
- Chemours proposal in 2055: 60% emission reduction from a very low base at no additional cost to the users.

SUMMARY AND CONCLUSIONS

- Attachment 1, Chapter 1 demonstrates that all F-gases (current and future) fulfilling the PFAS definition used by the Dossier Submitters should be exempted from the scope of this restriction because there is no risk to be addressed at EU level. This consideration also applies to the persistent degradation products of F-gases, such as TFA, for which the risks for both human health and the environment are de minimis.
- Even if this is not accepted. The cost of a ban would be disproportionate. Additional risk management measures, such as enhanced inspection intervals, technician training and system design improvements, should be implemented to further minimize emissions. Emissions (which are already at a low level) can be reduced by as much as 60% by 2055 at no additional cost.
- If the DSs still wish to pursue their derogation-based approach, the derogations are too short and the socio-economic consequences of a ban would be disproportionate compared to the environmental benefit of a restriction:
    - The total additional cost to the European society equates to € 254.9bn between 2025 and 2055;
    - 76.3 TWh waste heat will not be able to be converted and transformed into useful energy due to the lack of a technical solution after the ban of F-gases
    - Without the use of HFOs, many European sustainability objectives could be at risk
    - Cost per tonne of emissions saved in 2055 is disproportionate:
        - EUR 326.3M per tonne of emission reduction based on Chemours estimated emission calculation;

- Therefore, the following derogations will be required to avoid disproportionate socio-economic impacts on society.

    - Existing equipment using F-gas technologies:
      Existing industrial high temperature heat pumps and organic Rankine cycle equipment which uses F-gases cannot be retrofitted to use alternative refrigerants. Therefore, a ban on F-gases would prevent this equipment being serviced and maintained, and lead to premature retirement. **A permanent derogation** is therefore justified to avoid the unnecessary costs of replacing this equipment. (This justification was used by the Dossier Submitters for their proposed derogation 5i, although this derogation was time-limited and restricted to existing HVACR equipment only.);

    - Industrial high temperature heat pumps and organic Rankine cycle applications:
      HFOs already offer energy efficient solutions for a broad range of HTHP technology across the different temperature and application requirements, without the problems exhibited by alternatives, such as narrow range of application or high flammability. We assume that 50% of waste heat cannot be recovered without the use of F-gases; this would result in significant increases in energy use and cost. **A derogation** for F-gases in this application is therefore justified.

      It is not possible to specify a meaningful (evidence-based) time-limited derogation/transition period because it is not clear that alternatives can ever be economically competitive. Hence the costs of a ban are expected to remain disproportionate for the foreseeable future.

F. Fire Suppressants application submission

USES, SUB-USES, AND EMISSION CONTROL

F-gases, when used as fire extinguishing agents, provide performance above and beyond standard code requirements. As fire suppressants, F-gas extinguishing agents are an additive, elective technology. The phase-out of halon migrated many fire protection applications to alternative, non-fluorinated technologies.[292] As such, where users can shift to alternative technologies, they have already done so. F-gas extinguishing agents, however, remain a relevant and necessary technology to protect those hazards where the risk of loss or downtime outweighs the significant added cost of F-gases and the performance limits of non-fluorinated alternatives.

The broad range of applications and the unique requirements of individual facilities– such as data centers, control rooms, commercial aviation, or museums and other facilities with historic or high value assets– makes it very challenging to claim that an alternative non-PFAS technology is viable across a general use category. Even application categories, such as data centers, each have unique criteria and requirements for the fire protection technology.

EMISSIONS AT END-OF-LIFE

At the end of a fire suppression system's operating life, the F-gas extinguishing agent is recovered, recycled, and reused to support new or existing fire suppression systems. As experienced with halon, the globally installed base of F-gas fire systems is actively recovered and recycled to support new and existing critical systems, limiting emissions and releases of agent for decades in a circular product life cycle. [293,294]

PERFORMANCE BENEFITS

F-gas fire extinguishing agents are superior to alternatives, especially in terms of efficiency and asset protection. F-gas fire extinguishing agents act extremely quickly, in ten seconds or less, and as non-reactive gases, they do not interact with the critical assets being protected. Stored as a compressed liquid, fluorocarbon extinguishing agents have a low weight and small space profile, giving them particular

[292] UN Environment Programme (2018). *Montreal Protocol on Substances the Deplete the Ozone Layer Report of the Halons Technical Options Committee 2018 Assessment Report*. https://ozone.unep.org/sites/default/files/assessment_panels/HTOC_assessment_2018.pdf
[293] https://www.nist.gov/system/files/documents/el/fire_research/R0601303.pdf
[294] https://www.harc.org/_files/ugd/4e7dd1_64188eee6f554bf5966fbd24f97b552a.pdf

advantage in small operational areas, common in many applications such as aviation, military vehicles, and data centers for example.[295,296,297,298]

SAFETY & SUSTAINABILITY BENEFITS

The sole purpose of F-gas fire extinguishing agents is the safety of people and critical assets in the event of a fire. These fire systems hold the F-gas in a contained system and is only dispensed during a fire event. The system, which can last decades, is regularly serviced as required by code to ensure that the F-gas agent does not leak and the system is prepared and ready for a fire event.[299] [300] This circular, life and property saving technology is critical and represents a very low emissive application.

NO EQUIVALENT ALTERNATIVES

Since the phase-out of halon, the development of new substances in the fire protection sector has been intensively pursued. Applications that can use alternatives have already been converted. Despite more than 30 years of research however, viable alternatives have not yet been found for certain, mission-critical applications. This is because existing alternatives have proven limitations that restrict their application areas. To date, F-gas technology provides the only molecules with sufficient safety, appropriate physical properties, and efficacy. Existing alternatives do not provide the balance of requirements for applications where size/weight and effectiveness are critical. Fluorinated fire suppression systems are therefore chosen, specifically to protect high-value assets, critical operations, and people where alternative options are unacceptable. [301,302]

[295] Bein, D. A Review of the History of Fire suppression on U.S. DOD Aircraft*. National Institute of Standards and Technology.* https://www.nist.gov/system/files/documents/el/fire_research/R0601290.pdf
[296] https://www.fire.tc.faa.gov/Systems/LAVEX/MPS
[297] Mazzone, R. et al. Halon Replacement in Airplane Lavatory Trash Receptacle Extinguishers. *Boeing Commercial Airplane Group.* Available at: https://www.nist.gov/system/files/documents/el/fire_research/R0200474.pdf
[298] Gann, R. (1995) Fire Suppression System Performance of Alternative Agents in Aircraft Engine and Dry Bay Laboratory Simulations*. National Institute of Standards and Technology*. https://www.govinfo.gov/content/pkg/GOVPUB-C13-7531177ea5b318343149ab43649374e1/pdf/GOVPUB-C13-7531177ea5b318343149ab43649374e1.pdf
[299] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=2001
[300] https://www.iso.org/standard/79444.html
[301] UN Environment Programme (2018). *Montreal Protocol on Substances the Deplete the Ozone Layer Report of the Halons Technical Options Committee 2018 Assessment Report.* https://ozone.unep.org/sites/default/files/assessment_panels/HTOC_assessment_2018.pdf
[302] McCormick, S. and Clauson, M. *US Army Ground Vehicle Compartment Halon Replacement Program.* https://www.nist.gov/document/r0002178pdf

SOCIO-ECONOMIC ANALYSIS

F-gas extinguishing agents remain an additive, elective technology for protecting hazards where the risk of loss to human life, property, or business continuity, exceeds the significant added cost of this technology. The use of alternative technologies that do not provide an equivalent balance of features and characteristics increases the likelihood of loss of high-value or irreplaceable assets and/or disruption of ongoing operations of critical infrastructure. It can also jeopardize the safety of people in and around these operations. These socio-economic costs may not be quantifiable but are incredibly important to consider.

The implementation of the F-gas Regulation in Europe has reduced the supply of F-gas extinguishing agents in Europe, and future supply will further decline year over year. This dynamic, in addition to the technical challenges, reduces the incentives for developing new products. Eliminating the use of F-gas extinguishants exposes many sectors of the European market to the risk of being disrupted in future fire incidents at critical facilities.

Review of environmental impact of the proposed derogation for fire suppressants:

The F-gas regulation phase-down schedule has already reduced the future use of fluorinated agents in new fire suppression systems to critical uses. Both the F-gas phasedown and Kigali Amendments will continue to reduce new supplies of F-gas fire suppressing agents to the market over time. Limiting the release of extinguishing agents from installed systems while actively recovering and recycling the agent at the end of useful life increases the utility value of these materials and further reduces potential emissions. As experienced with halon, the globally installed base of F-gas fire systems is actively recovered and recycled to support new and existing critical systems, limiting emissions and releases of agent for decades in a circular product life cycle. [303,304] Eliminating the responsible use of the agents removes the market for recycling and destroys value-in-use and promotes unnecessary and irresponsible releases to atmosphere.

F-gases have been commercialized as replacements for ozone-depleting substances such as chlorofluorocarbons (CFCs) and halons. The development of these chemicals for use in fire and explosion suppression applications has been instrumental in achieving the accelerated halon production phase-out mandated by the Montreal Protocol on Substances that Deplete the Ozone Layer. The remaining applications for this technology are critical applications where the limitations of lower cost alternatives outweigh any potential risk. As cited by the fire protection industry, the industry fully supports the goal of minimizing non-fire emissions of fire protection agents and is committed to continuing to contribute to both ozone layer and climate change mitigation[305]. The overriding concern is to reduce the risk to people and property from the threat of fire through the use of products and systems that have been proven to be effective.

[303] https://www.nist.gov/system/files/documents/el/fire_research/R0601303.pdf

[304] https://www.harc.org/_files/ugd/4e7dd1_64188eee6f554bf5966fbd24f97b552a.pdf

[305] https://www.nist.gov/system/files/documents/el/fire_research/R0201304.pdf

CONCLUSION

The use of F-gas fire extinguishing agents remains a critical requirement for some applications despite existing regulatory pressures eliminating use in non-critical applications. As such, there are remaining fire applications where alternative technologies are insufficient to provide the necessary fire and life safety for critical facilities and assets to allow for a safe and successful transition to alternative technologies, and we defer to the recommendations of the sector experts.

G. Propellants application submission

FUNCTIONALITY

There are many ways to propel a product from a container, however, fluorochemical aerosol technologies provide several benefits to the final product performance and safety, as well as customer experience that cannot easily be matched using only non-fluorinated propellants or other dispersion technologies.[306,307,308]

Given their safety and formulating flexibility, HFCs are used in formulations to reduce volatile organic compound (VOC) emissions from hydrocarbons, improving ground air quality. In addition to their non or low flammability, HFCs are noted for their exceptionally low odor and good solvency. They are used to make less flammable colognes and perfumes, especially for essential oil that may precipitate high molecular weight resins in ethanol/hydrocarbon blends or pure hydrocarbon systems. HFCs also work well with many surfactant systems to stabilize aerosol foams, allowing them to be rubbed out on use and not resist liquefaction.[309]

In aerosol dusters, F-gas propellants are used as a single component to clean electronics and computer equipment. In particular, HFC-134a is the preferred choice when flammability is of concern in such aerosol applications, as it is non-flammable. These applications generally include cleaning and lubricating sprays for machinery where there is a risk of ignition. For applications requiring a completely non-flammable propellant, HFC-134a and HFC-227ea are currently the sole choices.

Along the same lines, table E.102 on page 304 of Appendix E references propellants used as carrier fluids and considers the option of a longer derogation period based on technical needs. It is important to consider that for this application there are no alternatives available that are non-flammable and provide a similarly high-performance.

ALTERNATIVES

While the Annex E claims that alternatives to F-gas propellants are widely available, there are currently no equivalent non-fluorinated alternatives or dispersion technologies available that would adequately meet the safety, performance, and customer experience requirements for propellants. The challenge is the compromise that is required to use an alternative, considering aspects such as flammability, toxicity, flow performance, or product application.

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[306] Sanders, P.A., (1979). Handbook of Aerosol Technology, 2nd edition, Van Nostrand Reinhold Co.
[307] Shepherd, H.R., (1961). Aerosols: Science and Technology, *Interscience*.
[308] Guomin, J., et. al., (1998) Aerosol Propellant Handbook, *Cosmos Books*.
[309] Nelson, Thomas P & Wevill, Sharon L. (1990) Aerosol Industry Success in Reducing CFC Propellant Usage *US EPA Air and Engineering Research Laboratory*. EPA/600/S2-89/062.

Disadvantages of alternatives to the PFAS propellants (HFC-134a, HFC-227ea, HFO-1234zeE) include the following:[310,311,312]

The PFAS propellants (HFC-134a, HFC-227ea, HFO-1234zeE) provide valuable advantages over compressed gas systems employing air, nitrogen, nitrous oxide, or carbon dioxide. PFAS propellants are employed in the form of a compressed liquefied gas, which provides a constant container pressure and hence consistent spray characteristics and product performance until all of the contents have been discharged. In the case of the compressed gas propellants, the container pressure decreases rapidly with product use, changing the characteristics and performance of the delivered spray. As the pressure in the container drops, the rate of spray delivery drops and the spray becomes increasingly coarser. Compressed gas propellants also produce wetter and less forceful sprays. The solubility of compressed gas propellants in liquids is so small that they rarely produce sprays of a fine particle size, and their use is hence limited to the delivery of coarse sprays or liquid streams.

The PFAS propellants HFC-134a and HFC-227ea offer the advantage of being nonflammable. Alternatives such as hydrocarbon propellants, HFC-152a and the PFAS propellant HFO-1234zeE are flammable. The PFAS propellants, and the non-PFAS propellant HFC-152a, are not classified as volatile organic compounds (VOCs), an additional advantage over the hydrocarbon propellants.

CONCLUSION

To summarize, propellants are needed in technical aerosols for applications where non-flammability and high technical performance of sprays are required. All propellants using F-gases exhibit a lack of available and feasible alternatives to allow for a safe and successful transition to alternative technologies, and we defer to the recommendations of the sector experts.

[310] Sanders, P.A., (1979). Handbook of Aerosol Technology, 2nd edition, Van Nostrand Reinhold Co
[311] Shepherd, H.R., (1961). Aerosols: Science and Technology, *Interscience*.
[312] Guomin, J., et. al., (1998) Aerosol Propellant Handbook, *Cosmos Books*.

H. Medical Devices application submission

USES, SUB-USES, AND EMISSION CONTROL

For respiratory drugs there are currently two inhaler systems commonly in use: (Pressurized) Metered Dose Aerosol Inhalers, *(p)MDI,* and Dry Powder Inhalers, *DPI*. MDI inhalers are among most commonly prescribed pulmonary treatments around the world,[313] as they are often the best option for many patients (e.g. panicking patients, elderly or young children) and reliable in dosage per use. While MDIs dispense the active ingredient autonomously through fluorinated propellants (e.g., HFC-134a, HFC-227ea) into the respiratory tract, DPIs require a strong lung pull by the patient to apply the necessary amount of active ingredient in the appropriate particle size.

F-gases are also used as solvents to clean medical equipment. For example, F-gases are critical to meeting the stringent cleanliness standards required for medical implant throughout the manufacturing and assembly process and before use/implantation.

PERFORMANCE BENEFITS

When discussing MDIs, patients tend to prefer an easier to use inhaler system, as provided by MDIs.[314] MDIs provide consistent use for patients through their easy-handling design (active agent dispensing instead of strong long pull). The MDI delivered dose is independent of inspiratory effort at a time when patients are struggling to breathe. This is why MDIs are often the best option for many patients (e.g. panicking patients, elderly or young children).[315]

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[313] Ohnishi, K. et al. (2022) Medical and Chemical Technical Options Committee: 2022 Assessment Report, *UN Environment Programme Ozone Secretariat*, pp. 252. https://ozone.unep.org/system/files/documents/MCTOC-Assessment-Report-2022.pdf.

[314] Nakanishi, Y. et al. (2022). Association Between Patient Preference for Inhaler Medications & Asthma outcomes: *J Asthma Allergy* https://www.dovepress.com/association-between-patient-preference-for-inhaler-medications-and-ast-peer-reviewed-fulltext-article-JAA.

[315] Baron C, Shur J (Apr 2022). Investigating the Propellant Pathways Leading to a Sustainable Future for MDIs. *ONdrugDelivery*, *pp. 131, 49-52*. https://ondrugdelivery.com/wp-content/uploads/2022/04/Pulmonary-Nasal-ONdD-Apr-2022-Issue-131-LoRes.pdf

SAFETY AND SUSTAINABILITY BENEFITS

The safety and benefits of MDI usage has been confirmed through extensive toxicological tests.[316] As CFCs have been successfully phased out in the Montreal Protocol, HFC-based inhalers have been proven as an effective solution, maintaining the affordability, reliability, and performance of the previous-generation MDIs.

In making the switch from CFC inhalers to HFC inhalers, companies have also removed the emissions of ozone depleting substance.[317]

NO EQUIVALENT ALTERNATIVES

While DPIs could be considered an alternative to MDIs, they are not a viable or effective solution for many patients because they[318,319,320,321,322,323,324]

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[316] Emmen, H. H. et al. (2000) Human safety and pharmacokinetics of the CFC alternative propellants HFC 134a (1,1,1,2-tetrafluoroethane) and HFC 227 (1,1,1,2,3,3, 3-heptafluoropropane) following whole-body exposure. *Regulatory toxicology and pharmacology, pp. 32(1), 22–35*. https://doi.org/10.1006/rtph.2000.1402

[317] Montreal Protocol on Substances that Deplete the Ozone Layer (2018) Report of the Medical and Chemical Technical Options Committee 2018 Assessment Report, *UN Environment Programme*. https://ozone.unep.org/sites/default/files/2019-04/MCTOC-Assessment-Report-2018.pdf

[318] Jones, R. et al. (2017) The comparative effectiveness of initiating fluticasone/salmeterol combination therapy via pMDI versus DPI in reducing exacerbations and treatment escalation in COPD: a UK database study, International *Journal of Chronic Obstructive Pulmonary Disease, pp. 12, 2445–2454*. https://doi.org/10.2147/COPD.S141409.

[319] Ming S. et al. (2017) P274 Comparison of the initiation of COPD treatment with licensed FDC ICS/LABA treatments in terms of disease control and cost effectiveness*, Thorax, Vol 72, A232*. https://thorax.bmj.com/content/72/Suppl_3/A232.1.

[320] Muraki M et al. (2017) Which inhaled corticosteroid and long-acting β-agonist combination is better in patients with moderate-to-severe asthma, a dry powder inhaler or a pressurised metered-dose inhaler?, *National Library of Medicine, Vol 24(1), pp 1395–1400*. https://pubmed.ncbi.nlm.nih.gov/28929816/

[321] Hojo M et al. (2016) Comparison of the clinical effects of combined salmeterol/fluticasone delivered by dry powder or pressurized metered dose inhaler. *National Library of Medicine, Vol 37, pp 43–48*. https://pubmed.ncbi.nlm.nih.gov/26898348/

[322] Kerwin E. M. et al. (2017). Pharmacokinetics, pharmacodynamics, efficacy, and safety of albuterol (salbuterol) multi-dose dry-powder inhaler and ProAir® hydrofluoroalkane for the treatment of persistent asthma: results of two randomized double-blind studies. *National Library of Medicine, Vol 36(1), pp 55–65.* https://pubmed.ncbi.nlm.nih.gov/26541599/.

[323] Bjermer L. (2014) The importance of continuity in inhaler device choice for asthma and chronic obstructive pulmonary disease. Respiration; international review of thoracic diseases. *National Library of Medicine, pp. 88(4), 346–352.* https://doi.org/10.1159/000363771.

[324] Muraki M et al. (2017) Which inhaled corticosteroid and long-acting β-agonist combination is better in patients with moderate-to-severe asthma, a dry powder inhaler or a pressurised metered-dose inhaler? *National Library of Medicine, Vol 24(1), pp 1395–1400*. https://pubmed.ncbi.nlm.nih.gov/28929816/.

- Are not suitable for emergency inhalers since it requires a strong lung pull by the patient, rendering them unusable by patients with reduced lung function;[325]
- Have proven ineffective and not viable especially in the cases of young children and elderly patients;
- Do not provide the immediate delivery of medication to the respiratory tract that MDI can deliver;
- Cannot be used by people who experience lactose intolerance, as they contain small doses of lactose.

A new HFC propellant, HFC-152a is being considered as drop-in alternative and Annex E claims that HFC-152a will be available on the market starting in 2025. This timeline is too ambitious, when taking into account the current challenges for market release and up-scaling, such as the time needed for formulation development / approval / implementation and potentially necessary inhaler design updates.

SOCIO-ECONOMIC ANALYSIS

The proposed regulation is based on an assumption that there are no cost implications for industry or authorities to successfully implement replacements. This is unrealistic and inaccurate.

While HFC-152a is in the process of approvals, few pharma manufacturers have announced the initiation of formulation and development efforts. Progressing all various formulations through the European approval process in the proposed 18-month period is near impossible due to:

- The complex approval process and number of formulations required to be processed;
- The uncertainty of long-term regulatory framework;
- The high cost of transition;
- The risk of being unable to recoup cost in the current health care environment.

For an effective switch, an inhaler must not only be cost effective but also appropriate to the needs of the patient. Therefore, technical alternatives are not feasible for bridging a transition period as young children, elderly, panicking, and/or disabled patients have challenges using DPIs.[326,327]

Review of environmental impact of the proposed derogation for medical devices:

It is critical that an appropriate time frame is granted to overcome transition challenges, such as developing the various formulations without compromising patient care. The proposed regulation with

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[325] Montreal Protocol on Substances that Deplete the Ozone Layer (2018) Report of the Medical and Chemical Technical Options Committee 2018 Assessment Report, *UN Environment Programme*. https://ozone.unep.org/sites/default/files/2019-04/MCTOC-Assessment-Report-2018.pdf.
[326] Attar-Zadeh, D. et al. (2021) Health-care Resource Requirements and Potential Financial Consequences of an Environmentally Driven Switch in Respiratory Inhaler Use in England *Journal of Health Economics and Outcomes Research, pp. 8(2), 46–54.* https://doi.org/10.36469/001c.26113
[327] Wilkinson A., et al. (2018) Costs of switching to low global warming potential inhalers. An economic and carbon footprint analysis of NHS prescription data in England. *BMJ Open*. https://bmjopen.bmj.com/content/9/10/e028763.

an 18-month transition phase is not feasible. The full period of transition, based on previous experience, could require more than ten years to complete with a well-coordinated, globally driven, industry effort.

CONCLUSION

The proposed 18-month derogation creates a significant risk for patients seeking critical, life-sustaining treatments. The timeframe suggested does not take into account the necessary time to complete a transition as the transition from CFCs to HFCs took well over ten years to complete with a globally driven effort. To define the appropriate transition from HFC-134a and HFC-227ea to HFC-152a, we defer to the recommendations of the sector experts.

I. Solvents application submission

USES, SUB-USES, AND EMISSION CONTROL

Solvents are used in a variety of applications, such as carrier fluids, heat transfer fluids, and critical cleaning. Fluorinated solvents play a major role in:

- Temperature control of semiconductor manufacturing processes
- In extremely specialised critical cleaning applications where the highest and strictest standards must be met
- As the only carrier fluid for fluorinated lubricants

Current safety requirements for airbags, critical aerospace electronics, liquid oxygen service cleaning and medical equipment all have specific cleanliness requirements that can only be met with F-gas solvents;[328] they are critical to keeping these lifesaving devices free of contamination and operating at peak performance. Their lack of solubility in various solutions makes F-gas solvents the prime candidate for successful operations across various applications.

PERFORMANCE BENEFITS

F-gases have proven unparalleled in their use for lubricants, electronics, semiconductors, and critical cleaning. Fluorinated lubricants are used in the harshest conditions of each industry due to their:

- Ability to withstand and operate successfully at a range of temperatures and pressures
- Insolubility in organic solvents
- Ability to form a sealant, keeping external contaminants away from the sanitized applications

These capabilities uniquely enable F-gas-based solvents to meet cleanliness requirements, while also ensuring equipment operates smoothly and is not compromised.

Fluorinated fluids are non-flammable, safe, and exhibit favorable physical properties, including excellent thermal, environmental, and dielectric properties, making them a critical solution in sensitive manufacturing processes. In fact, **fluorinated fluids are the only known non-flammable heat transfer fluids for the semiconductor industry** that can provide the wide temperature range along with the dielectric properties needed.[329]

Among all commercially available cleaning agents, F-gas-based solvents have:

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[328] Mudawar, I. and Maddox, D.E. (1989) 'Critical heat flux in subcooled flow boiling of fluorocarbon liquid on a simulated electronic chip in a vertical rectangular channel', *International Journal of Heat and Mass Transfer*, 32(2), pp. 379–394. https://doi.org/10.1016/0017-9310(89)90184-1.

[329] SIA PFAS Consortium, The Impact of a Potential PFAS Restriction on the Semiconductor Sector Report No. 2022-0737 Rev. 0. April 13, 2023. Section 7

- The highest wetting index, making them highly efficient
- Excellent compatibility with sensitive materials, enabling broad applications
- High efficacy, removing contaminants while evaporating with little to no residue

SAFETY & SUSTAINABILITY BENEFITS

Alternative solvents exhibit safety and sustainability concerns, therefore making alternatives less sustainable than F-gas solvents:

- Although water/glycol solutions are not flammable, it is classified as a volatile organic compound (VOC[330]), which have high vapor pressure and are common ground water contaminants. It is also classified as a hazardous air pollutant (HAP[331]) by the US EPA, which are also known as toxic air pollutants and are suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.
- Alcohols are flammable liquids and require certain precautions for handling and storage;

NO EQUIVALENT ALTERNATIVES

As it currently stands, no alternative solvents maintain the required performance standard across applications. F-gas solvents are also the only available option that offer non-flammability and non-toxic characteristics.

Alternatives risk damaging potentially life-saving equipment. Water/glycol solutions for example are problematic and cannot be applied in many industries[332] such as heat transfer fluids due to:

- Limited range of operating temperatures[333];
- Radiation absorption and Incompatible with many semiconductor process tools using radio frequency (RF) power;
- Poor dielectric properties;
- High risk of corrosion.

Another problem is flammability, such as with alcohol-based solutions or synthetic hydrocarbons.[334] Chlorinated solvents and hydrocarbons are also toxic, which increases the safety risk.

Critical cleaning includes a wide range of solvent applications many of which require compliance with codes/standards. As a result, alternatives must be considered on a case-by-case basis. Examples of impacted uses include:

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330 https://www.epa.gov/indoor-air-quality-iaq/what-are-volatile-organic-compounds-vocs
331 https://www.epa.gov/haps/what-are-hazardous-air-pollutants
332 https://www.epa.gov/sites/default/files/2016-02/documents/pfc_heat_tranfer_fluid_emission.pdf
333 https://www.epa.gov/sites/default/files/2016-02/documents/pfc_heat_tranfer_fluid_emission.pdf
334 ASHRAE (2001). Handbook Fundamentals, *Atlanta: American Society of Heating, Refrigerating and Airconditioning Engineers, Inc.*

- **Industrial precision cleaning** fluids, such as for use in oxygen-enriched environments or for vapor degreasing for example for the removal of sub-micron particles for electronics. No alternatives currently exist;
- **Semiconductor manufacturing**: Given the small, very dense and complex components, high-precision, electrostatically polar cleaning fluids are required. No alternatives currently exist;[335]
- **Metal 3D printing:** Alternative solvents would drastically lengthen the debonding process and cleaning cycle, while reducing cleaning performance and efficiency.

There is currently no alternative that incorporates all the properties of F-Gas solvents, resulting in the need to use alternatives that may be toxic, flammable, thermally unstable, or corrosive.

SOCIO-ECONOMIC IMPACT

It would be extremely costly to transition to alternatives and could lead to the obstruction of production processes in various vital industries:

- **Critical cleaning:** The cost of equipping with alternatives could be 4-5 times higher than the cost of an F-gas vapor degreaser;
- **Aerospace and electronics:** Inferior cleaning agents would have an impact on highly critical and sensitive production processes, either through possible contamination by residues, or delays in processes due to longer cleaning cycles;
- **Medical:** No alternatives exist today for the specialized cleaning of medical device;.
- **Semiconductor:** Eliminating F-gases for semiconductor production would result in significant supply chain issues impacting everything from computers to vehicles to military equipment. Semiconductor fabrication relies on fluoropolymers, F-gases, and specialty fluids to safely and effectively produce and test high-quality chips. Without these fluorinated technologies, the broader European supply chain would cease operations leading to economic losses of €63.4 billion[336]. Europe would lose its 10% global semiconductor chip market share and consequently fail to fulfill the objectives in the EU CHIPS Act and other EU strategic objectives.

The impact of these disruptions is expected to reach billions of dollars in the European Union.[337]

In addition, alternatives have demonstrated lower thermal stability and—for many applications—there are no alternatives.

[335] SIA PFAS Consortium, The Impact of a Potential PFAS Restriction on the Semiconductor Sector Report No. 2022-0737 Rev. 0. April 13, 2023. Section 7

[336] Independent Socioeconomic Analysis: Estimated 10-year impact to the European economy (profit and social costs) of a ban of PFAS where no viable alternative is available

[337] Yoon, J.-I. *et al.* (2023) 'Perspective chapter: Ultra-low temperature chillers for semiconductor manufacturing process', *Latest Research on Energy Recovery* [Preprint]. https://doi.org/10.5772/intechopen.98547.

CONCLUSION

Alternatives come with significant limitations and further risks, and because of this would take multiple years for testing to verify performance and compatibility with other measures, such as medical implants. The use of F-gas solvents in critical cleaning, semiconductor process cooling, and carrier fluids solvents lack available and feasible alternatives to allow for a safe and successful transition to alternative technologies, and we defer to the recommendations of the sector experts.