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PFAS in the treatment of skis — Use, Emissions and Alternatives

Wood Group UK Limited – April 2021

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Report for

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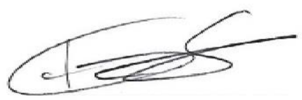

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Management systems

This document has been produced by Wood Environment & Infrastructure Solutions UK Limited in full compliance with our management systems, which have been certified to ISO 9001, ISO 14001 and ISO 45001 by Lloyd's Register.

Contents

List of abbreviations

Abbreviation	Full expression/term
COF	Coefficient of friction
CMR	Carcinogenic, mutagenic or reprotoxic
EEA	European Economic Area
EU	European Union
FIS	International Ski Federation
OECD	Organisation for Economic Co-operation and Development
PBT/ vPvB	Persistent, bioaccumulative and toxic / very persistent and very bioaccumulative
PFAS	Per and polyfluoroalkyl substances
PFCA	Perfluoroalkyl carboxylic acids
PFOS	Perfluorooctane sulfonic acid
PFOA	Perfluorooctanoic acid
REACH	Registration, Evaluation, Authorisation & restriction of Chemicals (EU's main chemicals legislation)
SFA	Semi-fluorinated n-alkanes
WWTP	Waste water treatment plant

1. Introduction

1.1 Per- and polyfluoroalkyl substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS) are a family of man-made chemicals that have been extensively used in a wide number of different industrial and consumer applications since the 1950s due to their unique physical and chemical properties (such as water-, oil- and grease-repellence and high chemical and thermal stability). The OECD[1] estimates that there are approximately 4,700 known individual chemical substances in the PFAS family, while others estimate that closer to around 6,000 substances belong to this group.[2]

Uses of PFAS include in textiles and leather; cosmetic products; food contact materials; paper and board; firefighting foams; household articles and consumer mixtures; construction products; lubricants and greases; industrial chemicals used in chrome plating; semiconductors; mixtures for treatment of skis; medical devices and apparel; applications within the oil, gas and mining industry; refrigeration and cooling applications; transportation (automotive, aviation etc.); and photographic surface layers.[3]

Some of the unique physicochemical properties of PFAS that have made them so useful and popular in these uses could also result in negative impacts on the environmental and human health.[4] PFAS either are, or degrade to, very persistent chemicals that accumulate in humans, animals and the environment.[5] Their resistance to degradation, and high mobility in the environment mean that PFAS are now found everywhere, including remote environments such as the Arctic. PFAS have been observed to contaminate water and soil in most European Union (EU) countries and it is extremely difficult and costly to clean up such contamination[6].

A number of PFAS are known to display toxic and/or bioaccumulative effects. Health effects in humans associated with exposure to certain PFAS include increased cholesterol levels, impact on infant birth weights, effects on the immune system, increased risk for cancer, and thyroid hormone disruption.[7] Some PFAS are classified in the EU as toxic for reproduction, the liver and as suspected carcinogens.[8]

While, within the past decade, several 'longer chain' PFAS compounds (e.g., PFOS, PFOA) have been restricted or banned under EU legislation, more recently, there have been mounting concerns and evidence that 'short chain' PFAS are also very persistent and very mobile in the environment, potentially leading to contamination of the environment in the future. This is a serious concern, particularly where manufacturers and industry may have switched from longer chain to shorter chain PFAS following the previous regulatory actions.

The European Commission has recommended that actions on the EU level to phase out PFAS should be taken to ensure that the use of PFAS is phased out in the EU, unless it is proven essential for society[9].

[1] https://www.oecd.org/chemicalsafety/risk-management/synthesis-paper-on-per-and-polyfluorinated-chemicals.htm
[2] https://www.concawe.eu/wp-content/uploads/2016/06/Rpt_16-8.pdf
[3] Juliane Glüge et al. (2020) An overview of the uses of per- and polyfluoroalkyl substances (PFAS), https://pubs.rsc.org/en/content/articlelanding/2020/em/d0em00291g#!divAbstract
[4] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/aboutPFAS/
[5] European Environment Agency (2019), Emerging chemical risks in Europe — 'PFAS', https://www.eea.europa.eu/themes/human/chemicals/emerging-chemical-risks-in-europe
[6] Nordic Council of Ministers (2019). The cost of inaction. A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf
[7] Letter from Ministers of Denmark, Luxembourg, Norway and Sweden to the Executive Vice-President for the European Green Deal & Climate Action and Commissioners calling for an EU action plan for PFAS (2019). Elements for an EU-strategy for PFASs https://www.regjeringen.no/contentassets/1439a5cc9e82467385ea9f090f3c7bd7/fluor---eu-strategy-for-PFAS---december-19.pdf
[8] https://www.hbm4eu.eu/the-substances/per-polyfluorinated-compounds/
[9] European Commission (2020) Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment, https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

1.2 This report

In May 2020, it was announced that Denmark, Germany, the Netherlands, Norway and Sweden would jointly analyse restriction options for PFAS on the basis of their high persistence in the environment and prepare a restriction proposal over the next two years. [10] The restriction proposal will potentially cover all PFAS rather than specific individual compounds and may include the use of fluoropolymers. It would be taken forward under the EU's regulation on the registration, evaluation, authorisation, and restriction of chemicals (REACH)[11].

A call for evidence to inform this process was held, closing at the end of July 2020. Questions were addressed to the whole supply chain including manufacturers, importers, distributors, and downstream users.

The restriction will consider a range of different uses of PFAS. Along with the inputs from this stakeholder consultation, a number of projects are being conducted to gather and assess the evidence regarding the use of PFAS in specific uses. During these projects targeted stakeholder interviews were performed to further increase the understanding of the different applications.

This report provides an overview of the results from the study investigating the use of PFAS in ski treatments. This includes the following:

- An overview of PFAS in ski treatments (Section 2) – detailing the specific uses for PFAS in this sector, and the function they provide that makes them valuable;
- PFAS in ski treatments from the European perspective (Section 3) – looking at the level of use of PFAS in this sector in Europe, the quantity of PFAS released to the environment and how humans can be exposed from these uses; and
- Alternatives to PFAS in ski treatments (Section 4) – discussing the feasibility of alternatives to PFAS in this sector.

[10] https://echa.europa.eu/-/five-european-states-call-for-evidence-on-broad-pfas-restriction
[11] https://www.echa.europa.eu/web/guest/regulations/reach/understanding-reach

2. Overview – PFAS in ski treatments

Waxes are an important means of lubrication in skiing, to reduce friction between the base of the skis and snow, allowing the skis to glide more freely. There are three main types of friction that require specific lubrication in skiing[12]:

- **Dry friction** – when dry snow granules come in contact with the ski base;
- **Wet friction** – when a high moisture content snow creates suction between the ski base and snow; and
- **Electrostatic friction** – when a ski base runs on snow creating an electrostatic attraction between the ski and snow.

Ski wax can come in a variety of different types, each designed for specific conditions, compositions, or a certain performance level. The most common forms of wax are listed in Table 2.1.

Table 2.1 Overview of different ski wax types[13]

Type	Market	Method of application	Use
Block wax	Most common wax form	Block wax needs to be melted on the ski base once it is heated up with an iron, then ironed into the pores of the bases evenly to allow faster gliding.	Waxes in block form last the longest on skis.
Liquid wax	Found at high and low end of the cost spectrum	Supposed to be applied onto a cloth or it comes with an applicator then rubbed on the bases of the skis Often used in conjunction with other forms of wax including fluorocarbon waxes	Short-term solution to allow for faster gliding properties for up to 24hrs.
Paste wax	Very economical and easy to apply.	Small fabric applicator to apply and buff in. The longer you buff it into the base the longer it lasts on your skis. Can be used as an overlay	Typically available in a universal temperature range
Powder wax	Typically have high costs due to the high amount of fluorocarbons they contain	Designed to be used after a few layers of block wax are applied. Used to increase gliding properties	Often used sparingly for important races only
Spray wax	Typically have high costs	Once it is sprayed on, allow it to absorb and dry for 5 minutes, then use a cork to further buff it in. Typically used on top of several layers of high-end block wax to offer the best gliding properties.	Most commonly found in high-end finishing racing wax as an overlay

12 https://the-raceplace.com/pages/ski-wax-faqs
13 https://www.skis.com/Buying-Guide-for-Ski-Wax/buying-guide-5-3-2013,default,pg.html

In each case, the specific composition of the wax varies depending on the different snow conditions, humidity levels and weather conditions for which they are designed. Commonly the composition of waxes is divided into the following categories (Table 2.2).

Table 2.2 Overview of different ski wax composition

Wax composition	Price	Properties	Labelling
Pure Fluorocarbon	Expensive products as they have a high fluorocarbon content	Comes in liquid, powder or block form. Liquid form is the most popular. High resistance to dirt and oils to provide a long lasting, fast gliding ski	Typically have FC or Cera in the title of the wax.
High Fluorocarbon	Typically more expensive ski waxes. The higher the fluorocarbon content the more expensive	Provide the highest amount of gliding properties in areas with high humidity, man-made snow, dirty snow or places with very cold temperatures Made in every temperature range	Typically has HF in the title of the wax
Low Fluorocarbon	Best value wax when you compare price and performance	Available in every temperature range Can be used by themselves or to prepare the base	Typically has LF in the title of the wax
Hydrocarbon	Contain no fluorocarbons and are very economical	Very durable and repel dirty snow conditions very well Can be used by themselves (best in colder conditions), or they can be used to help prepare bases for use with higher-end waxes	Typically has CH in the title of the wax
Eco-friendly/plant based wax	More expensive than typical hydrocarbon wax	Often made from a mix of naturally occurring waxes. Tend to be biodegradable	Often labelled 'eco'

PFAS have commonly been used in the production of gliders and other ski wax products used for preparation of skis, including the preparation of cross country and downhill skis, and for snowboards, as well as in mixtures for cleaning and impregnation of skin skis. The key property that PFAS provide in this application is a high water repellency (hydrophobicity) thus allowing a suitably low surface tension for the skis on snow. Waxes are an important means of lubrication in skiing, to reduce friction between the base of the skis and snow, allowing the skis to glide more freely. It has been shown that the use high fluorinated waxes can result, on average, in a 4% increase in performance of the skis.[14]

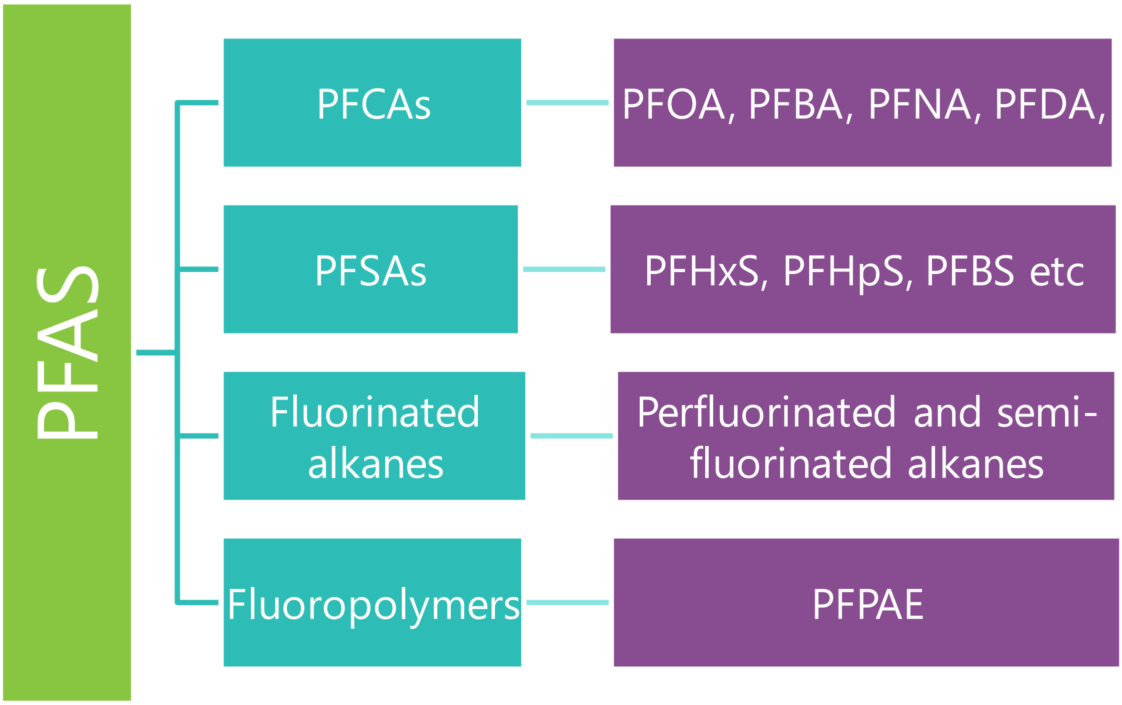
Skin skis differ from traditional skis in that they are designed to allow skis to slide forward but not backward[15]. Initially, mohair, a natural material from the hair of goats, was used for skin skis. It was then substituted by nylon skin material treated with Teflon™ or by a mix of the two. Real mohair treated with Teflon is used on high-performance models[16]. Nowadays, mainly synthetic skins are used for country and alpine skiing when going uphill, as the skins grip the snow and provide a forward kick. They are then easily

[14] Breitschädel F., Haaland N., Espallargas N. 2014. A Tribological Study of UHMWPE Ski Base Treated with Nano Ski Wax and its Effects and Benefits on Performance. Procedia Engineering. 72:267-272
[15] https://www.webcyclery.com/about/skin-skis-101-pg259.htm
[16] https://www.webcyclery.com/about/skin-skis-101-pg259.htm

removed for skiing downhill[17]. Given that the skin mimics the functions provided by grip wax, the skis do not require any grip wax. It can be necessary to apply anti-icing products to the skins to eliminate icing, as is done for grip wax-treated skis and the skin should be cleaned periodically[18]. The glide zone of the skis (i.e., in front of and behind the kick) needs to be re-waxed every 100km travelled, similar to classic skis[19] and in most cases, it is possible to use the same wax for both skin and traditional skis.

The main PFAS substances used in ski waxes are perfluoroalkanes and semi-fluorinated alkanes (Figure 2.1). Fluoropolymers are also used in some waxes. The semi-fluorinated alkanes used are di-block and tri-block semi-fluorinated n-alkanes (SFAs)[20] and are typically mixed with normal paraffins in the formulations of ski waxes. Perfluoroalkyl carboxylic acids (PFCAs) of varying carbon chain lengths (6–22 carbons) are often found as residual impurities from the manufacture in commercially available fluorinated ski waxes. PFCAs are not thought to have a technical function in the ski waxes given their relative low levels compared to the perfluoroalkanes and SFAs. Even when PFAS substances are not used as raw materials by ski waxes producers, they can be present as impurities or as degradation products[21].

Figure 2.1 Typical PFAS substances present in ski waxes (including impurities or unintentionally added).

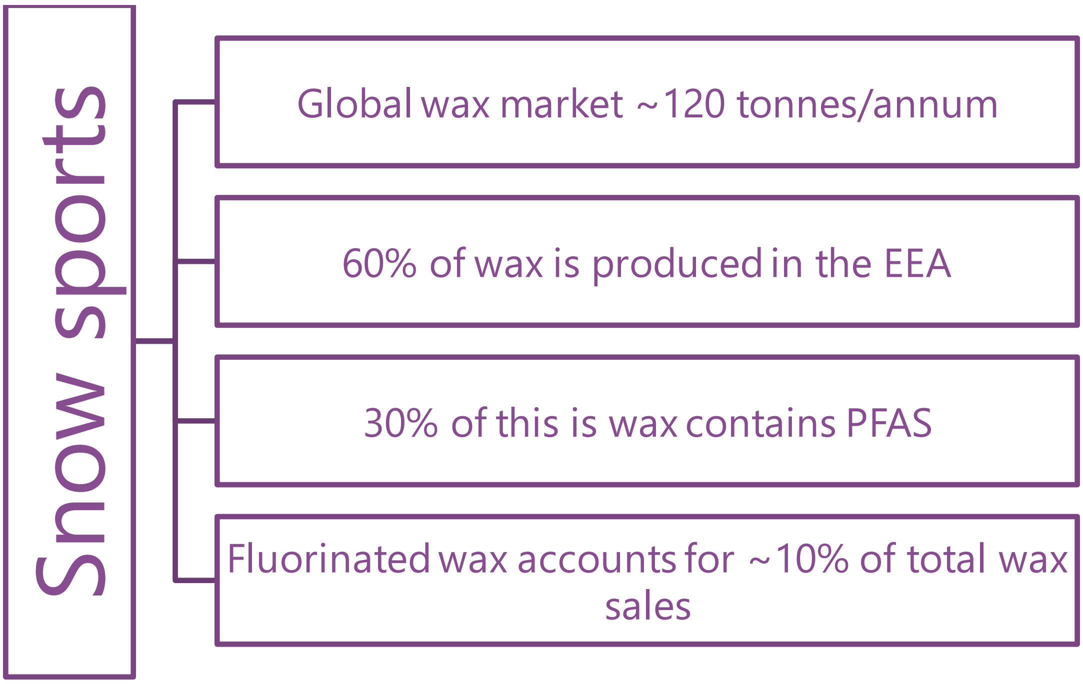


[17] https://www.newmoonski.com/articles/skin-skis-101-pg239.htm#:~:text=Skin%20Skis%20101%20%E2%80%93%20Skin%20skis,for%20grip%20on%20the%20snow.&text=Originally%2C%20strips%20of%20animal%20hide,of%20skis%20for%20uphill%20travel
[17] https://www.webcyclery.com/about/skin-skis-101-pg259.htm
[18] https://www.webcyclery.com/about/skin-skis-101-pg259.htm
[19] https://www.crosscountrysports.com/care-for-your-skin-skis/
[20] Di-block and tri-block SFAs are fluorinated compounds with a linear structure consisting of a hydrocarbon $H(CH_2)_m$ segment attached to a fluorocarbon $(CF_2)_nF$ segment for di-block compounds and to two fluorocarbon $F(CF_2)_n$ segments for tri-block compounds. Napoli M. Diblock and triblock semifluorinated n-alkanes: preparations, structural aspects and applications. J Fluorine Chem. 1996. 79:59–69.
[21] https://www.swixsport.com/en/about-swix/sustainability/health-environment/

3. PFAS in ski treatments – European perspective

Previous estimates from the literature indicate that[22] the global production of ski waxes is estimated to be several tonnes per year, and the chemical composition of waxes is continuously evolving[23]. However, the stakeholder consultation performed in this project indicated that the global market for ski waxes was larger than several tonnes and amounts to approximately 120 tonnes per year. Around 60% of the total market of ski wax is produced in the EEA and the other main producers are USA, Japan and Russia. However, fluorine-free ski waxes account for some 70% of that market, the remaining 30% (~21 tonnes of wax) is fluorinated products[24] (Figure 3.1**Error! Reference source not found.**). These results indicate that the ski wax industry is likely to be one of the smaller users of PFAS, if compared to the textile and the firefighting foams industries. For example, the estimate tonnage of PFOA and PFOA-related substances used in textiles (not including imports) and fire-fighting foams in the EU after 2015 would be 300t and 15-30t respectively[25]. However, despite the small amount of PFAS based waxes produced, such amount becomes significant with respect to the consequences on human exposure.

Figure 3.1 High level market overview of ski waxes in the EEA (information obtained from stakeholder consultation)



Fluorinated waxes tend to be used primarily during competitions; however, professionals are known to use fluorine-free waxes during training. Similarly, amateur skiers mostly use fluorine-free alternatives. However, in

[22] Plassmann, M. M.; Berger, U. Trace Analytical Methods for Semifluorinated-Alkanes in Snow, Soil, and Air. Anal. Chem. 2010, 82, 4551–4557, DOI: 10.1021/ac1005519
[23] https://pubs.acs.org/doi/10.1021/acs.est.9b02533
[24] Stakeholder Interview personal communication
[25] ECHA (2014) Annex XV Restriction Report Proposal for a Restriction, Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances. https://echa.europa.eu/documents/10162/e9cddee6-3164-473d-b590-8fcf9caa50e7

some countries it is still common to use fluorinated waxes, also among amateur skiers. Historical trends in use of ski wax indicate that:

- The highest use year for non-PFAS based ski wax was 1978, where 300 tonnes of glide waxes were used[26];
- Some companies no longer manufacture ski waxes containing PFAS and are currently selling off their remaining stock. Companies have been working on the development of non-fluorinated alternatives since 2013; and
- Since 2017 the PFAS-based ski wax market has shrunk for various reasons: because of the higher prices of some PFAS-based waxes; due to global policy developments related to the use of PFOS/PFOA, and also due to decreasing number of professional athletes[27].

Production of PFAS based waxes is expected to diminish in the following years. Due to increasing concern and publicity regarding the potential human health and environmental effects caused by the use of PFAS in ski wax treatments, there is a concerted move within this sector towards phasing out the use of PFAS and moving towards safer alternatives. In particular, in 2019 the International Ski Federation (FIS) set to introduce a ban on PFAS in waxes in all competitive ski disciplines from their 2020-2021 season, a move that follows national-level bans imposed, for example by the Norwegian Ski Association in 2017. However, in October 2020 the FIS Council decided to postpone the implementation of the ban of fluorinated waxes until the start of the 2021-22 season, beginning on July 1, 2021. This delay was due to the fact that they are still developing a Fluorine Tracker, an instrument that would detect the presence of PFAS on the ski, that would make the competitions fair.Emissions and Exposure

3.1 Environmental emissions

Overview

This section considers the potential environmental release of PFAS compounds from the use of PFAS-based products and fluoropolymers in ski waxes.

3.1.1 Approach

For this assessment, a basic source-flow model has been developed. The development of this source-flow approach began with a consideration of the key life-cycle stages and what kinds of emissions may occur at each life-cycle stage. Four basic life-cycle stages are considered where it is possible for emissions to occur, or for material to flow through into the next life cycle stage:

- Formulation of the ski wax. This includes consideration of the PFAS substances used within the ski wax. Note, that it was assumed that the life-cycle begins at this stage rather than the manufacture of the PFAS themselves;
- Storage. For other sectors beyond ski-waxes, storage can potentially be an important life-cycle stage for potential emissions. Therefore, for completeness 'Storage' has been included within the current source-flow approach. However, during storage of ski waxes it is unlikely that leaks or spillages occur, which would directly contribute to environmental emissions. Therefore, emissions from this stage are assumed to be zero;
- In-use. Active use of ski waxes is likely the most important life-cycle stage. To provide a higher level of disaggregation this phase is split into two sub-components:

[26] Stakeholder Interview personal communication
[27] Stakeholder Interview personal communication

  - Emissions to the environment during the application of ski-wax to skis/snowboards etc; and
  - Further emissions to the environment associated with the continued service life (i.e., during skiing).

- Waste. The waste cycle includes three key pathways: landfill of wastes and/or end of life product (i.e., any unused final quantities of wax discarded), thermal destruction (incineration) and wastewater treatment plants.

3.1.2 Estimated emissions

The information provided through stakeholders suggests that the European Union is a major manufacturer of ski-waxes (60% of global production). It is therefore assumed that no imported ski-wax will be needed and that all ski-wax manufactured will service the EU's needs. Data from one stakeholder provided working concentrations of PFAS in ski waxes as somewhere between 0.2 – 15% w.w of wax, therefore a middle value of 7.6% w.w has been used to calculate total quantities of all PFAS (which includes both fluoropolymers and non-polymeric PFAS) in use for ski-waxes in the European Union.

The "in-use" phase of the model was then further refined to incorporate different kinds of use and application and how these may affect the type of emission and usage rate.

In particular the model identifies two key sets of activities under the in-use phase which have been used to help further divide this phase into two sub-phases:

- Firstly, emissions may occur during the application of ski-wax to skis / snowboards. This is potentially the single biggest point of release in the life-cycle. Based on consultation with industry, the efficiency of applying ski-wax to skis/snowboards etc is relatively poor. The average of the values provided suggests that 80% of ski-wax applied is lost during the application process. This can occur both indoors and outdoors over snow. Further feedback suggests a significant proportion of lost material may be recaptured and consigned to waste (e.g., via vacuuming). Therefore, it is assumed that 80% is initially lost, with 40% (half) recaptured and consigned to waste and 40% (half) truly lost to the environment, with an equal split between water and land. The remaining 20% is retained on the skis/snowboard; and
- Secondly, after application there may be further losses during service life (i.e., skiing). It is assumed that 100% of the wax applied is lost during this phase through erosion of the wax.

Note that alongside these two sub-phases there will also be quantities of wax which are discarded into the waste disposal system via public refuse bins or at home via general refuse. In lieu of better data it is assumed that 90% of the wax purchased is used, with 10% consigned to the waste cycle.

The overall levels of release to different environmental media for the PFAS substances considered in this study are summarized in Table 3.1, Table 3.2 and Figure 3.2. It must however be noted that due to a lack of information, a number of assumptions have been made in the model, which mean that the estimates are associated with relatively high uncertainty.

However, the model makes clear that the emissions from manufacture and waste processes are secondary to the 'in-use' phase, with application being the primary emission source. Where the application of PFAS can be considered a wide and dispersive use, it is perhaps not unsurprising that the key stage of release is during use, with the key receiving environment surface water (and soil).

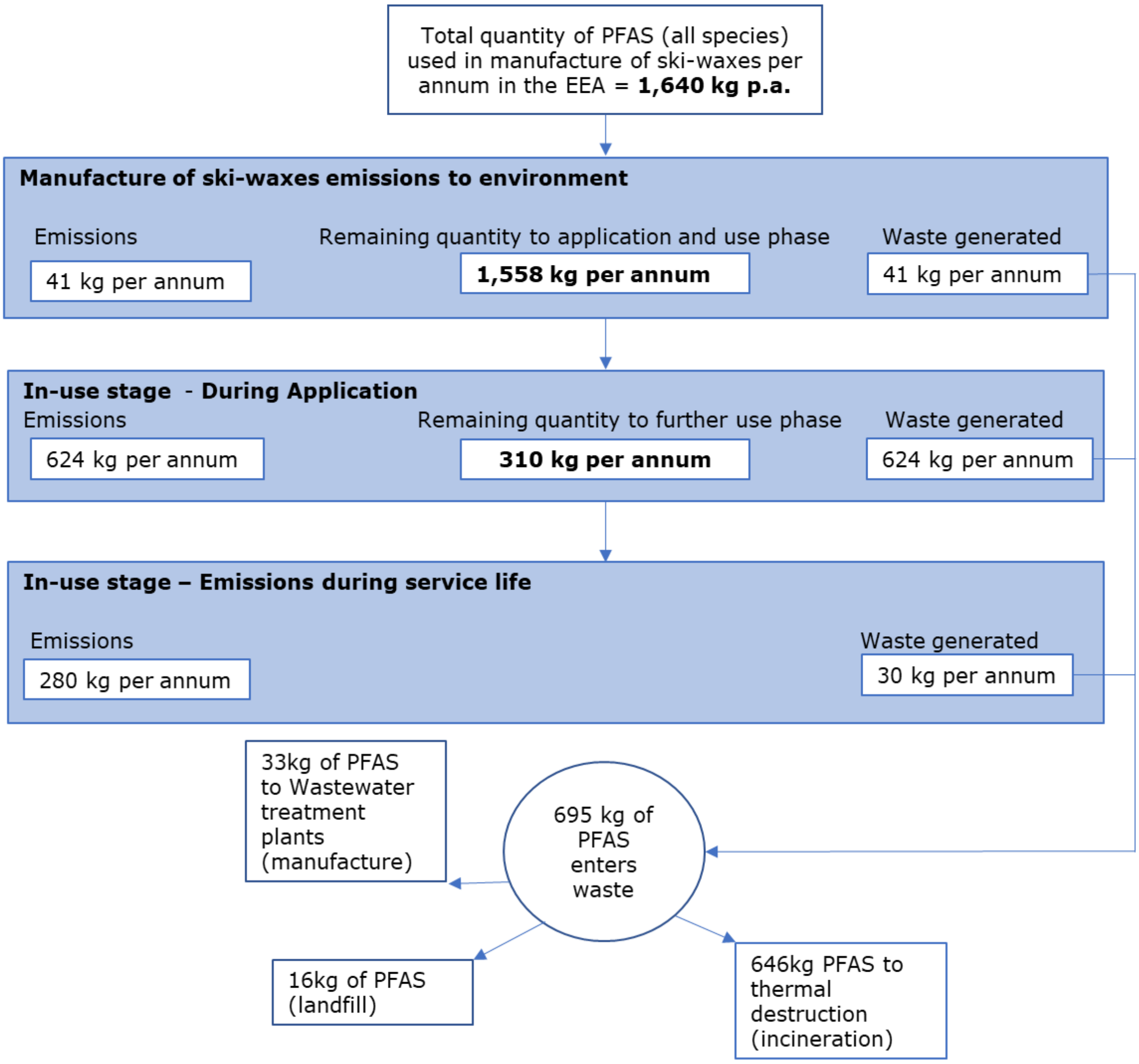
Table 3.1 Overview of emissions by different environmental compartment for all life-cycle stages (excluding waste) combined (in kg) for 2020.

Substance group	Air	Fresh surface water	Soil (true release)	Total
PFAS (all species)	41	452	452	945

Table 3.2 Overview of emissions by different life-cycle stages (in kg) for 2020

Substance Group	Formulation (of ski-waxes)	Storage	In-use (application)	In-use (further service life)	Waste	Total
PFAS (all species)	41	0	624	280	695	1640

Figure 3.2 Material flow diagram for PFAS (all species including fluoropolymer) in ski-waxes for the European Union



3.2 Emission estimates time-series

This section provides additional estimates to map ski wax production/use trends covering the backward-looking time-series (1990-2020) as well as projections (2020-2050) for a business-as-usual scenario and REACH restriction (assuming no exemption is granted for ski-waxes).

Based on the feedback from the call for evidence and stakeholder engagement, the peak year for production and consumption of ski-wax globally (all formulations, including both PFAS and fluorine free) was 1978, where 300 tonnes of wax was used. However, it is important to comment that the use of PFAS based substances only came into circulation at a later date, with the first patents lodged in 1990. Based on the call for evidence, market data for the latest year suggests total global production for ski-wax in 2020 (again, all formulations) was 120 tonnes, based on feedback from EU's largest manufacturer. This suggests that overall global consumption of ski-wax has declined since the peak years of the late 1970s.

Further details for the reduction in production volumes have not been identified, however, it can be hypothesised that part of the reduction may be due in part to improvements in formulations meaning that less wax is needed to achieve the same level of efficacy. The use of PFAS (in part) may also have contributed to this improved performance. It may also reflect a reduction in number of people skiing / using ski-wax. Further analysis has not been completed on this issue specifically.

Additionally, the call for evidence suggests that 60% of global production is within the EEA, with the majority (assumed in the current study to be 100%) retained for use within the EEA. The evidence gathered also provides a split between fluorine-based waxes (30%) and non-fluorinated waxes (70%) for the year 2020.

Concerns regarding PFAS meant that the transition away from fluorinated compounds more generally may have begun as early as 2006[28] . However, there may have been a slower transition away within the ski-wax sector, with the decline in PFAS-based ski-wax assumed to have commenced around 2010 in-line with the mounting regulatory pressure on longer chain perfluorosulfonic and carboxylic acids, particularly PFOS and PFOA.

The first patents for use of PFAS-based substances in ski-wax come from 1990[29] . Data on usage rates for that year have not been identified, and therefore expert judgement has been needed to assign an 'entry-level' starting point for the market, assumed to equate to 10% (or 15 tonnes of ski-wax). From this point the growth in use of PFAS-based substances would have grown sharply based on the assumed enhanced performance of PFAS-based ski-waxes. Based on expert judgement, it is assumed that peak use for PFAS-based ski-wax would have been achieved around 2000, with a 50% market share (equivalent to 52.5 tonnes of ski-wax). After 2010, the use of PFAS-based substances in ski-wax is commented as going into decline, falling from the 50% market share in 2010 to the 30% market share in 2020 (equivalent to 21 tonnes of ski-wax) based on the feedback from the CfE and stakeholder interviews.

Further feedback from the call for evidence has highlighted industry efforts have accelerated the transition away from PFAS-based waxes from 2014 onward by developing alternatives, with use of PFAS-based ski-wax now primarily for competitive users.

The working concentration of PFAS within the wax has been retained as a constant 7.6% w.w. Therefore, any decline in quantity of PFAS in use is directly attributable to the decline in the use of PFAS-based wax more generally. Based on these assumptions the production and use rates are detailed in Table 3.3. No estimates have been provided for any change in formulations (i.e., change of PFAS substance, or greater/lower working concentrations).

[28] Grip and Glide: A Short History of Ski Wax | International Skiing History Association
[29] Official gazette of the United States Patent and trademark office, September 1990, Patent for CERA F lodged by Swix.

Forecasting future usage rates and technologies is very challenging and cannot readily consider emergence of novel technologies or unpredicted sudden world events (with Covid-19 being a good example). Furthermore, the further forward in time the projection is cast the greater the uncertainty in future trends or events. Therefore, any estimate of usage as far forward as 2050 should be treated with a great deal of caution and used only as indicative of possible usage rates and associated emissions.

For the purposes of the future projection estimates, a conservative estimate assumes a full REACH restriction implemented by the end of 2023, with a three-year transition window. Final legal use of PFAS in ski-waxes is assumed to expire by the end of 2026. This kind of transition window is broadly in line with other REACH restrictions (3-5 years).

Table 3.3 Estimated historical production rates for PFAS-based ski wax

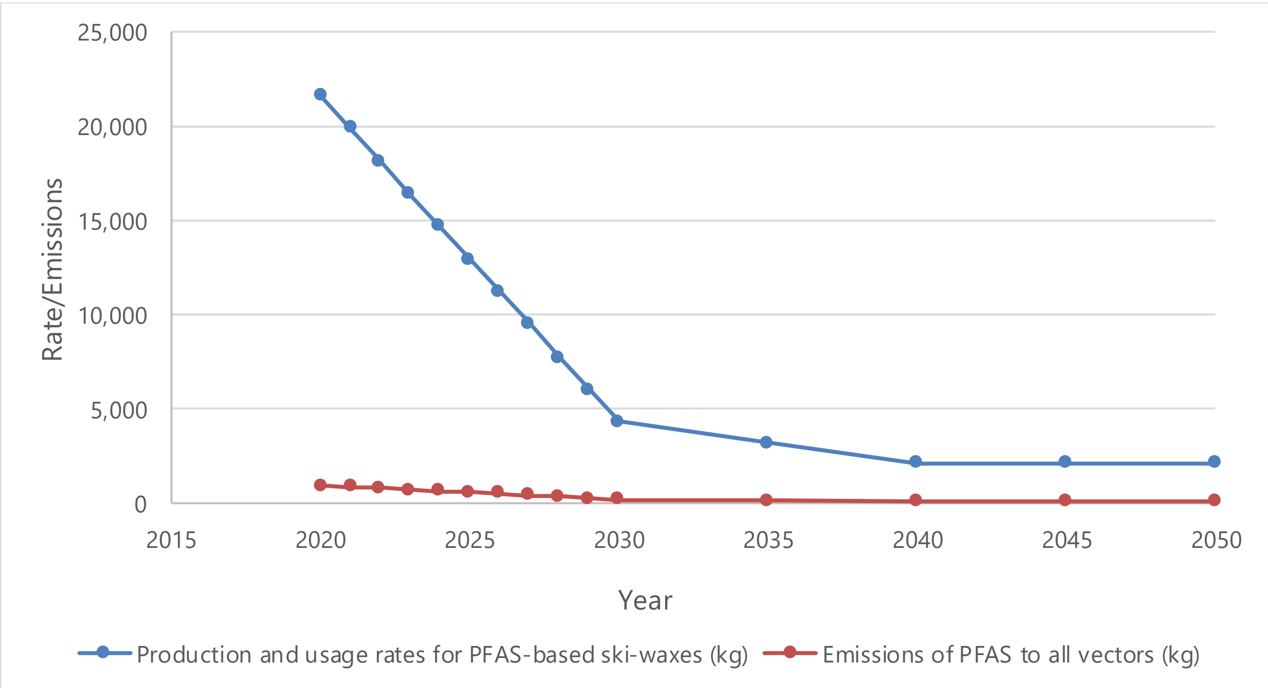
Year	Global production (tonnes)	EEA fraction of production (percentage)	Total EEA ski-wax production (all formulations) (tonnes)	Proportion of EEA production covering fluorinated waxes (percentage)	PFAS-based ski-waxes produced in the EEA (tonnes)
1978	300	60%	180	0%	0
1990	250	60%	150	10%	15
1995	225	60%	135	30%	40.5
2000	200	60%	120	50%	60
2005	175	60%	105	50%	52.5
2010	150	60%	90	50%	45
2015	135	60%	81	40%	32.4
2020	120	60%	72	30%	21

Feedback from the International Ski Federation (FIS) has highlighted that movement is underway to ban the use of PFAS-based waxes in sporting events associated with the FIS. This is expected to be implemented within the next few years. This sits alongside a wider proposed restriction in the use of PFAS-based waxes in Norway. Therefore, it is assumed by 2030 there will be an 80% decline in use (against the baseline 2020 usage rates). The remaining 20% in use reflects non-race events and activities outside of Norway. It is further expected that this usage rate will continue to decline over the subsequent 10 years as other alternatives reach market saturation. Post-2040 a small quantity (assumed to be 10% by the current baseline) may continue. Table 3.4 and Figure 3.3 provide projections for future usage rates and associated emissions (using the same model and assumptions as the baseline year) to all environmental vectors.

Table 3.4 Usage rates and emission projections for a business-as-usual scenario.

Year	Production and usage rates for PFAS-based ski-waxes (kg)	Emissions of PFAS to all vectors (kg)	Annual decline compared to previous year (percentage)
2020	21,600	945	-
2021	19,870	870	8%
2022	18,100	795	8%
2023	16,400	720	8%
2024	14,700	640	8%
2025	12,900	570	8%
2026	11,200	500	8%
2027	9,500	410	8%
2028	7,700	340	8%
2029	6,000	265	8%
2030	4,300	190	8%
2035	3,200	140	-
2040	2,100	95	-
2045	2,100	95	-
2050	2,100	95	-

Figure 3.3 Usage rates and emission projections per year (based on a BAU scenario)



3.3 Human exposure

During ski wax application, professional waxers as well as amateurs come in direct contact with the fumes derived from the melting temperature of the wax. Brushing and sanding the product on the ski cause further inhalation and consequent presence of PFAS in the human blood. This occurs especially when the wax is applied without any protection. However, at the elite level and in countries where there is high awareness of the risk level of such substances, protective equipment, such as masks with ventilation, gloves, and long sleeves, are sometimes used. In addition, the wax should be applied in an open or well-ventilated area, which is not always the case. For example, one study correlates the concentration of PFCAs in professional ski waxers blood serum to exposure from work room aerosols where fluorinated ski waxes and powders have been used[30].

During application, a proportion of the product is brushed off the ski and can fall on the floor – unless the wax is applied with a rotor fleece, so that all the wax is either contained or applied to the ski. The removed product tends to be discarded to general waste or even in the snow/outside, but some ski wax producers and European Economic Area (EEA) countries (e.g., Norway) have recommendations in place for waste wax to be disposed of by waste handling companies (e.g., through incineration).

With respect to **human exposure** to PFAS substances in the ski industry, the number of people that might be potentially exposed is estimated considering different categories. In particular:

- **Producers of ski waxes:** According to interviews with some of the main ski wax producers, around 100-200 people are employed by at least 20-25 ski wax producers (many of which are small companies) in the EEA[31]. This includes the production of both PFAS-based and fluorine-free ski waxes, as most producers offer both products. However, producers are less likely to be directly exposed to PFAS substances;
- **Wholesale, distribution and retail:** No information on the number of workers in wholesale, distribution and retail of ski waxes is currently available. However, these workers are very unlikely to be directly exposed to PFAS-based ski waxes because the waxes are packed during these supply chain stages;
- **Application of waxes to skis**:
  - The total number of people involved in the waxing of skis with PFAS-based ski waxes is highly uncertain, because at lower or amateur level skiing competitions athletes may or may not manage their equipment themselves; and
  - For higher level competitions, the number of professionals involved in applying PFAS-based ski waxes can be estimated based on interviews with ski wax manufacturers. Such estimates differ among themselves. However,, the order of magnitude of professional ski waxers seems to be around a few hundreds.
- **End-users (skiers)**: PFAS-based ski waxes are mostly used during competitions. Competition skiers are then estimated to be in the order of 7 million in the EEA[32]. However, such estimate is based on uncertain assumptions so it should be considered as a rough indication of the potential order of magnitude only.

[30] Ingegerdsson Freberg B, Småstuen Haug L, Olsen R, Daae H, Hersson M, Thomsen C, Thorud S, Becher G, Molander P, and Ellingsen D (2010). Occupational Exposure to Airborne Perfluorinated Compounds during Professional Ski Waxing. https://pubs.acs.org/doi/10.1021/es102033k

[31] Stakeholder Interview personal communication

[32] According to Statista (https://www.statista.com/statistics/801008/europe-number-of-people-skiing-by-country/), there are ca 1.2 million people who ski in Norway and 60 million in the EEA, as of May 2020. The extrapolation is calculated as: 140,000 competition skiers in Norway / 1.2 million total skiers in Norway * 60 million total skiers in the EEA = 7 million competitions skiers in the EEA.

Regarding potential human **exposure via the environment**, it should be noted that ski waxes account for only a small share of total PFAS use. As a consequence, ski waxes are most likely not very significant in terms of total environmental PFAS exposure. However, environmental exposure might occur when waxes are released during skiing onto the track where people are skiing. Stakeholder consultation highlighted contrasting opinion with respect to the amount of ski wax released to the environment during skiing, ranging from 1-5% – depending on the contact area between the ski and the snow and on the snow conditions – to all of the wax. In addition, given the very small amounts of PFAS in the waxes it should be considered that the amounts of PFAS found in snow could come from other sources like air, the ski clothes, lubricants used in lifts and vehicles, or fire-fighting foams[33]. However, a study examining the presence of PFAS in soil, earthworms (*Eisenia fetida*), and Bank voles (*Myodes glareolus*) from a skiing area in Trondheim, Norway found long chain PFCAs at high concentrations, compared to the reference area with no skiing activities which was dominated instead by short-chained PFCAs[34]. Similarly, a more recent study found evidence of extremely high levels of both long and short chain PFAS in the snow at the starting line of a ski race. Importantly, the 14 PFAS detected in the snow matched what has been found in ski wax. PFAS levels diminished at around 4 km from the starting line. The soil was contaminated by the same four dominant PFAS that were present in the snow samples, although at a lower concentration. Groundwater contained only short chain PFAS at low concentrations[35].

[33] Interview with FIS.
[34] Grønnestad R, Vázquez BP, Arukwe A, Jaspers VLB, Jenssen BM, Karimi M, Lyche JL, and Krøkje Å (2019). Levels, Patterns, and Biomagnification Potential of Perfluoroalkyl Substances in a Terrestrial Food Chain in a Nordic Skiing Area. https://pubmed.ncbi.nlm.nih.gov/31691564/
[35] Carlson, L and Tupper, S (2020). Ski wax use contributes to environmental contamination by per- and polyfluoroalkyl substances https://www.researchgate.net/publication/343914356_Ski_wax_use_contributes_to_environmental_contamination_by_per-_and_polyfluoroalkyl_substances

4. Alternatives to PFAS in ski treatments

4.1 The feasibility of alternatives

Due to increasing concern and publicity[36] regarding the potential human health and environmental effects caused by the use of PFAS in ski wax treatments, there is a concerted move within this sector towards phasing out the use of PFAS and moving towards safer alternatives.[37] As a result, **a number of companies have developed alternative fluorine-free ski wax products**.

In almost all cases a mixture of substances is used in various percentage combinations for each of the fluorine-free alternatives to attain the necessary functions of the wax. The available alternatives are mainly based on hydrocarbons and paraffins, where paraffin waxes make up the majority[38]. Siloxanes are another option, but they are subject to environmental concerns[39]. New nanoparticles are also being developed as alternatives[40]. Alterations to the ski itself can also be used to improve the performance of the ski and therefore "replace" some of the functionality of the wax.

To assess the possible viability of the alternatives identified, the table below provides a consideration of both the technical feasibility (i.e., ability to provide the required functionality) and economic feasibility (e.g., unit and operational costs associated with its use) of the possible alternatives compared with the PFAS-based waxes.

Table 4.1 Summary of technical and economic feasibility for alternatives

Product type		**Hydrocarbon and paraffin waxes**
Manufacturer		Multiple – examples include Swix, Toko, Brav
Chemical composition		Substances listed in safety data sheets: Hydrocarbon and paraffin waxes
Technical feasibility	Applications areas (as specified in technical specification)	Multiple ski waxes are available for all the different applications types and temperature/weather conditions
	Compliance with international performance standards	N/A
	Examples of use experience and performance compared to PFAS-containing waxes	Performance (speed) is slightly reduced especially in poor weather conditions, such as high humidity.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	None
	Need for changes in equipment	No change necessary. Same equipment can be used in manufacture of waxes and application to the skis
Economic feasibility:	Unit price as compared with PFAS-containing wax for same application	Often less expensive to buy than PFAS waxes

[36] Several Norwegian press reports are available:
https://www.dagbladet.no/arkivert/sport/populaere-skiprodukter-fulle-av-gift/71866854
https://www.dagbladet.no/sport/mamma-skal-do/71942554
https://www.dagbladet.no/glidens-pris/
[37] https://www.skiracing.com/future-without-fluoros-a-complete-guide/
[38] Stakeholder Interview personal communication. It was also suggested part of the reason for their popularity was that their melting points in the range of 22°C to 70°C were practical for ski waxes.
[39] Interview with NILU
[40] Interview with NILU

Product type		Hydrocarbon and paraffin waxes
	Relative volume required to achieve comparable/best possible performance	Depends on product type and application method but similar to PFAS waxes. For hot wax – 10-15g per set. For liquid wax – 0.5g per set
	Storage, shelf-life	~3 years
	Frequency of wax replacement	No different to PFAS waxes. Depends on the amount of skiing performed by the user.
Availability:	Volume manufactured, sold and used in the EEA	Data on volume considered confidential by manufacturers. No issues with supply identified
	Production capacity in the EEA	No data but no issues with supply identified
Risks:	CMR properties	Substances not classified with CMR properties
	Other potential human health concern	No data
	PBT or vPvB properties	Substances in the product do not meet the PBT/vPvB criteria
	Other environmental risk concern	No data
	Conclusion on risks	As the constituents are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products.

From a technical perspective, **alternatives are broadly capable of providing the required functionality of PFAS based waxes.** However, a loss of functionality can be registered. Its importance depends among other things on the type of ski sport. For example, in alpine skiing where the race lasts 100 seconds, the use of PFAS changes the performance of a few tenths of seconds because the ski is flat on the snow just for few seconds in this sport. For cross-country skiing on the other hand, it has an important impact on the athletes' performance of about 1 to 4 minutes in a 10-15 km race. It also depends on the snow condition. For example, with very humid snow (80%) in a 10 km cross country race, an athlete using alternatives would be 1 minute slower than if he used PFAS-based waxes, a significant change of the speed of the ski. As a result, when the weather is warmer, PFAS-based products perform much better than alternatives, while the difference between the two products is much smaller when the snow is cold. Despite these differences, the technical feasibility is confirmed by the fact that alternatives are already being used by both consumers and professional athletes during training. As a matter of facts, they are currently marketed and sold in Europe, and consultation with industry and national authorities suggest they are in use in significant volumes. As a result of the proposed restriction, the overall speed of some competitions, notably cross-country races, would likely be reduced, but there would still be a level playing field because all athletes would equally be forced to use fluorine-free alternatives. Hence, the difference in performance would not affect the fairness of the competition or the nature of the sport more generally. However, given the potential advantage athletes can gain by illegally using PFAS-based wax, testing for presence of PFAS in the wax before races may be needed to enforce the ban.

Alternative ski waxes tend to be less expensive than PFAS based waxes. This is because the substances used in the alternatives are widely available and fluorochemistry is expensive in comparison. The application rate and replacement rate are broadly similar between alternatives and the PFAS based ski waxes.

What is not clear yet is the impact that alternative waxes have on the environment. If alternatives are not persistent, they will not accumulate in the environment like some PFAS. Overall, the **risk posed by hydrocarbons and paraffin waxes is less than that of PFAS substances**, however there may still be some risks present when alternatives are released on the snow while skiing, and on the professionals who apply the product due to the fact that human health and environmental concerns have rarely been investigated.

5. Summary

This report has examined the use of PFAS in the ski wax sector. The main points to consider for the use of PFAS in the ski industry are:

- PFAS substances are used in the production of ski waxes as they provide valuable technical properties to the ski. In particular, they guarantee high water repellency, allowing a suitably low surface tension for the skis on snow, and they reduce friction between the base of the skis and snow. In most cases, it is possible to use the same wax for both skin and traditional skis, especially for colder temperatures. There are also skin-ski-specific waxes, both PFAS-based and non-fluorinated alternatives. Prices vary but they are not more expensive than waxes for classic skis and as they are glide waxes they are only applied to a smaller section of the ski;
- Fluorinated waxes tend to be used mostly during competitions, as athletes and amateur skiers also use fluorine-free alternatives during training because of price constraints. The ski wax industry is therefore likely to be one of the smaller users of PFAS, if compared to the textile and the firefighting foams industries;
- Despite the relatively small amount of PFAS based waxes produced, such amount becomes significant with respect to the consequences on human exposure. During ski wax application, the waxers come in direct contact with PFAS substances, especially when the wax is applied without any protection. Correlation has been found between the concentration of PFCAs in professional ski waxers blood serum and air (in work rooms) where fluorinated ski waxes and powders have been used; [41]
- Environmental exposure can occur when waxes are released during skiing onto the snow. Long chain PFCAs at high concentrations have been found in the soil and biota of skiing areas, compared to reference areas where no skiing activities took place[42]. However, given the small amounts of PFAS in the waxes, it should be considered that in some cases the amounts of PFAS found in snow could come partly from other sources; and
- Available alternatives exist and are mainly based on hydrocarbons and paraffins. From a technical perspective, alternatives are broadly capable of providing the required functionality of PFAS based waxes. From a societal perspective, no significant substitution costs are expected to result from the proposed restriction because the cost of alternatives is similar, if not lower in many cases. Cheaper alternative waxes would imply a reduction in income to ski wax manufacturers, but an equal saving to ski wax users.

[41] Ingegerdsson Freberg B, Småstuen Haug L, Olsen R, Daae H, Hersson M, Thomsen C, Thorud S, Becher G, Molander P, and Ellingsen D (2010). Occupational Exposure to Airborne Perfluorinated Compounds during Professional Ski Waxing. https://pubs.acs.org/doi/10.1021/es102033k

[42] Grønnestad R, Vázquez BP, Arukwe A, Jaspers VLB, Jenssen BM, Karimi M, Lyche JL, and Krøkje Å (2019). Levels, Patterns, and Biomagnification Potential of Perfluoroalkyl Substances in a Terrestrial Food Chain in a Nordic Skiing Area. https://pubmed.ncbi.nlm.nih.gov/31691564/