Per- and Poly-fluoroalkyl Substances (PFAS) in Artificial Turf: Academic, municipal, and other testing efforts

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A number of organizations have conducted PFAS testing in artificial turf materials. These include academic studies as well as testing conducted by nonprofit organizations, municipalities, and manufacturers or vendors, sometimes with the assistance of consulting firms. This document provides a compilation of results that have been reported from many of these testing efforts.

This document is a companion to an earlier Lowell Center publication, Per- and Polyfluoroalkyl Substances (PFAS) in Artificial Turf: Test Methods.[1] Please see that publication for background about sources of PFAS in artificial turf, and for a discussion of key considerations related to test methods. For another recent summary of test results, see the New Jersey Department of Environmental Protection's Technical Memorandum on PFAS in Artificial Turf.[2] Additional detail on PFAS test methods can be found in ITRC's report, Per- and Polyfluoroalkyl Substances (PFAS): Technical/Regulatory Guidance.[3]

Test results are summarized below for academic studies; regional and municipal testing; testing organized by nonprofits, community organizations, and journalists; and test data provided by manufacturers. The tests summarized here have been carried out using a variety of methods and approaches. This document does not provide an evaluation of the robustness, accuracy, or precision of the methods or results.

Academic studies

Academic studies have explored a range of methods for assessing PFAS in artificial turf materials, and expanded the information available on the presence of PFAS in these materials. Results from these studies are summarized in Table 1.

Lauria et al. 2022. Researchers measured total fluorine (TF), extractable organic fluorine (EOF), and targeted PFAS in carpet backing, carpet blades, and infill samples from 17 artificial turf fields in Stockholm, Sweden.[4] The infill samples included thermoplastic olefins, thermoplastic elastomer (TPE), styrene-butadiene rubber (SBR), sand, ethylene propylene diene monomer rubber (EPDM), and organic materials (i.e., cork, bark, and coconut).

TF was measured in all samples. TF was higher in thermoplastics and EPDM than in SBR and organic material infills. EOF was measured in 42% of samples. Among specific PFAS examined in the targeted analysis, long chain perfluoroalkyl carboxylic acids (PFCAs) were detected most frequently.

The authors explain that "collectively, these results point toward polymeric organofluorine (e.g., fluoroelastomer, polytetrafluoroethylene, and polyvinylidene fluoride), consistent with patent literature."[4]

The authors estimate that each field contained 0.315–17.439 kg of fluorine that would eventually be landfilled or incinerated.

Zuccaro et al. 2022. Zuccaro et al. (2022) conducted a pilot study assessing an extraction-analysis method to identify and quantify fluorotelomer alcohols (FTOHs) in artificial turf carpet and crumb rubber infill made with shredded used tires.[5] FTOHs make up a "class of PFAS known to be volatile precursors of other, more harmful PFAS such as PFOA." Samples were extracted using a solvent and analyzed by gas chromatography-mass spectroscopy (GC-MS). 8:2 FTOH was measured in artificial turf fibers (1.0 ng/ µL (ppm)) and in crumb rubber infill.

Whitehead, 2023. Whitehead (2023) used several testing methods to analyze 27 samples of artificial turf blades to determine the presence of PFAS.[6]

For context, Whitehead explains that fluorinated polymer processing aids (fPPAs) are "added directly to raw plastic resins" prior to the resins being "heated, mixed, and extruded or blown into a final plastic product." Thus, the fluorinated polymer is incorporated into the final plastic product as part of the manufacturing process.

Whitehead used PIGE to measure TF in samples before and after an extraction. TF ranged from below detection limit to 2.94 µg F/cm2. Results showed only minor changes after extraction, suggesting that "much of the fluorine present in these samples is from nonextractable, potentially polymeric, sources of fluorine." This is consistent with the uses of fPPAs in plastic and rubber products described in the existing literature.

Whitehead also conducted targeted tested for 21 individual PFAS using liquid chromatography tandem mass spectrometry (LC-MS/MS). All artificial turf samples had detectable amounts of at least one type of PFAS, though four of the samples had concentrations below the quantification limit. PFAS with a chain of eight or fewer carbons (short-chain) such as PFBA, PFOA, and PFHxS, were measured most frequently. The median sum of PFAS concentrations in the turf samples was 5.1 ng/g (ppb) and the highest sum of PFAS concentrations was 41.7 ng/g (ppb).

Fourier-transform infrared (FTIR) spectroscopy was used to characterize carbon-fluorine bonds in artificial turf samples. Results were compared with fluorinated polymer processing aids that are added to artificial turf polymers. Results were "indicative of the presence of organic fluorine in these samples, with a strong degree of similarity between spectra collected from samples to that of raw fluorinated polymer processing aids." This information further supports the possibility that fluorinated polymers were added to the resin.

A TOP assay was performed on four samples including artificial turf and product packaging. Because this testing included both artificial turf and other plastic products, this information is relevant primarily for refining methodologies. The three samples that had lower total concentrations of PFAS before oxidation did not have significant changes in concentration after oxidation. This was likely because those samples did not contain substantial quantities of the precursor PFAS that break down into the degradation products that were measured in the TOP assay. One sample had a higher concentration of PFAS before oxidation, and showed a higher concentration of degradation products after oxidation. This suggested that the sample contained higher quantities of the precursors that were measured in the TOP assay.

A conclusion of this study was that "these results suggest that much of the total fluorine signals measured in these plastics are from nonextractable, likely polymeric sources. These results are aligned with what might be expected, given fluorinated polymer processing aids being polymeric PFAS. This highlights that targeted analysis techniques are likely to miss significant portions of the PFAS that are present on various plastic products." In other words, this study further supports the importance of carefully choosing test methods that can accurately characterize PFAS content in artificial turf materials.

Table 1. Summary of PFAS testing from academic studies.

Source	Summary
Lauria et al. (2022)[4]	Total fluorine (TF), extractable organic fluorine (EOF), and targeted PFAS tests in 51 samples of artificial turf from fields in Stockholm, Sweden. Samples were separated into carpet backing, carpet blades, and infill. **TOTAL FLUORINE** • "TF was observed in all 51 samples (ranges of 16–313, 12–310, and 24–661 µg of F/g in backing, filling, and blades, respectively)." • TF was higher in thermoplastics and EPDM than in styrene butadiene rubber (SBR) and organic material infills. **EXTRACTABLE ORGANIC FLUORINE** • Backing: range from <LOD - 145 ng of F/g (ppb) • Infill: range from <LOD - 179 ng of F/g (ppb) • Blades: range from <LOD - 192 ng of F/g (ppb) **TARGETED ANALYSIS** • Results were reported as the sum of fluorine in a sample. • Backing: <LOD - 0.63 ng of F/g (ppb) • Infill: <LOD - 0.15 ng of F/g (ppb) • Blades: "absent"
Zuccaro et al. (2023)[5]	A pilot study assessing an extraction-analysis method to measure fluorotelomer alcohols (FTOH) in artificial turf carpet and crumb rubber infill. Samples were extracted using a solvent and analyzed by gas chromatography-mass spectrometry (GC-MS) in scanning ion mode (SIM). **FLUOROTELOMER ALCOHOLS PILOT TEST:** • "8:2 FTOH was detected in artificial turf fiber and crumb rubber infill samples at concentrations of 1.0 and 0.71 ng/µL [ppm], respectively. This translates to 300ng 8:2 FTOH/g artificial turf fiber and 110ng 8:2 FTOH/g crumb rubber. By contrast, 4:2 FTOH and 6:2 FTOH were not found to be present in detectable levels."
Whitehead (2023) (dissertation)[6]	Analyzed PFAS in 27 samples of artificial turf blades using several methods. **TOTAL FLUORINE** • Measured using particle-induced gamma ray emission (PIGE) spectroscopy. • TF ranged from <LOD to 2.94 µg F/cm2. **TARGETED ANALYSIS** Targeted testing for 21 PFAS using liquid chromatography tandem mass spectrometry (LC-MS/MS)

	• PFAS were detected in all samples. Median sum of PFAS concentrations in the turf samples was 5.1 ng/g (ppb) and the highest sum of PFAS concentrations was 41.7 ng/g (ppb). **ORGANIC FLUORINE** • Organic fluorine was measured using fourier-transform infrared (FTIR) spectroscopy. Results were "indicative of the presence of organic fluorine in these samples, with a strong degree of similarity between spectra collected from samples to that of raw fluorinated polymer processing aids." **TOP ASSAY (four samples only)** • "[T]he samples which had low or small sum of PFAS concentrations before TOP assay didn't have significant changes in their sum of PFAS concentrations. The sample which had the highest sum of PFAS concentrations before TOP assay showed a more significant increase in measured concentrations." • Results suggest that "the concentrations of fluorine measured through PIGE are likely indicative of PFAS which does not undergo transformation" into the compounds measured in the TOP assay.
Notes: Summaries in this document do not include any evaluation of the robustness, accuracy, or precision of the methods or results. Concentrations are shown in the units that were used in the original source. We have also added ppm, ppb, or ppt in parentheses for ease of interpretation. <LOD = below level of detection.	

Regional and Municipal Studies

The Martha's Vineyard Commission in Massachusetts tested artificial turf carpet, wood infill, shock pad, and two adhesives used during the installation of an artificial turf field.[7] The analyses included targeted analyses; TOP assay; and total fluorine analysis. Some of the results were derived using the synthetic precipitation leaching procedure (SPLP), an EPA method "designed to determine the mobility of both organic and inorganic analytes present in liquids, soils, and wastes."[8]

PFAS were detected in all materials. For example, the total organic fluorine analysis measured 70 ppm in the carpet, and lower quantities in other materials. Additional results are summarized in Table 2.

The City of Portsmouth, New Hampshire installed an artificial turf field in 2021. The product was marketed as "PFAS-free." Concerned residents and an environmental advocacy group led testing on samples of new artificial turf material. An independent laboratory measured TF on artificial turf blades, backing, and shock pad. TF was between 16 ppt – 119 ppm in the materials, indicating likely presence of PFAS.[9] Dr. Graham Peaslee, a PFAS expert at University of Notre Dame, reviewed these results and explained "these total fluorine measurements are typical for plastics that have been manufactured with PFAS-based polymer processing aids – which will leave residues of these PFAS at the part-per-million level on the artificial grass."[9]

The City of Portsmouth later initiated further testing with help from a consulting group. This effort included a targeted analysis that tested for 70 individual PFAS chemicals; TOP assay; and a non-targeted analysis. The materials tested included artificial turf carpet, walnut shell infill, and shock pad. The results showed presence of several types of PFAS in the carpet, infill, and shock pad. For example, in the walnut shell infill, the targeted analysis detected six PFAS, and the TOP assay detected four PFAS post-oxidation.[10] Results are summarized in Table 2.

Table 2. Summary of PFAS testing led by regional institutions and municipalities.

Source	Summary
Martha's Vineyard, MA (2020).[7] Laboratory results interpreted by consultants at Tetra Tech	Analysis of PFAS in samples of artificial turf carpet, wood infill, shock pad, and two adhesives used during field construction. **TARGETED ANALYSIS** ***"Total PFAS by isotope dilution method"*** • Detected certain PFAS at concentrations above the method detection limit (MDL) but below the RL, yielding the following estimated values: Carpet: PFPeA: 0.148 ng/g (ppb); Wood infill: PFPeA: 0.455 ng/g (ppb); Adhesive: 6:2FTS: 0.848 ng/g (ppb). ***Synthetic Precipitation Leaching Procedure*** • "Select PFAS compounds were detected in the SPLP analysis that were not detected in the total PFAS analysis." • "The PFAS6 compounds were detected in the SPLP analysis of the [turf carpet] (1.02 ng/L), [shock pad] (1.40 nanograms per liter(ng/L)), the [wood infill] (5.01 ng/L) and the [adhesive] (0.395 ng/L). However, these PFAS6 compounds were not detected in the total PFAS analysis at concentrations above the RL or the MDL." (All units shown here are equivalent to ppt.) • "The detection of PFAS compounds in the samples of the synthetic turf components via SPLP PFAS analysis but not via total PFAS analysis may suggest that these products contain PFAS compounds that were not extractable via the analytical method utilized for total PFAS analysis (isotope dilution method), but were extractable by the more rigorous SPLP extraction process." **TOTAL OXIDIZABLE PRECURSOR (TOP) ASSAY** • PFAS were not detected during the pre-oxidation measurements. • The measurements made after oxidation detected perfluorobutanoic acid (PFBA) in all sample materials at concentrations above the method detection limit but below the reporting limit, yielding estimated values between 2.11 ng/g to 28.7ng/g. • "Perfluoroheptanoic acid (PFHpA) was detected in the oxidized sample of the [wood infill] at a concentration of 20.4 ng/gPFAS6: 5.01 ng/L (ppt)" • "Perfluoropentanoic acid (PFPeA) was detected in the oxidized sample of the [adhesive] at a concentration of 6.08 ng/g." This concentration was above the method detection limit but below the reporting limit, yielding an estimated value. **TOTAL ORGANIC FLUORINE** • "Total organic fluorine was detected in the [carpet] at a calculated concentration of 70 parts per million (ppm), the [shock pad] (26 ppm), [an adhesive] (10 ppm), and [a second adhesive] (11 ppm). Fluoride ions were not detectable above the RL of 10 ppm, suggesting that the total fluorine detected in these samples likely represents primarily organic fluorine. However, because the RL in some cases is close to the detected concentration of total fluorine, it is possible that the portion organic fluorine could be lower. Total fluorine was not detected in the sample of the [wood infill] above the RL of 10 ppm." **Additional note from consultant report** The consultant noted that there were difficulties in the laboratory's approach. "The detection limits achieved by the laboratory were elevated because of the limited sample weight utilized during extraction and the dilutions required by the low density sample matrix."

Portsmouth, NH (2021) initial community testing[9]	The environmental group Non Toxic Portsmouth, with guidance from the Ecology Center, initiated PFAS testing of new samples of artificial turf blades, carpet backing, and shock pad. An independent laboratory measured total fluorine in these materials. **TOTAL FLUORINE** • Carpet: TF: 83- 119 ppm • Backing: TF: 16 ppm • Shock pad: TF: 61 ppm • Comments on results by Dr. Graham Peaslee at University of Notre Dame: "These total fluorine measurements are typical for plastics that have been manufactured with PFAS-based polymer processing aids – which will leave residues of these PFAS at the part-per-million level on the artificial grass." [9]
Portsmouth, NH (2022) testing initiated by City of Portsmouth. Laboratory results interpreted by consultants at TRC[10]	Eurofins Lancaster Labs tested PFAS artificial turf carpet, walnut shell infill, and a foam shock pad. Results summarized here show presence of substances only. See full report for concentrations. **TARGETED TESTING AND TOP ASSAY** PFAS was measured pre- and post- oxidation. The pre-oxidation analysis measured "70 individual [targeted] PFAS using a modified version of USEPA Method 537.1, with isotope dilution liquid chromatography/dual mass spectrometry" in samples of material. This method is considered a targeted test method. Samples were also oxidized and measured for PFAS precursors. • Carpet: There were no detectable concentrations of PFAS in pre-oxidized samples. • Eight individual PFAS were detected in samples after oxidation (one PFAS, 6:2 FTSA, was also detected in a blank sample). For example, "PPF acid was detected at 1.08 ng/g [ppb]." • Shock pad: Three PFAS were detected in pre-oxidized samples (one PFAS, 6:2 FTSA, was also detected in a blank sample). Six PFAS were detected in samples after oxidation. • Walnut shell infill: Six PFAS were detected in pre-oxidized samples. For example, "PFMOAA was detected at a concentration of 5.16 ng/g [ppb] and PPF acid was detected at a concentration of 41 ng/g [ppb]." Four PFAS were detected in samples after oxidation. **NON-TARGETED ANALYSIS** "Non-targeted QTOF-MS [quadrupole time of flight mass spectrometry] analyses were performed on each sample to determine if "other" PFAS were present that were not included in the analysis of the 70 individual PFAS." • Results were "qualitative estimations of presumptive positives." Several additional chemicals were found in these samples, but only one, bis(2,2,3,3,4,4,4- heptafluorobutyl) carbonate, was tentatively identified in the carpet sample. The other chemicals were reported as "unknown."
Notes: Summaries in this document do not include any evaluation of the robustness, accuracy, or precision of the methods or results. Concentrations are shown in the units that were used in the original source. We have also added ppm, ppb, or ppt in parentheses for ease of interpretation. <LOD = below level of detection. "PFAS6" refers to the six PFAS regulated in drinking water in Massachusetts at the time the testing was conducted: PFOS, PFOA, PFHxS, PFNA, PFHpA and PFDA.	

Nonprofits, Community Organizations, and Journalists

A number of nonprofits, community organizations, and journalists have conducted PFAS testing on artificial turf. Below are some examples.

Original testing reported in The Intercept. In 2019, two nonprofit organizations tested artificial turf carpet and found evidence of the presence of PFAS in the material. Their results were reported in *The Intercept.*[11] The organizations tested backing of both new turf and older, discarded turf. They also tested a number of samples of artificial grass blades (carpet fibers).

They detected 6:2-fluorotelomer sulfonic acid (6:2 FTSA) in the backing of the new turf sample. 6:2 FTSA has a 6-carbon chain, and is considered a short-chain PFAS because of the way in which it breaks down. In many cases, short-chain PFAS have been adopted as substitutes for longer-chain PFAS.

They detected perfluorooctane sulfonate (PFOS) in the backing of the discarded, older turf sample. PFOS is a long-chain PFAS that is no longer manufactured in the US due to concerns about health and environmental effects.

They also tested a number of synthetic turf fiber samples and found that all of them contained quantities of fluorine that suggest the presence of PFAS.[11]

Since the initial finding of PFAS in artificial turf, other community groups and municipalities have submitted samples of new and older turf to commercial and research laboratories for various types of PFAS analyses.

Woodbridge, CT. Residents in the town of Woodbridge, CT initiated testing of stormwater samples collected from a swale located beside an artificial turf installation site.[12] The artificial turf was marketed as a PFAS-free product. The lab used a targeted PFAS method to test 18 PFAS in stormwater runoff before and after the installation of an artificial turf field at Amity Regional High School in 2021. The levels of PFOA and PFOS measured after installation were higher than the levels measured before installation. Three other PFAS were also detected in the post-installation stormwater samples (see Table 3).

Philadelphia Inquirer. The *Philadelphia Inquirer* obtained samples of the artificial turf samples used by the Philadelphia Phillies from 1977 – 1981. They shared samples with researchers at the University of Notre Dame and an independent lab for PFAS testing. They found the presence of 16 PFAS, including PFOA (12 ppt) and PFOS (5.5 ppt).

PEER and CEH. In 2024, both PEER[13] and CEH[14,15] have conducted additional testing, as shown in Table 3.

Table 3. Summary of PFAS testing initiated by nonprofits, community organizations, and journalists.

Source	Summary
NONPROFIT AND COMMUNITY ORGANIZATIONS	
Testing reported in *The Intercept* (2019).[11] Results summarized by New Jersey Department of Environmental Protection.[2]	Targeted and total fluorine testing conducted on new turf carpet samples; targeted testing conducted on used sample. **TARGETED ANALYSIS** • New turf carpet sample: 6:2 FTSA: 300 ppt • Used turf carpet sample: PFOS: 190 ppt **TOTAL FLUORINE ANALYSIS** • New turf carpet blades: 44-255 ppm
Woodbridge, CT (2021)[12]	Samples of stormwater runoff were collected before and after the installation of an artificial turf field from a swale located near the artificial turf field installation site. Targeted analysis EPA method 537.1 was used to test the runoff for 18 PFAS. **TARGETED ANALYSIS of runoff** • Before installation: PFOA: 4.60 ng/L (ppt); PFOS: 5.52 ng/L (ppt) • After installation: PFOA: 7.57 ng/L (ppt); PFOS: 6.44 ng/L (ppt); PFBS: 1.39 ng/L (ppt); PFHxA: 3.33 ng/L (ppt); PFHpA: 2.04 ng/L (ppt)
Preliminary dermal exposure tests by Public Employees for Environmental Responsibility (PEER)[13]	Used skin wipes to measure PFAS on four individuals before and after play. Results showed differences in pre- and post-play PFAS levels for artificial turf and grass.
Center for Environmental Health (CEH)[14,15]	CEH tested samples of artificial grass used for residential applications. PFOS was detected during testing. Based on the levels detected, CEH sent California Proposition 65 notices of violation to relevant parties.
JOURNALIST	
Philadelphia Inquirer (2023)[16]	The *Philadelphia Inquirer* purchased samples of artificial turf carpet used by Philadelphia Phillies from 1977 – 1981 and sent samples to Eurofins Lancaster Labs and University of Notre Dame. Eurofins conducted targeted testing for 70 individual PFAS. **TARGETED ANALYSIS** • Testing indicated presence of 16 PFAS, including PFOA (12 ppt) and PFOS (5.5 ppt).
Notes: Summaries in this document do not include any evaluation of the robustness, accuracy, or precision of the methods or results. Concentrations are shown in the units that were used in the original source. We have also added ppm, ppb, or ppt in parentheses for ease of interpretation. <LOD = below level of detection.	

Manufacturers

Determining which chemicals are present in a product can be challenging because chemical contents are frequently not disclosed by the manufacturer. In response to public concern about PFAS, some artificial turf

manufacturers have recently begun providing test data of their own. Table 5, below, shows examples of two manufacturers that have provided test data.

As shown in the table, one manufacturer used targeted analysis to test for the presence of PFOA and PFOS.[17] Because the manufacturer only examined two chemicals, these test data are of limited value in determining whether PFAS are present in the product. In addition, the detection limit was 100 ppt, so the two chemicals could not be accurately measured or detected below 100 ppt.[17] Neither chemical was detected above this threshold.

Testing from another manufacturer was discussed in an article in the *Philadelphia Inquirer*. The manufacturers stated that the artificial turf was free of PFAS based on lab testing. However, experts consulted by the journalists suggested that the laboratory test results had limited value, in part because of high detection limits.[18]

In some cases, targeted tests have been used to inform PFAS-free statements. For example, one manufacturer states that their "entire range for artificial products showed non-detectable levels of PFAS at 100 parts per trillion."[19] This statement was based on results from measuring PFOS and PFOA only.[17]

In response to debates over PFAS-free claims, certain manufacturers have proposed definitions of the term "PFAS-free." For example, one manufacturer defines a product as PFAS-free if it contains "less than 100 ppm total organic fluorine."[20] (The manufacturer cites a California regulatory threshold for PFAS in juvenile products.[21])

Table 4. Examples of PFAS testing led by manufacturers.

Source	Summary
Artificial turf manufacturer example #1 (2023)[17]	The manufacturer sent sample a of artificial turf carpet to a lab for targeted analysis of PFOA and PFOS. The samples were "extracted via EPA method 3545A with the resulting solution analyzed via HPLC/TS/MS to determine the presence of each analyte. The lowest calibrated detection is at 100 parts per trillion." **TARGETED ANALYSIS OF PFOA AND PFOS** • PFOA and PFOS: None detected below 100 ppt. Note: The test was set up to detect concentrations below 100 ppt.
Artificial turf manufacturer example #2 (2022)[22] Results summarized by The Philadelphia Inquirer (2024)[18]	The manufacturer sent samples of artificial turf marketed as PFAS-free to RTI Laboratories Inc. for targeted PFAS testing. **TARGETED ANALYSIS** • The laboratory's summary of results stated that "all extractable PFAS compounds were non-detect at a level of 2-4 ug/kg (ppb)."[22] • Experts consulted by *The Philadelphia Inquirer* expressed concerns about the testing methods and the high detection limits used. They noted that lower detection limits and a total organic fluorine test would have yielded results that are more informative.[18]
Notes: Summaries in this document do not include any evaluation of the robustness, accuracy, or precision of the methods or results. Concentrations are shown in the units that were used in the original source. We have also added ppm, ppb, or ppt in parentheses for ease of interpretation. <LOD = below level of detection.	

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The Lowell Center for Sustainable Production uses rigorous science, collaborative research, and innovative strategies for communities and workplaces to adopt safer and sustainable practices and products to protect human health and the environment. The Lowell Center is composed of faculty, staff, and graduate students at the University of Massachusetts Lowell who work with citizen groups, workers, businesses, institutions, and government agencies to build healthy work environments, thriving communities, and viable businesses that support a more sustainable world.

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