# 1 INTRODUCTION

This fact sheet outlines the current understanding of the role of volatile and semivolatile per- and polyfluoroalkyl substances (PFAS), referred to in this fact sheet as vapor-forming PFAS, in the assessment and evaluation of the vapor intrusion (VI) pathway. Information for PFAS is referenced in multiple sections of the ITRC *PFAS Technical and Regulatory Guidance Document and Fact Sheets* (PFAS-1 Guidance Document, see **https://itrcweb.org/pfas-guidance/** (ITRC 2026a)), including references, acronyms, and glossary lists. Information for evaluation of the VI pathway is referenced in the ITRC VI Toolkit Document (see **https://itrcweb.org/vapor-intrusion-toolkit** (ITRC 2026b)), including references, acronyms, and glossary lists. References used in this fact sheet are listed **Section 8**. This fact sheet provides a review of current scientific literature, the reasons why this pathway is under consideration, current knowledge gaps, and hurdles that will need to be considered before a site investigation decision associated with VI pathways is made. As of September 2025, the transport of vapor-forming PFAS from the subsurface to indoor air via the VI pathway has been identified as a possibility but has not been conclusively demonstrated in the lab or field; lab- and field-based research studies are currently underway.

This fact sheet has been prepared to support state and federal environmental staff, as well as others (including stakeholders, project managers, and decision makers), to gain an understanding of the current state of the science for vapor-forming PFAS and their potential role in the VI pathway. As such, this fact sheet describes the current understanding of key topics related to vapor-forming PFAS (see **Table 1**).

**Table 1. Summary of key topics covered in the fact sheet with the current understanding and related references and known research efforts.**

| Topic | Current Understanding | References & Forthcoming Research |
|---|---|---|
| Volatility | Limited reliable data available for PFAS physical and chemical properties to help define vapor-forming compounds | PFAS-1, Physical and Chemical Properties **Table 4-1**(ITRC 2026a); Abusallout et al. (2022); Hammer and Endo (2022); Endo (2023); USEPA (2023) |
| PFAS air regulatory values (e.g., risk-based screening levels) | Various regulatory agencies have developed guidance values and criteria for PFAS in air | **PFAS Environmental Media Values Table** (ITRC 2026a); ECOS (2025) |
| PFAS air and soil vapor sampling and analytical methods | Method USEPA TO-17 has been modified to analyze for a subset of PFAS | Schumacher et al. (2024); Hayes et al. (2025) |
| | Larger subsets of PFAS can be analyzed for point sources via stack testing methods (e.g., USEPA OTM-45, OTM-50); however, the methods have not been modified for VI-related sampling | Wallace et al. (2024) |
| Presence of vapor-forming PFAS in soil vapor | Vadose zone transport is an active area of research | USEPA (2023); Schumacher et al. (2024); ESTCP Project ER24-4485 (2024)(Completion anticipated in 2027) |
| Presence of vapor-forming PFAS in indoor and outdoor air | Fluorotelomer alcohols (FTOHs), perfluoroalkane sulfonamides (FASAs), perfluoroalkane sulfonamido ethanol (FASEs), and ultrashort-chain PFAS (ultrashort PFAS) have been detected in indoor and outdoor air samples. Not all vapor-forming PFAS are known or able to be detected by currently published vapor sampling methods | Zhi et al. (2024); Wallace et al. (2024); Schumacher et al. (2024); ASTM (2024) |

| Topic | Current Understanding | References & Forthcoming Research |
|---|---|---|
| Possible indoor air sources of vapor-forming PFAS | Active area of research. FTOHs are commonly detected in indoor air samples | Li and Kannan (2024) |
| Transformation of vapor-forming PFAS to nonvolatile end points/transformation of nonvolatile PFAS to vapor-forming PFAS | Nonvolatile terminal PFAS, such as perfluorononanoic acid (PFNA), perfluorooctanoic acid (PFOA), and perfluoroheptanoic acid (PFHpA), can also be formed from degradation of FTOHs, and perfluorooctane sulfonic acid (PFOS) can be released from transformation of perfluorooctane sulfonamido ethanol (FOSE) | Wijayahena et al. (2025) |

Although research has shown that certain PFAS "have sufficient vapor pressures to be designated as vapor-forming chemicals and; thus, be a concern for VI into the indoor air of residences and buildings overlying a contaminated soil or groundwater source" (USEPA 2023), there is still little information or consensus as to what concentrations in the subsurface warrant a VI assessment and what concentrations in indoor air may be of concern. For example, there is currently a lack of data related to inhalation toxicity values for vapor-forming PFAS, which is discussed in greater detail in Section 2.2 below. Given the current knowledge gaps associated with vapor-forming PFAS and the potential implications on the VI pathway, this fact sheet provides only a cursory discussion on the current state of science, but does not include a detailed discussion on the following topics:

- Vapor-forming PFAS inhalation toxicity values
- Estimation of vapor-forming PFAS inhalation exposure risks due to VI
- PFAS VI site types
- PFAS investigation protocols
- PFAS-specific VI conceptual site models
- Particulates (for example, aerosols, mists, fumes, dust), which are generally not considered as part of the VI pathway
- Direct entry of PFAS-impacted liquids into a building (for example, as a result of the direct volatilization of impacted groundwater to indoor air)
    - Considerations for the direct volatilization of impacted groundwater to indoor air (for example, in the case of shallow groundwater entry in a basement or basement sump) is discussed in the VI Direct Volatilization Fact Sheet.
- Transformation of vapor-forming PFAS to nonvolatile end points, or transformation of nonvolatile PFAS to vapor-forming PFAS

As discussed in the PFAS-1 Guidance Document, the list of known PFAS is extensive and evolving (Section 2.2, Table 2.1 (ITRC 2026a)). A complete list of PFAS that are considered vapor-forming chemicals (VFCs) is unknown, though some known volatile and semivolatile PFAS have been identified and may be of potential relevance from a VI perspective. Figure 1 presents a qualitative graphic indicating that a subset of PFAS have been identified as VFCs. The dashed lines on the graphic indicate that the extent of the overlap between PFAS and VFCs is currently unknown. Additionally, the size of the circles should not be interpreted as quantitative comparison of the number of PFAS and VFCs that are known to exist.

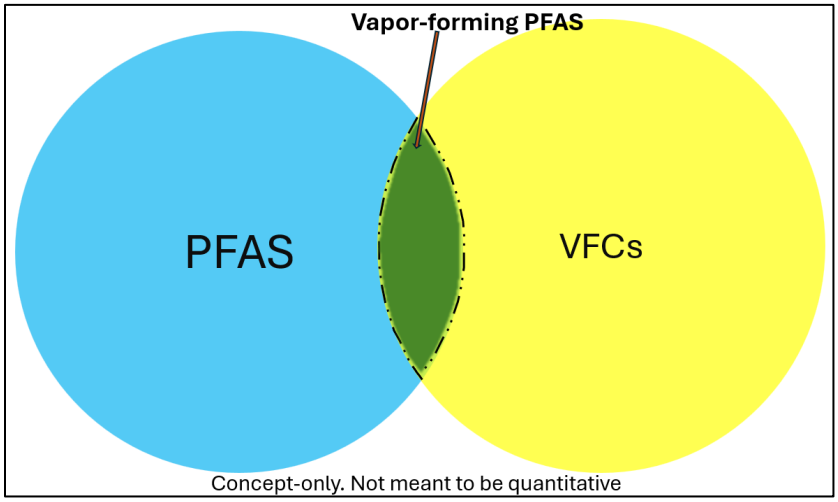


**Figure 1. Conceptual relationship between PFAS and VFCs.**

*Source: C. Regan, Haley & Aldrich. Used with permission.*

## 1.1 Relevant Definitions and Other ITRC Documents

To effectively use this fact sheet, it is important to understand the concept of VI, as well as pertinent information about the family of chemicals known as PFAS. The following definitions of PFAS and vapor intrusion, as defined by ITRC, are relevant to this fact sheet. Included below are also references to relevant sections of ITRC's PFAS-1 Guidance Document and VI Toolkit Documents where more information on these two topics can be found.

PFAS constitute a large family of synthetic fluorinated chemicals, exceeding several thousand in number, that might be in commercial use or present in the environment. The compounds vary widely in their chemical and physical properties. The PFAS-1 Guidance Document (https://itrcweb.org/pfas-guidance/) provides an in-depth understanding of PFAS, including information on physical and chemical properties (Section 4), history and use (Section 2), fate and transport (Section 5), sampling and analysis (Section 11), and human and ecological health effects (Section 7).

VI occurs when subsurface vapors migrate into overlying buildings through vapor transport pathways and impact indoor air. If present at sufficiently high concentrations in indoor air, these vapors may exceed a risk threshold for the health and safety of building occupants. The VI pathway can be relatively complex, depending upon several factors, including but not limited to the subsurface environment, building conditions and use, and vapor source (distinguishing whether the vapors in indoor air are attributable to a subsurface or indoor air source). The general topic of VI is discussed in ITRC's VI Toolkit, (see https://itrcweb.org/vapor-intrusion-toolkit) which includes an introduction to VI (VI 101). If a specific PFAS is sufficiently volatile to be considered a VFC, then it could be assumed that vapor migration in the subsurface and subsequent vapor transport into a building would be conceptually similar for vapor-forming PFAS as for other non-PFAS VFCs (for example, chlorinated volatile organic compounds (VOCs), petroleum hydrocarbons). This conceptual site model (CSM) may be simplified to the figure below (Figure 2). However, unlike VFCs typically encountered at VI sites, vapor-forming PFAS may transform into nonvolatile or ionic PFAS in the environment. In addition, nonvolatile PFAS may transform into a vapor-forming PFAS in the environment (Wijayahena et al. 2025). As a result, potential PFAS transformations thus add further complexity in developing a VI CSM for vapor-forming PFAS.

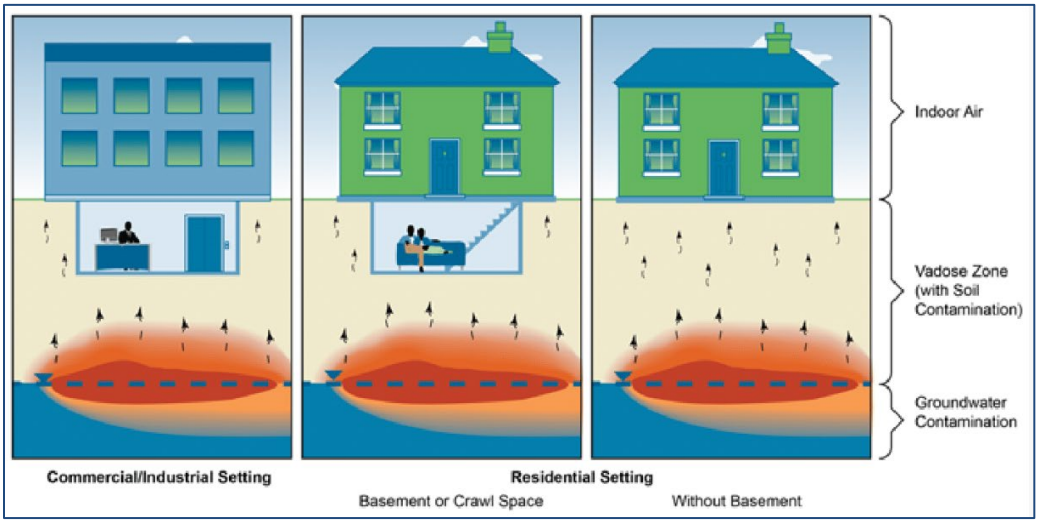


**Figure 2. General VI CSM (ITRC PVI-1, 2014)**

## 1.2 Why Discuss PFAS and Vapor Intrusion?

PFAS were identified as contaminants of emerging concern in the early 2000s, and have since been the focus of numerous studies evaluating their potential to cause adverse effects in humans (see Section 7.1 of the PFAS-1 Guidance Document). Concerns over PFAS effects on humans and ecological receptors have led some state and federal agencies to recommend or promulgate health-based screening levels or standards for PFAS in both groundwater and soil, which drive potentially responsible parties to sample and investigate potential PFAS impacts at their properties.

From a VI perspective, in cases where VFCs (for example, chlorinated VOCs, petroleum hydrocarbons) with health-based screening levels are identified in site soils or groundwater, or both, guidance documents often recommend a VI assessment (for example, soil vapor sampling, indoor air sampling) be performed if buildings are present or could be present in the future. Therefore, the purpose of this fact sheet is to summarize the current state of the science related to vapor-forming PFAS and their potential relevance to the VI pathway.

According to USEPA's current VI research (https://www.epa.gov/land-research/vapor-intrusion-research), comingled subsurface chemical sources that include vapor-forming PFAS may be of concern during VI site assessments. In 2023, USEPA's Office of Research and Development published a report summarizing a study looking for vapor-forming PFAS, in particular FTOHs, in soil vapor at a PFAS manufacturing facility and a municipal solid waste landfill (USEPA 2023). This study, described in more detail in Section 3.1 below, concluded that "with the presence of PFAS in soil, soil gas (including sub-slab soil gas), and groundwater, the potential for VI has been recognized; however, the final confirmatory analysis of indoor air to complete the exposure pathway is lacking" (USEPA 2023). Although researchers have recognized the potential for VI of vapor-forming PFAS, quantitative risk evaluation of the VI pathway requires inhalation toxicity values for vapor-forming PFAS, which are currently being studied.

The State of Hawai'i Department of Health (HI DOH) is the only known state agency that has published interim risk-based screening levels in the context of VI (HI DOH 2025). Additional information regarding the current understanding of volatile PFAS inhalation toxicity is presented in Section 2.2.

This fact sheet summarizes studies that provide preliminary information on PFAS as they relate to VI.

## 1.3 What Questions Are Currently Relevant to the PFAS VI Discussion?

This fact sheet has been prepared to summarize what has been reported in the research to date to address the following questions:

- Are PFAS volatile, and if so, which compounds?

- Do vapor-forming PFAS have risk-based screening levels for inhalation exposure?
- Are PFAS found in soil vapor?
- Are PFAS found in indoor and outdoor air?
- How do we currently sample and analyze PFAS in soil vapor and air?
- What are the expected PFAS source distinction challenges in VI investigations?

# 2 PFAS VOLATILITY AND INHALATION RISK

For PFAS to present a VI concern, they must be classified as a VFC and have the potential to be present in vapors at concentrations that pose a risk to human health. This section covers the current knowledge regarding PFAS volatility and inhalation toxicity.

## 2.1 Volatility

The volatilization of PFAS is highly dependent on individual physical and chemical properties of the compound and site conditions. USEPA's VI guidance discusses the use of vapor pressures and Henry's law coefficients as indicators for screening whether a chemical with known inhalation risks is sufficiently volatile to migrate from soil or groundwater and pose a potential VI concern (USEPA 2015). USEPA (2015) considers a compound to be volatile if it has a "vapor pressure greater than 1 millimeter of mercury (mm Hg) or a Henry's law coefficient greater than $10^{-5}$ atmosphere-meter cubed per mole" (atm $m^3$ $mol^{-1}$). Numerous compounds meet this volatility criterion, including a number of both anionic and neutral PFAS (Abusallout et al. 2022; Schumacher et al. 2024). See **Table 4-1** from the PFAS-1 Guidance Document.

As discussed in greater detail in Section 4.2 of the PFAS-1 Guidance Document, there are limited reliable data on the physical and chemical properties related to PFAS volatilization. For example, reported Henry's law coefficients can span multiple orders of magnitude for a single PFAS (see **Table 4-1** (ITRC 2026a)), making it difficult to know which values are most representative of the compound's behavior in the environment. The underlying reasons for the large range in physical and chemical properties are unclear, but may be attributed to differences in measurement conditions, experimental methodology, or modeling assumptions (Abusallout et al. 2022; Hammer and Endo 2022; Endo 2023; USEPA 2023; Zhang and Suuberg 2023; Licul-Kucera et al. 2025). Thus, there is some ambiguity whether certain compounds meet the USEPA volatility definition when the range of estimated or measured vapor pressures or Henry's law coefficients, or both extend both below and above the thresholds.

The volatilization of anionic PFAS is influenced by pH-dependent aqueous phase dissociation. In general, PFAS that are acidic at circumneutral (environmentally relevant) pH have lower reported vapor pressures and higher water solubilities, which significantly limits their potential for volatilization from water to air. However, the literature suggests that certain PFAS that are ionized in aqueous solution would not be ionized if present in an organic phase such as a NAPL or asphalt (Bastow, Douglas, and Davis 2022). Literature evidence exists for the direct sublimation of PFOA in the solid phase to air (Kaiser et al. 2010; Zhang et al. 2020). Some PFAS contain specific functional groups that increase their volatility (for example, the alcohol functional group in FTOHs). Transport of anionic PFAS in air is generally understood to primarily occur through association with airborne aerosols and other small particulates and in the vapor phase (Ahrens et al. 2012; Ahrens et al. 2013; Karásková et al. 2018; Tao et al. 2023) (see Section 5.2.4 and Section 5.3.2 of the PFAS-1 Guidance Document for additional discussion regarding partitioning of PFAS to air).

Although inhalation exposure to PFAS may occur as inhalation of PFAS-containing dust and aerosols, the ideal data to understand VI-related PFAS risks would consist of toxicity information only for vapor-phase PFAS via the inhalation pathway. At this time, vapor-phase occurrence is most understood to be associated with neutral PFAS such as FTOHs, FOSE, perfluorooctane sulfonamide (FOSA), and ultrashort-chain PFAS (considered to include 3 or fewer carbon atoms) (see Section 7.1.8 of PFAS-1 Guidance Document). It should be recognized, however, that certain vapor-forming PFAS can undergo transformation to nonvolatile PFAS in environmental media. PFAS transformation is influenced by physical, chemical, and biological conditions.

## 2.2 Inhalation Risk

One aspect of PFAS VI is whether there are vapor-forming PFAS that migrate from subsurface into indoor air; another is whether PFAS VI occurs at appreciable levels to be a concern for human health. Evaluation of health risk and development of health-protective screening levels requires an understanding of exposure levels (doses) and toxicity information (response levels). USEPA has developed Regional Screening Levels (RSLs) that are "chemical-specific concentrations for individual contaminants in air, drinking water, and soil" that represent acceptable risk levels and, "if exceeded, may warrant further investigation" (USEPA 2024). These RSLs are based on default exposure parameters and factors (USEPA 2024).

Risk-based RSLs cannot be developed when there is insufficient toxicity information, such as for emerging chemicals of concern and chemicals whose exposure, metabolic, and toxicity behavior is poorly understood. As of 2025, USEPA has not developed inhalation-based RSLs for any PFAS, including the PFAS that are considered volatile enough to potentially be part of the inhalation exposure pathway.

As noted in USEPA's RSLs (USEPA 2024), for inhalation exposures, the required human health-based toxicity information includes noncancer Reference Concentration values (RfC) and cancer-based inhalation unit risk (IUR) values. In combination with exposure estimates, RfCs and IURs are used to develop screening levels that would be protective of noncancer and cancer-based health effects via the inhalation exposure pathway. An RfC (expressed in units of $\mu g/m^3$) is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (USEPA 2022). The IUR is defined as "the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 $\mu g/m^3$ in air" (USEPA 2022). IUR toxicity values are expressed in units of $(\mu g/m^3)^{-1}$.

To estimate health-protective indoor air concentrations, inhalation-based toxicity criteria are needed. The current USEPA RSLs (USEPA 2024) do not have inhalation-based toxicity values for carcinogenic or noncarcinogenic endpoints for any of the listed PFAS. Similarly, of the 96 PFAS included in the Oak Ridge National Laboratory Risk Assessment Information System (ORNL RAIS; ORNL 2023), none have inhalation toxicity criteria, whether IUR for carcinogens or various reference concentrations for noncarcinogens (acute, subchronic, short-term, or chronic). However, there is one known state agency, HI DOH, that has recently published interim VI risk-based screening levels for volatile/semivolatile PFAS (two for subsurface vapor and six in indoor air) (HI DOH 2025). HI DOH has established interim soil vapor screening levels for two ultrashort-chain (defined as having three or fewer carbon atoms) PFAS: trifluoroacetate (TFA), also called perfluoroethanoate, (PFEtA-); and perfluoropropanoate (PFPrA-). However, HI DOH acknowledged the unknowns with respect to potential toxicity associated with volatile and semivolatile PFAS and that relevant PFAS sampling and analysis methods have not been established. As such, the HI DOH interim PFAS Environmental Action Levels guidance does not currently require VI assessments for sites associated with PFAS (HI DOH 2025).

Reliable toxicity and health effects information for vapor-phase PFAS are currently lacking. Inhalation toxicology studies in humans or laboratory animals were not identified for FTOHs, FOSE, and FOSA (see Section 7.1.8 of the PFAS-1 Guidance Document). It is notable that studies suggest that oral and inhalation toxicokinetics are similar for certain PFAS and, therefore, systemic toxicity effects would likely be similar regardless of whether the intake route was oral or inhalation. For example, one study by Monnot et al. (2022) involved an in-depth analysis of two of the most studied PFAS—PFOA and PFOS—drawing on published research on PFAS ingestion toxicity, physiologically based pharmacokinetic (PBPK) modeling, and inhalation exposures compared with blood serum levels. PBPK modeling is an established mathematical approach that uses a range of biological and chemical data to predict chemical behavior throughout the body and provide toxicity information. The study authors concluded that there is sufficient evidence to support route-to-route extrapolation for certain PFAS. However, this study was limited to the two PFAS for which the most toxicity data are available (PFOS and PFOA), and these are currently understood to be predominantly nonvolatile under typical vadose zone conditions.

Further, the literature lacks reliable oral toxicity information for vapor-forming PFAS. Therefore, the approach used by some agencies of estimating inhalation toxicity for vapor-phase PFAS by extrapolation from oral toxicity data is also not

possible at this time. Although some states, such as New Jersey Department of Environmental Protection (NJDEP), developed inhalation toxicity values for PFOS, PFOA, and hexafluoropropylene oxide dimer acid (HFPO-DA, Gen-X) using route-to-route extrapolation (NJDEP 2019, 2022), these PFAS are understood to be predominantly nonvolatile in the vadose zone. Therefore, it's unclear if they are likely to be relevant from a VI perspective.

Several ultrashort-chain (ultrashort) PFAS have been reported in indoor air although their association with dust or as vapor-phase in soil vapor is not clear and requires more research (Zheng et al. 2023). Trifluoroacetic acid (TFA) has also been reported in soil vapor (Freeling and Björnsdotter 2023). Available toxicity and health effects information from all exposure routes for ultrashort PFAS were reviewed (see Section 1.4.4 of the PFAS-1 Guidance Document). Among the ultrashort perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkane sulfonic acids (PFSAs), some limited health effects information based on animal studies was found only for TFA, perfluoropropionic acid (PFPrA), perfluoro-2-methoxyacetic acid (PFMOAA), and trifluoromethanesulfonic acid (TFMS). Reliable dose-response information that could be used to develop inhalation-based toxicity values was not noted in these studies.

**Section 4** of this fact sheet presents a discussion of PFAS criteria for air that state agencies and other organizations have developed. The PFAS air criteria published so far (see the **PFAS Environmental Media Values Table** in the PFAS-1 Guidance Document) are based on route-to-route extrapolation of ingestion-based toxicity criteria being adjusted to derive inhalation toxicity criteria.

# 3 CURRENT UNDERSTANDING OF PFAS IN SOIL VAPOR AND AIR

## 3.1 PFAS in Soil Vapor

The unsaturated conditions in the vadose zone create extensive air-water interfaces that can attract PFAS, significantly increasing their retardation and limiting their movement through the soil column (Sharifan et al. 2021). Studies have demonstrated that adsorption of anionic PFAS at these interfaces accounts for a substantial portion of their overall retention (see Section 5.4.2.1 of the PFAS-1 Guidance Document). In contrast, the fate and transport of neutral PFAS in the vadose zone remains less understood. Titaley et al. (2022) evaluated various AFFF concentrates (1974 to 2010) and quantified select neutral PFAS at milligram per liter levels in the aqueous phase. Using the Johnson and Ettinger (J&E) model (1991), the study estimated indoor air concentrations resulting from simulated AFFF spill scenarios. The model projections indicated that indoor air PFAS concentrations migrating from the subsurface could exceed concentrations found emanating from background sources by several orders of magnitude. However, the J&E model may not be an appropriate method for predicting VI for PFAS-impacted sites, in part because the J&E model does not consider that chemical transformations/biodegradation and volatile PFAS can transform to nonvolatile forms in the environment. Further, the volatility of PFAS and toxicity values are also still being researched. Although the Titaley et al. (2022) study quantified select neutral PFAS in aqueous phase associated with an AFFF source, several of the VI–related modeling assumptions require further evaluation to better understand the potential implications from a VI perspective.

A recent USEPA (2023) study underscored the need to better understand vapor-phase transport of PFAS in the vadose zone. This study analyzed groundwater, soil vapor, and ambient air samples from an active PFAS manufacturing facility in New Jersey and a municipal solid waste (MSW) landfill in Georgia (USEPA 2023; Schumacher et al. 2024). Indoor air samples were not collected as part of the study, which are typically needed to help definitively demonstrate a complete VI pathway. The samples were tested for select PFAS, including FTOHs and PFCAs, using several analytical methods, including a modified USEPA Method TO-17 for analyzing select PFAS in soil vapor. The findings provide a preliminary assessment of vapor-phase PFAS in soil vapor at these sites.

At the New Jersey site, both FTOHs and PFCAs were detected in ambient air and sub-slab and exterior soil vapor samples collected on multibed sorbent tubes analyzed using a thermal desorption (TD)-GC/MS/MS method (USEPA Method TO-17; USEPA 1999) (Schumacher et al. 2024; Table 1); however more recent laboratory testing of the TD-GC/MS/MS method by the same group suggested that the identification of PFCAs with this method is subject to potential positive interferences from thermally labile PFAS (Hayes et al. 2025).

Recent studies have also analyzed PFAS in MSW landfill gas (Lin et al. 2024; Titaley et al. 2023). The studies, conducted in the southeastern United States, both found that FTOHs were the predominant class of PFAS in landfill gas samples. In Lin et al. (2024), FTOHs comprised 87%–97% of total neutral PFAS in landfill gas samples. They found that the total mass of fluorine leaving the landfills as landfill gas was comparable or greater than the mass leaving the landfill as leachate.

## 3.2 PFAS in Indoor and Outdoor Air

Numerous studies have identified select PFAS in both indoor and outdoor air. Outdoor ambient air sources of PFAS are typically highest near industrial facilities that produce PFAS or use PFAS chemicals or products in manufacturing; areas proximal to Class B firefighting foam use; waste management facilities, including landfills and wastewater treatment plants; and areas of biosolids production and application (Wallace et al. 2024). Both ionic and neutral PFAS can be transported both locally and globally (see Section 5.2.4 and Section 5.3.2 of the PFAS-1 Guidance Document for additional discussion regarding partitioning of PFAS to air). PFAS have been detected in indoor air in homes, offices, and other indoor environments (Shoeib et al. 2004; Shoeib et al. 2005); see Section 6.1.2 of the PFAS-1 Guidance Document. Examples of potential indoor air sources of PFAS include stain- and water-resistant coatings used on many consumer products, such as carpet, upholstery, clothing, grease-resistant paper, food packaging, and nonstick cookware and ingredients used in cleaning products, personal care products, cosmetics, paints, varnishes, and sealants. The PFAS-1 Guidance Document (see Section 6.1 and Section 17.1) provides a summary of indoor air concentrations of PFAS that have been reported in the literature in schools, homes, and offices prior to 2022. The PFAS-1 Guidance Document (see Section 2.5, Table 2.6) also includes a list of PFAS products and uses.

Vapor-forming PFAS in subsurface and indoor air are most relevant for potential VI considerations. Although many of the PFAS in air studies have not differentiated between ionic (nonvolatile) and neutral (volatile or semivolatile) PFAS, an increasing number of recent studies have considered them separately (Wallace et al. 2024; Li and Kannan 2024; Eichler et al. 2023). The most widely studied PFAS in air include FTOHs, FASAs, and FASEs (Wallace et al. 2024).

A study by Li and Kannan (2024) analyzed 58 PFAS, including FTOHs, FOSAs, and FOSEs in home, office, and outdoor air in North America and detected FTOHs (principally 6:2 FTOH, 8:2 FTOH, and 10:2 FTOH) at the highest concentrations overall (total FTOHs were detected at 1900 +/- 2000 pg/$m^3$ [picograms/cubic meter]). The indoor sources for these FTOHs are suspected to be associated with various products and materials listed in this subsection (for example, carpet, upholstery, nonstick cookware, personal care products, paints, sealants) and in industrial buildings, if AFFF has been released, from concrete surfaces (Douglas et al. 2023). The Li and Kannan (2024) study differentiated between neutral and ionic species in air and determined that the legacy long-chain ionic PFAS were predominantly particulates (86% and 74% of PFCAs and PFSAs, respectively, detected in air were detected as particulates). By contrast, the neutral PFAS—FTOHs and FOSAs—were detected in the particulate phase in only 3% and 7% of samples, respectively, with the remaining proportion associated with the vapor phase. The study completed by Eichler et al. (2023) found results similar to Li and Kannan (2024), with FTOHs as the dominant PFAS detected in indoor air in several North Carolina homes (for example, 6:2 FTOH ranged from 1,800 to 49,000 pg/$m^3$).

Collectively, an increasing body of research has identified PFAS in both outdoor and indoor air environments. However, as discussed throughout this fact sheet, no studies have demonstrated that PFAS detections in indoor air are associated with the subsurface to indoor air VI pathway. Given the prevalence of vapor-forming PFAS found in commonly used materials and products, source distinction (for example, distinguishing between PFAS from an environmental release/VI versus from a background source) is challenging and is expected to be an important consideration in developing and evaluating potential VI CSMs.

For the purposes of this fact sheet, “background sources to air“ refers to the presence of volatile PFAS in indoor air that is not due to an environmental release at the site and is not due to VI. Section 2.5, Table 2.6 of the PFAS-1 Guidance Document has a compilation of PFAS used in various products, industries, and applications. This may be a starting point for understanding potential contributions of PFAS to background indoor air.

The presence of PFAS in indoor air due to background (for example, PFAS volatilization from consumer products), or an ambient outdoor air source migrating to indoor air (for example, outdoor air that is transported indoors through natural or

mechanical means), can confound the assessment of VI and is expected to present challenges in data interpretation and developing accurate PFAS VI CSMs. PFAS background sources are the subject of ongoing research as noted above. Additional discussion and information regarding the concept of background sources to indoor air is included in the Background Sources to Indoor Air Fact Sheet of the ITRC VI Toolkit (see https://itrcweb.org/vapor-intrusion-toolkit).

# 4 PFAS IN AIR REGULATORY CONSIDERATIONS

Although the understanding of PFAS in air in 2025 is more complete than even 5 years ago, there are still many unknowns. One such unknown is VI of PFAS. Although PFAS VI could occur, the significance is not understood. Knowledge about which PFAS are VFCs and present in the subsurface and how they transform is still developing. Even if PFAS VI occurs and can be measured, health-protective, numerical indoor air criteria would be needed to evaluate the data.

Various regulatory agencies have developed benchmark criteria for PFAS in air, as shown in the **PFAS Environmental Media Values Table** in the PFAS-1 Guidance Document. Additional information is included in the ECOS (2025) report. These regulatory agencies include state departments throughout the United States, international agencies, and the American Conference of Governmental Industrial Hygienists. Because measuring and controlling PFAS in air is still developing, many of these air criteria differ from one another, and only one known agency has developed interim screening levels specific to VI (HI DOH 2025). In general, the air values were developed for PFAS with different structures—such as PFOS, PFOA, and PFBA—and to be applied in different situations. For example, some air criteria are created for occupational exposures, whereas others are for outdoor ambient air exposures. Because of this, there are no standardized air criteria that are widely accepted among these various agencies.

In 2021, the USEPA released a PFAS Strategic Roadmap (PFAS Roadmap) that outlines the USEPA's goals from 2021 to 2024 to help address the PFAS problem (USEPA 2021). The PFAS Roadmap focuses on various environmental media, and it includes goals related to addressing, measuring, and evaluating risks from PFAS in air. However, VI is not specifically mentioned in the PFAS Roadmap. On the other hand, as described in **Section 3.1**, USEPA published a report in 2023 documenting the findings of a PFAS study of two sites where PFAS had been released (USEPA 2023). FTOHs and PFCAs were found in soil gas, and the results suggest that both may migrate in the vapor phase. But, without corresponding indoor air data, a completed VI exposure pathway could not be established. In the meantime, given the range of adverse health effects associated with PFAS exposures in general, USEPA concluded in the 2023 report that a VI assessment should be considered at sites with "high" PFAS concentrations (an undefined threshold) in shallow soil and groundwater. However, as discussed in **Section 2.2**, quantitative risk evaluation of the VI pathway requires inhalation toxicity values for vapor-forming PFAS, which are currently being studied. There is only one known state agency, HI DOH, that has published interim VI-related risk-based screening levels for a limited number of volatile PFAS, which are indicated to be under review (HI DOH 2025). This unknown should be considered prior to evaluating a site for VI from volatile PFAS.

# 5 SAMPLING AND ANALYTICAL METHODS

To date, several peer-reviewed studies on the evaluation of quantitative PFAS concentrations in the vapor phase have been published. These studies included the collection of soil vapor, sub-slab vapor, or indoor/outdoor air samples using both active and passive sampling methods with a variety of sorbents (for example, thermal desorption tubes using modified USEPA Method TO-17, polymeric resins [for example, XAD] sorbents, polyurethane foam [PUF] disks, or polyethylene [PE] sheets). Although various methods have been implemented in research settings, most of which focus on PFAS in air, few studies have focused on PFAS sampling in soil vapor. Additionally, sampling PFAS presents challenges, such as potential cross-contamination or precursor transformations during the sampling process (for example, during sample preservation, storage, analysis). As a result of the limited research and numerous sampling challenges, there are no standardized methods for sampling vapor-forming PFAS in air or soil vapor.

Researchers have primarily analyzed these samples using thermal desorption (TD)/GC/MS (for example modified USEPA Method TO-17) to quantify concentrations of neutral PFAS (Morales-McDevitt et al. 2021; Wallace et al. 2024; Hayes et al. 2025). Recent research has demonstrated that volatile PFAS could be preconcentrated in gaseous phases using solid-

phase microextraction (SPME; Martínez-Pérez-Cejuela et al. 2025). Current research has included the development of a modification to USEPA Method TO-17 for quantification by tandem MS and multiple reaction monitoring (MRM) to improve sensitivity and selectivity (Schumacher et al. 2024; Hayes et al. 2025). It should be noted that some of these methods do not separate gas-phase and particle-bound PFAS. Research on PFAS in the vapor phase remains ongoing, with numerous investigations at various stages of implementation or completion. Some of these studies include using additional vessels for the collection of media samples (evacuated canisters, BottleVACs, and other sorbents) and the development of new test methods or modification of existing test methods (for example, OTM-55). However, currently there are no standardized and validated methods for analysis of vapor-forming PFAS in soil gas. ASTM methods relevant to indoor air have recently been released (ASTM 2024). Stationary source testing methods (OTM-45 and OTM-50) are not currently applicable to VI (USEPA 2024).

For details on soil vapor, sub-slab vapor, or indoor/outdoor air sampling and analytical methodologies please refer to the Sampling and Analytical Methods section of the VI Toolkit Document. For additional important information on collecting environmental media samples specifically for PFAS analysis, see Section 11.1, General Sampling BMPs, of the PFAS-1 Guidance Document, including current information for Air Emissions to Air and Ambient Air (see Section 11.1.7.12).

# 6 RISK COMMUNICATION

The rapidly evolving science of PFAS with specific respect to VI can make providing explanations to stakeholders difficult. Transparency about the many unknowns will improve risk communication. Most stakeholders consider PFAS as a group of contaminants, which can cause confusion when conducting VI investigations, because many PFAS are not VFCs at environmentally relevant conditions.

PFAS risk communication should include the need for educating stakeholders about uncertainties associated with the content of this fact sheet, such as:

- Differences between PFAS in indoor air associated with particulate matter versus vapor phase
- Current limited toxicity data for volatile PFAS
- Evolving sampling and analytical methods
- Challenges with distinguishing background sources of volatile PFAS to indoor air

In addition to the technical information provided in this fact sheet, the ITRC Vapor Intrusion Community Engagement section (see **https://itrcweb.org/vapor-intrusion-toolkit**) discusses ways to communicate these issues to the stakeholders, including regulators and practitioners.

Additional ITRC references for risk communication are listed here:

- PFAS-1 Guidance Document, Risk Communication and Stakeholder Perspectives Sections: **https://itrcweb.org/pfas-guidance/**
- ITRC Risk Communication Toolkit: **https://itrcweb.org/risk-communication-toolkit-guide/**

# 7 PFAS VI EVALUATION CONSIDERATIONS & DATA GAPS

The current understanding of the VI potential of PFAS is hindered by multiple data gaps and uncertainties. Directly relevant laboratory- and field-based research studies remain limited, leaving several questions about the VI potential for PFAS unresolved. Key challenges and data gaps include limited standardized sampling and analytical methods, a limited understanding of PFAS fate and transport in the vadose zone, limited toxicological data to evaluate inhalation risks, and limited understanding of the physical and chemical properties of vapor-forming PFAS under environmentally relevant conditions.

There are limited reliable data on the physical and chemical properties related to PFAS volatilization. For example, Henry's law coefficients can span multiple orders of magnitude for a single PFAS. There are also thousands of PFAS for which the volatility has not been studied. Despite these unknowns, there is greater confidence that select PFAS—such as FTOHs, FASAs, FASEs, and some ultrashort-chain PFAS such as TFA—exhibit volatility and may be of potential relevance to the VI pathway. Limited field studies have shown PFAS in soil gas, indoor air, and ambient air. However, no studies have demonstrated vapor-forming PFAS transport from a subsurface source to indoor air.

Although USEPA (2023) has recommended consideration of VI assessments at sites with "high" PFAS concentrations in shallow soil or groundwater, no federal risk-based thresholds have been defined. Some state agencies (for example, California Department of Toxic Substances Control and New Jersey DEP) have developed provisional inhalation toxicity values for select PFAS; however, these are limited to PFOA, PFOS, and Gen-X, which are understood to be predominantly nonvolatile in the vadose zone. Therefore, it's unclear if they are relevant from a VI perspective. The State of Hawai'i DOH is the only known state agency to publish interim risk-based soil vapor screening levels, but it currently does not require VI assessments at PFAS sites.

Given the current knowledge gaps with respect to volatile PFAS and the VI pathway, site assessments may be premature. However, in assessing sites with "high" concentrations of potentially volatile PFAS in shallow soil or groundwater "near" buildings, regulators and responsible parties should be aware that assessment of PFAS VI could be appropriate in the future. Environmental project managers and others involved in sites should therefore be aware of ongoing research and communicate with transparency the current uncertainties related to the potential relevance of vapor-forming PFAS on the VI pathway prior to making site management decisions.

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