Appendix E.1

Supplemental Artificial Turf Field Materials Analysis – Exponent (December 2022)

EXTERNAL MEMORANDUM

TO: ESA
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Environmental Science Association
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FROM: Sarah Parker, Ph.D., Managing Scientist, Exponent

DATE: December 21, 2022

PROJECT: 2209255.000

SUBJECT: River Park Project Artificial Turf Field Materials Analysis

Introduction

The River Park Project (the Project) proposed by Harvard-Westlake School (the School) is a proposed development in Los Angeles, California, located at 4141 Whitsett Avenue.[1] The plans for the Project include artificial turf components manufactured by FieldTurf, consisting of the Vertex CORE 2.5 synthetic turf carpet and Cryogenic Rubber 14-30 crumb rubber infill. Exponent, Inc. (Exponent) was asked to assess these two materials for their composition and potential to release certain chemical substances under the conditions of intended use. Specifically, Exponent understands that Environmental Science Associates (ESA) is requesting guidance related to 1) per- and polyfluorinated alkyl substances (PFAS) that may be present in synthetic grass blades and 2) metal compounds that may be contained in the crumb rubber infill proposed for the Project.

Qualifications

I am a Managing Scientist in the Polymer Science and Materials Chemistry practice at Exponent. Founded in 1967, Exponent is the largest engineering firm in the country dedicated primarily to assisting clients with challenges of an engineering or scientific nature. Exponent has over 1000 employees, the majority of whom hold advanced degrees in their fields of expertise.

I hold two academic degrees: (1) a Bachelor of Arts in Chemistry from Grinnell College, and (2) a Doctor of Philosophy in Chemistry from Harvard University. I have been practicing in the field

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[1] Harvard-Westlake River Park Project, Los Angeles City Planning. Available at: https://planning.lacity.org/development-services/eir/harvard-westlake-river-park-project-0, accessed November 28, 2022.

of chemistry for more than 15 years as a researcher at Grinnell College and Harvard University, in technical roles at ExxonMobil, and as a consultant with Exponent. I provide consulting services in all aspects of the field, including, but not limited to analysis of chemical composition, chemical reactivity and synthesis related to small molecules and materials, interactions of chemicals with polymeric and other materials, chemical selection and use in formulated materials, product design and development, failure analysis, and intellectual property analysis.

I have broad experience analyzing the chemical composition of products and materials, including the detection of impurities and contaminants. I routinely assess the quality of these products and their fitness for use in specified applications. I have formal training and practical experience with standardized and non-standardized analytical methods that are used to characterize substances, mixtures, and materials, including liquid chromatography-mass spectrometry (LC-MS) based methods and elemental analysis methods. I have specific experience with analytical methods used for the detection and identification of fluorinated chemicals including PFAS, and with methods that are used to identify and quantify the presence of metal-containing compounds in various chemical and materials samples.

During the pursuit of my doctoral degree at Harvard University under the direction of Dr. Tobias Ritter, I developed chemical catalysts including those used for the fluorination of organic molecules. These catalysts were intended for use in the synthesis of fluorinated drug candidate molecules and similar organofluorine compounds. In the course of this work, I characterized fluorinated organic compounds using various analytical methods including mass-spectrometry based methods, as well as fluorine nuclear magnetic resonance spectroscopy, Fourier-transform infrared spectroscopy, and elemental analysis methods.

A copy of my *curriculum vitae* is provided in Appendix A, and a list of materials considered in the preparation of this memo are provided in Appendix B.

The River Park Project

The Harvard-Westlake River Park Project involves the redevelopment of an approximately 17.2-acre lot, comprising the Weddington Golf and Tennis site and a portion of Los Angeles County land along the Los Angeles River, into an athletic and recreational facility for use by the Harvard-Westlake School and the general public. Recreational facilities proposed in the Project include an 80,249-square-foot gymnasium, a 52-meter swimming pool, eight tennis courts, two athletic fields, and 5.4 acres of publicly accessible open space and landscaped trails connecting to the adjacent Zen Greenway.[2]

Exponent understands that the artificial turf materials proposed for use in the Project are supplied by FieldTurf. The turf system proposed for use in this project consists of the Vertex CORE 2.5 synthetic turf carpet and Cryogenic Rubber 14-30 crumb rubber infill.

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[2] Harvard-Westlake River Park Project, case number ENV-2020-1512-EIR, available at https://planning.lacity.org/development-services/eir/harvard-westlake-river-park-project-0.

Artificial Turf Systems

Artificial or synthetic turf is a surfacing material designed to mimic the appearance and experience of a grass field. Artificial turf is a system with several components, including turf fibers, which give the appearance of "blades of grass," backing on which these fibers are sewn, and infill for support.[3] Gravel and optional leveling pads (*i.e.*, shock pads) are installed as a base below the artificial turf to provide drainage and stability for the system.[4,5] Since their introduction in the 1960s, turf systems have evolved to use different materials and methods of manufacturing.[6] Further, a variety of turf system products are currently offered by manufacturers that may use different materials and manufacturing methods. To help evaluate the quality of different sports fields and providers of artificial turf systems, the Synthetic Turf Council (STC)[7] has established Guidelines for Synthetic Turf Performance. This includes recommendations regarding the properties of the components (*e.g.*, fiber size, pile height, infill bulk density), quality guidelines (*e.g.*, artificial weathering, slope, water permeability), and performance guidelines (*e.g.*, impact attenuation, shock absorption, linear friction).[8]

Turf fibers, also referred to as yarn, are typically made from synthetic polymers that have been heated and extruded into fibers through a monofilament[9,10] or fibrillated tape[11] extrusion process. Polyamides, polyethylene, and/or polypropylene have all been used for manufacturing turf

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[3] Cheng, H., Hu, Y., Reinhard, M. (2014). Environmental and Health Impacts of Artificial Turf: A Review. *Environmental Science & Technology* 48, 2114-2129.

[4] Massey, R., Pollard, L., Jacobs, M., Onasch, J., and Harari, H. (2020). Artificial turf infill: a comparative assessment of chemical contents. New Solutions: *A Journal of Environmental and Occupational Health Policy* 30(1), 10-26.

[5] Shock Pad Systems, FieldTurf, see https://fieldturf.com/en/products/detail/shock-pad-systems/, accessed December 7, 2022.

[6] EPA/ORD and CDC/ATSDR, "Synthetic Turf Field Recycled Tire Crumb Rubber Research Under the Federal Research Action Plan, Final Report Part 1 – Tire Crumb Rubber Characterization," Volume 1, July 25, 2019, available at https://www.epa.gov/sites/default/files/2019-08/documents/synthetic_turf_field_recycled_tire_crumb_rubber_research_under_the_federal_research_action_plan_final_report_part_1_volume_1.pdf, p. 35.

[7] The Synthetic Turf Council (STC) is an organization founded in 2003. Membership includes builders, landscape architects, testing labs, maintenance providers, manufacturers, suppliers, installation contractors, infill material suppliers and other specialty service companies, see https://www.syntheticturfcouncil.org/page/AboutSTC, accessed December 14, 2022.

[8] Synthetic Turf Council Guidelines For Synthetic Turf Performance (2011), see https://cdn.ymaws.com/www.syntheticturfcouncil.org/resource/resmgr/files/stc_guidelines_for_synthetic.pdf, accessed December 14, 2022.

[9] Kolgjini, B., Schoukens, G., Shehi, E., and Kiekens, P. (2013). Bending behaviour of LLDPE monofilaments depending on cold drawing and composition of the LLDPEs. *Fibres & Textiles in Eastern Europe* (4 (100)), 23-30.

[10] Kolgjini, B., Schoukens, G., Kola, I., Rambour, S., Shehi, E., and Kiekens, P. (2014). Influence of heat treatment on the bending behavior of LLDPE monofilaments. *Autex Research Journal* 14(3), 187-199.

[11] Sandkuehler, P., Torres, E., and Allgeuer, T. (2010). Performance artificial turf components—fibrillated tape. *Procedia Engineering* 2(2), 3367-3372.

fibers.[12,13] The preferred choices of polymeric materials for artificial turf has changed over time, resulting in turf products with different characteristics and properties.[14,15,16] While older generations of artificial turf primarily used polyamide (PA) and polypropylene (PP), the modern "third generation" artificial turf generally uses linear low-density polyethylene (LLDPE).[17,18] These changes in polymeric material selection were generally intended to produce turf yarns with higher-performance attributes, such as durability (wear, tear, and degradation resistance), resiliency (elastic recovery), and softness (skin friendliness).[19]

Once extruded, the fibers are tufted onto a backing to create the turf carpet.[20,21] The backings are typically made of polyester or polypropylene with a secondary layer of latex rubber or

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[12] Hufenus, R., Affolter, C., Camenzind, M., Reifler, F. A. (2013). Design and Characterization of a Biocomponent Melt-Spun Fiber Optimized for Artificial Turf Applications. *Macromolecular Materials and Engineering* 298, 653-663.

[13] Sandkuehler, P., Torres, E., and Allgeuer, T. (2010). Performance artificial turf components—fibrillated tape. *Procedia Engineering* 2(2), 3367-3372.

[14] For example, first-generation artificial turf, such as AstroTurf was comprised of nylon pile on a polyester nylon mat that is double bonded to a closed-cell nitrile rubber and polyvinyl chloride pad on an asphalt base, which is different than modern the modern artificial turf constructions, see Levy, I. M., Skovron, M. L., & Agel, J. (1990). Living with artificial grass: A knowledge update: Part 1: Basic science. The American journal of sports medicine, 18(4), 406-412.

[15] Sandkuehler, P., Torres, E., and Allgeuer, T. (2010). Performance artificial turf components—fibrillated tape. *Procedia Engineering* 2(2), 3367-3372.

[16] Hufenus, R., Affolter, C., Camenzind, M., Reifler, F. A. (2013). Design and Characterization of a Biocomponent Melt-Spun Fiber Optimized for Artificial Turf Applications. *Macromolecular Materials and Engineering* 298, 653-663.

[17] Tay, S. P., Fleming, P., Forrester, S., and Hu, X. (2015). Insights to skin-turf friction as investigated using the Securisport. *Procedia Engineering* 112, 320-325.

[18] Ragaert, K., Delva, L., Van Damme, N., Kuzmanovic, M., Hubo, S., and Cardon, L. (2016). Microstructural foundations of the strength and resilience of LLDPE artificial turf yarn. *Journal of Applied Polymer Science* 133(43).

[19] Sandkuehler, P., Torres, E., and Allgeuer, T. (2010). Performance artificial turf components—fibrillated tape. *Procedia Engineering*, 2(2), 3367-3372.

[20] Center for Environmental Health, Department of Health in New York City, "Information About Crumb-Rubber Infilled Synthetic Turf Athletic Fields." Available at: https://www.health.ny.gov/environmental/outdoors/synthetic_turf/crumb-rubber_infilled/docs/fact_sheet.pdf, accessed November 29, 2022.

[21] We've got your back. FieldTurf. Available at: https://fieldturf.com/en/products/detail/backing-systems/, accessed December 14, 2022.

polyurethane applied after tufting.[22] Turf can be constructed with a range of pile heights, densities, shapes, and colors, which provide the field with distinct visual and physical properties.[23,24]

In synthetic turf systems intended for recreational use, dense fine particle materials called "infill" are added to act as the ballast, providing support to the turf fibers in the carpet and shock absorption to athletes on the field.[25,26] Infill is also reportedly used to improve traction, player safety, and/or to extend the synthetic turf's useful life.[27] The most widely used type of turf infill is made from recycled and shredded end-of-life tires, commonly referred to as crumb rubber.[28] The source of the tires can be automobile and/or truck tires, which are shredded by either an ambient or cryogenic grinding process.[29] This process breaks the tires into small pieces (reported diameters of approximately 1–6 mm),[30] and separates the rubber from other tire components such as adhering wire or fabric.[31]

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[22] Lauria, M., Naim, A., Plassmann, M., Faldt, J., Suhring, R., Benskin, J. (2022) Widespread Occurrence of Non-Extractable Fluorine in Artificial Turfs from Stockholm, Sweden. *Environmental Science & Technology Letters* 9, 666-672.

[23] Villwock, M. R., Meyer, E. G., Powell, J. W., Fouty, A. J., Hault, R. C. (2009) The effects of various infills, fibre structures, and shoe designs on generating rotational traction on an artificial surface. Proceedings of the Institution of Mechanical Engineers, Part P: *Journal of Sports Engineering and Technology* 223(1):11-19.

[24] Synthetic Turf Systems Explained. Motz Group. Available at: https://themotzgroup.com/sport_blog/synthetic-turf-systems-explained, accessed Nov. 13, 2022.

[25] Hufenus, R., Affolter, C., Camenzind, M., Reifler, F. A. (2013). Design and Characterization of a Bicomponent Melt-Spun Fiber Optimized for Artificial Turf Applications. *Macromolecular Materials and Engineering* 298, 653-663.

[26] Synthetic Turf Systems Explained. Motz Group. Available at: https://themotzgroup.com/sport_blog/synthetic-turf-systems-explained, accessed Nov. 13, 2022.

[27] Synthetic Turf Council Suggested Environmental Guidelines for Infill, August 2015, see https://cdn.ymaws.com/staging-stc.site-ym.com/resource/resmgr/guidelines/STC_Environmental_Guidelines.pdf, accessed December 14, 2022.

[28] Zuccaro, P., Thompson, D. C., de Boer, J., Watterson, A., Wang, Q., Tang, S., Shi, X., Llompart, M., Ratola, N., Vasiliou, V. (2022). Artificial turf and crumb rubber infill: An international policy review concerning the current state of regulations. *Environmental Challenges* 9, 100620.

[29] Infill Options for Your Needs, Field Turf, available at https://fieldturf.com/en/products/detail/infill-systems/, accessed November 22, 2022; Lim, L., and Walker, R., "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, p. 10.

[30] EPA/ORD and CDC/ATSDR, "Synthetic Turf Field Recycled Tire Crumb Rubber Research Under the Federal Research Action Plan, Final Report Part 1 – Tire Crumb Rubber Characterization," Volume 1, July 25, 2019, available at https://www.epa.gov/sites/default/files/2019-08/documents/synthetic_turf_field_recycled_tire_crumb_rubber_research_under_the_federal_research_action_plan_final_report_part_1_volume_1.pdf, p. 1.

[31] Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, p. 10.

What Are PFAS?

Per- and polyfluoroalkyl substances (PFAS) is a broad term used to describe certain manufactured chemicals that contain carbon-fluorine bonds. Although the term has been used by regulatory agencies, nongovernmental organizations, industries, and the academic community,[32] the definition varies depending on the context in which it is used.[33] Definitions of the term "PFAS" have also evolved over time since the introduction of this term in the early 2000s.[34] As a result, some substances that are considered to be PFAS according to one definition are not considered to be PFAS according to a different definition.

The term PFAS is frequently used to describe a set of small, perfluorinated alkyl surfactants (that contain fully-fluorinated carbon chains), including perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) (Figure 1).[35] Surfactants, including PFOA and PFOS, are chemical compounds that typically contain a reactive end group that interacts with water (because it is polar and hydrophilic) and a long "tail" that does not interact with water, such as a perfluorinated carbon chain. Surfactant chemicals are used in a wide range of products to reduce surface tension and stabilize mixtures of insoluble substances, such as in soaps and detergents, paints, shampoo and conditioner, and adhesives, to contribute specific properties. PFOA and PFOS chemicals were among the first PFAS to be commercially manufactured and used,[36] and have been widely used as surfactants in many applications including in surface treatments for textiles and in the manufacturing of fluorinated polymers (among other uses) since their development in the middle of the 20th century.[37]

However, current definitions of the term "PFAS" include a far larger set of substances and materials, and can be so broad as to include fluoropolymers such as polytetrafluoroethylene (PTFE) and fluorinated ethylene propylene (FEP) (Figure 1), which have significantly different physical and chemical properties compared to PFOS and PFOA.[38] In addition, some regulatory

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[32] ITRC. 2022. PFAS – Per- and Polyfluoroalkyl Substances, 2.2 Chemistry, Terminology, and Acronyms. Interstate Technology Regulatory Council. Available at: https://pfas-1.itrcweb.org/2-2-chemistry-terminology-and-acronyms/, accessed November 10, 2022.

[33] For example, ITRC recognizes that "there is no universally accepted definition of PFAS" (ITRC 2022). Similarly, USEPA states that "there is no precisely clear definition of what constitutes a PFAS substance given the inclusion of partially fluorinated substances, polymers, and ill-defined reaction products…" (USEPA 2022. PFAS Master List of PFAS Substances, CompTox Chemicals Dashboard. Available at: https://comptox.epa.gov/dashboard/chemical-lists/pfasmaster, accessed November 10, 2022).

[34] For example, the United States Environmental Protection Agency updated its definition of PFAS in 2022. "U.S. EPA Broadens Its Definition of PFAS" *Chemical & Engineering News*, November 4, 2022.

[35] Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., and van Leeuwen, S.P.J. (2011). *Int. Env. Assess. and Management* 7(4): 513-541.

[36] ITRC. "History and Use of Per- and Polyfluoroalkyl Substances." Available at: https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_History_and_Use_April2020.pdf, accessed December 19, 2022.

[37] Grabda, M., Oleszek, S., and Matsumoto, M. (2020). Per-and polyfluoroalkyl substances: Problematic emerging pollutants of aquatic environment. *Archives of Environmental Protection* 46(3).

[38] Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., and van Leeuwen, S.P.J. (2011). *Int. Env. Assess. and Management* 7(4): 513-541.

agencies and non-governmental organizations broadly define "PFAS" as any molecule with at least one fully fluorinated carbon atom,[39,40] which includes not only fluorosurfactants and fluoropolymers, but also other groups of chemicals that have not traditionally been considered PFAS, such as some refrigerant gases, pharmaceuticals, and pesticides.[41] These substances are all very different from one another from the perspective of chemistry, structure, and corresponding properties, which is why they are used for different purposes and in different ways. As a result, any discussion related to the presence of PFAS in a specific context, whether for performance, sourcing, environmental persistence, or health risk, must consider the specific chemistries that are present, not just the presence of "PFAS" generally, or the total amount of PFAS present.

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[39] Maine State Legislature. 2021. An Act to Stop Perfluoroalkyl and Polyfluoroalkyl Substances Pollution. 130LR0942(05). Available at: https://mainelegislature.org/legis/bills/getPDF.asp?paper=HP1113&item=5&snum=130, accessed November 10, 2022. OECD. 2021.

[40] Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance. Organisation for Economic Co-operation and Development, Environmental Directorate, Chemicals and Biotechnology Committee. ENV/CBC/MONO(2021)25. July 9, 2021.

[41] For example, the refrigerant 1,1,2,2-tetrafluoropropane has one fully fluorinated carbon atom (see: https://pubchem.ncbi.nlm.nih.gov/compound/1_1_2_2-Tetrafluoropropane, accessed November 10, 2022). The pharmaceutical Tipranavir contains one fully fluorinated carbon atom (see: https://commonchemistry.cas.org/detail?cas_rn=174484-41-4, accessed November 10, 2022). The fungicide Fluopyram contains two fully fluorinated carbon atoms (see: https://pubchem.ncbi.nlm.nih.gov/compound/Fluopyram, accessed November 10, 2022).

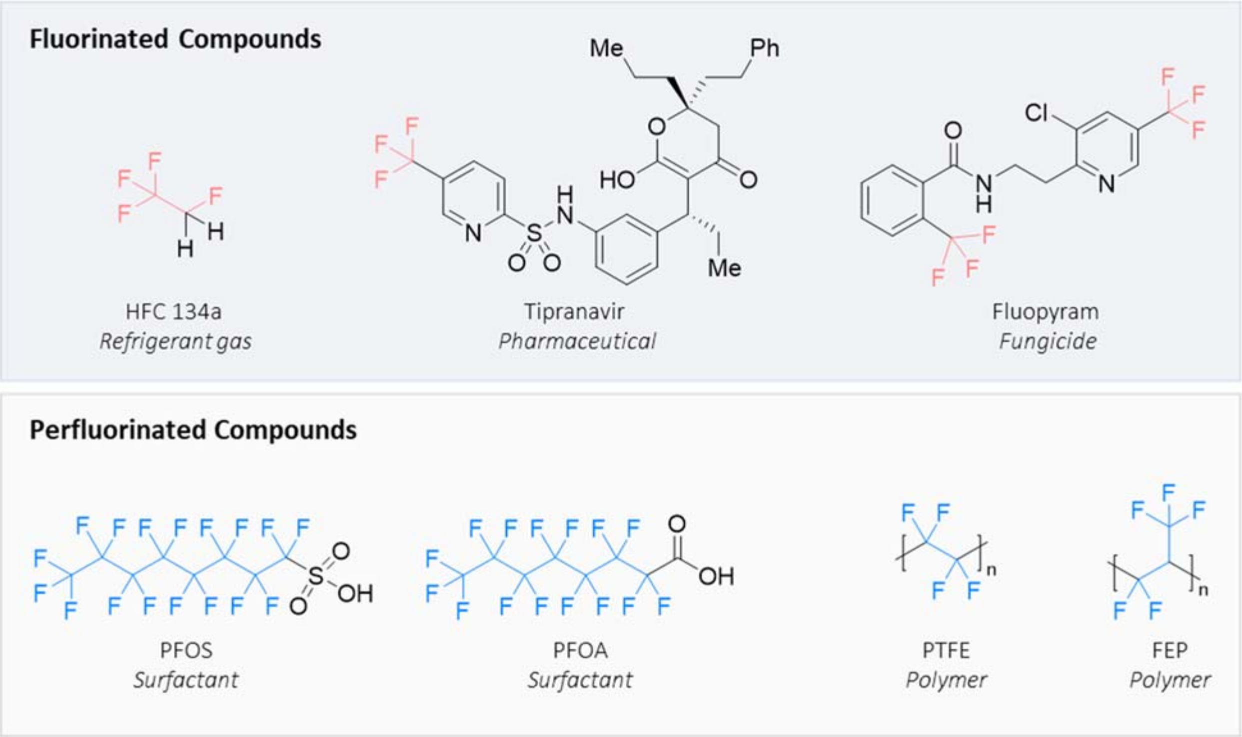

Figure 1. Comparing fluorinated and perfluorinated chemical structures. Fluorinated compounds, including HFC 134a, Tipranavir, and Fluopyram, show the “CF_3” group highlighted in orange. Perfluorinated compounds, including PFOS, PFOA, PTFE, and FEP, show perfluorinated carbon chains in blue. Structures in brackets repeat an unspecified (large) number of times to form a fluoropolymer.

Because structural features of a molecule influence its chemical and physical properties, PFAS have frequently been categorized by similarities in their chemical structures. For example, categorization has been based on the presence of certain functional groups, the length of perfluorinated chains, and the overall size of the molecule.[42,43] Two common and important categories of PFAS are small-molecule[44] surfactants (like PFOA and PFOS) and fluoropolymers (polymers containing a carbon-only polymer backbone with fluorine atoms directly attached to

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[42] ITRC. Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances (PFAS), https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_Naming_Conventions_April2020.pdf, accessed 13 Dec. 2022.

[43] OECD. Per- and Polyfluoroalkyl Substances (PFAS). https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/aboutpfass/Figure1-classification-of-per-and-polyfluoroalkyl-substances%20-PFASs.pdf, accessed 13 Dec. 2022.

[44] The term “small molecule” is used to differentiate molecules with low molecular weights (for example, below 500 daltons) from larger molecules like polymers and proteins that have different properties and characteristics as a result of their size. The term is often to distinguish molecules of different sizes in biological contexts because molecular size is one characteristic that influences the ability of a molecule to enter a cell. *See, e.g.,* Li, Q., & Kang, C. (2020). Mechanisms of action for small molecules revealed by structural biology in drug discovery. *International Journal of Molecular Sciences*, 21(15), 5262.

it).[45] While both of these types of PFAS contain poly- or perfluorinated carbon chains, their specific molecular characteristics differ in important ways. One of the features of a small molecule surfactant is its functional group (often a carboxylate, sulfonate, or similar anionic group), which allows it to interact with water-based substances and materials at that location and confers surfactant activity. Fluoropolymers, in contrast, have far larger poly- or perfluorinated chain segments and do not include reactive functional groups. As a result, fluoropolymers do not act as surfactants, are considered immobile in the environment, and are stable under many chemical and environmental conditions.[46]

Uses of PFAS

Historically and currently, fluorinated molecules are highly valued and useful because, to a degree that depends on the specific structure, they generally repel both water and oil, withstand high temperatures, and withstand chemicals and harsh reactive environments.[47] Therefore, they have been used across a wide range of industries, from industrial and commercial applications to household consumer products. Importantly, because small-molecule PFAS and fluoropolymers have distinct characteristics and properties, they are typically used in different types of applications.

For example, certain small-molecule PFAS are used in small amounts as additives for paints and coatings to reduce surface tension, resulting in a more uniform coating and conferring dirt and oil repellence.[48] Other small molecule fluorosurfactants have been used in consumer products such as carpets and textiles, in waterproofing treatments, in firefighting foams, and in many other applications where surfactant properties are beneficial or required.[49]

The size and stability of fluoropolymers contributes to their widespread use in many applications, including consumer electronics (*e.g.*, semiconductors, wire insulation), outdoor apparel and other

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[45] Note that other polymers that include fluorine atoms (such as polyethers and polymers with fluorinated side chains) are typically referred to as "fluorinated polymers," and are not included in the definition of the term "fluoropolymer." Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., De Voogt, P., ... and van Leeuwen, S. P. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins. *Int. Env. Assess. and Management* 7(4), 513-541.

[46] Henry, B.J.; Carlin, J.P.; Hammerschmidt, J.A.; Buck, R.C.; Buxton, L.W.; Fiedler, H.; Seed, J.; and Hernandez, O. (2018). *Int. Env. Assess. and Management* 14(3): 316-334.

[47] Gluge, J., Scheringer, M., Cousins, I.T., DeWitt, J.C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C.A., Trier, X., and Wang, Z. (2020) *Env. Sci. Proc. Impacts* 22: 2345-2373.

[48] OECD. 2022. Per- and Polyfluoroalkyl Substances and Alternative Coatings, Paints and Varnishes (CPVs), Report on the Commercial Availability and Current Uses, OECD Series on Risk Management, No. 70. Organisation for Economic Co-operation and Development, Environment Directorate.

[49] Glüge, J., Scheringer, M., Cousins, I. T., DeWitt, J. C., Goldenman, G., Herzke, D., ... & Wang, Z. (2020). An overview of the uses of per-and polyfluoroalkyl substances (PFAS). *Environmental Science: Processes & Impacts*, 22(12), 2345-2373.

specialized clothing, aerospace and automotive products, drinking water filtration systems, gaskets for chemical processing, and building materials.[50,51,52]

Certain applications of fluoropolymers that involve direct contact with humans and/or food are regulated by the FDA. For example, fluoropolymers are used in the development and production of pharmaceuticals because of several beneficial properties, including their chemical inertness, resistance to high temperatures, and ability to be easily cleaned.[53,54] Fluoropolymers have been approved in various forms for use in food contact applications and cookware since the 1960s, and have been described by the FDA as containing "a negligible amount of PFAS capable of migrating to food."[55] Another important application of fluoropolymers is in medical devices such as permanent medical implants. At present, there is a 50+ year history of material and product testing (*e.g.*, laboratory, animal and human studies of biocompatibility) and real world data associated with permanent implants and other medical devices that support the use of fluoropolymers in direct, long term contact with the body.[56,57] This helps illustrate the importance of separately assessing the benefits and risks associated with different types of PFAS: while EPA limits certain small-molecule PFAS (small molecule surfactants) concentrations in drinking water in order to *protect* human health, FDA-approved fluoropolymer sutures and implants (among other devices) are *intended for use* within the human body to enhance human health.

Fluoropolymers are also used as additives in other materials. One additive application that is relevant to artificial turf products is the use of certain fluoropolymers, including polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF), as processing aids in the

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[50] Henry, B.J.; Carlin, J.P.; Hammerschmidt, J.A.; Buck, R.C.; Buxton, L.W.; Fiedler, H.; Seed, J.; and Hernandez, O. (2018). *Int. Env. Assess. and Management* 14(3): 316-334.

[51] Glüge, J., Scheringer, M., Cousins, I. T., DeWitt, J. C., Goldenman, G., Herzke, D., ... and Wang, Z. (2020). An overview of the uses of per-and polyfluoroalkyl substances (PFAS). *Environmental Science: Processes & Impacts* 22(12), 2345-2373.

[52] Ebnesajjad, S. (2020). *Introduction to fluoropolymers: Materials, technology, and applications*. William Andrew, at Chapter 15.

[53] Lv, J., & Cheng, Y. (2021). Fluoropolymers in biomedical applications: state-of-the-art and future perspectives. *Chemical Society Reviews*, 50(9), 5435-5467.

[54] Pruitt, L. A. (2011). Fluorocarbon polymers in biomedical engineering. *Encyclopedia of Materials: Science and Technology*, 3216-3221.

[55] Certain PFAS have been approved for use in food contact and cookware applications, including fluoropolymer processing aids. U.S. FDA. Authorized Uses of PFAS in Food Contact Applications. Available at: https://www.fda.gov/food/process-contaminants-food/authorized-uses-pfas-food-contact-applications, accessed December 19, 2022.

[56] Lv, J., & Cheng, Y. (2021). Fluoropolymers in biomedical applications: state-of-the-art and future perspectives. *Chemical Society Reviews*, 50(9), 5435-5467.

[57] Pruitt, L. A. (2011). Fluorocarbon polymers in biomedical engineering. *Encyclopedia of Materials: Science and Technology*, 3216-3221.

formulation of artificial turf fibers.[58,59,60,61] These fluoropolymer processing aids are added to the polymer formulations at low levels, typically around 100-1000 parts-per-million (ppm), to facilitate processing and prevent certain types of processing issues (*e.g.*, sharkskin or surface melt fracture) that may be encountered during the fiber-forming process.[62,63,64,65] The addition of processing aids influences the frictional properties of the manufactured fibers,[66,67] which may reduce skin abrasion when a user's skin slides along the surface of the turf.[68]

Like fluoropolymers more generally, the properties of these fluoropolymer processing aids are significantly different than those of small-molecule fluorosurfactants such as PFOA and PFOS. These processing aids are inert materials that are known to withstand the high melting temperatures and extrusion processes for plastic component formation without deterioration.[69] Like fluoropolymers for other food contact applications, specific examples of fluoropolymer processing aids have been approved for use in food contact and packaging by the FDA for

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[58] 3M Dynamar Polymer Processing Additive FX 9613, Technical Data Sheet, Issued 12/16.

[59] Daikin PPA DA-310ST, Technical Data Sheet, 4/29/16.

[60] Arkema Kynar Flex 2801-00, Technical Data Sheet, 2022.

[61] Fluoropolymer processing aid (PPA 2620) to improve processability for artificial turf applications, see https://shjichang.en.made-in-china.com/product/mxdrpqTABnkG/China-Lubricant-Artificial-Grass-PPA2620-Polymer-Processing-Aid-Artificial-Grass-Lubricant.html, accessed November 15, 2022.

[62] Processing issues that are improved by fluoropolymer processing aids may include melt fracture (a process commonly referred to as "sharkskin"), die build-up, gel formation, surface defects, and other issues.

[63] Bigio, D., Meillon, M. G., Kharchenko, S. B., Morgan, D., Zhou, H., Oriani, S. R., ... and Migler, K. B. (2005). Coating kinetics of fluoropolymer processing aids for sharkskin elimination: The role of droplet size. *Journal of Non-Newtonian Fluid Mechanics* 131(1-3), 22-31.

[64] Dubrocq-Baritaud, C., Darque-Ceretti, E., and Vergnes, B. (2014). Fluoropolymer processing aids in linear-low density polyethylene extrusion: How to improve their efficiency? *Journal of Non-Newtonian Fluid Mechanics* 208, 42-52.

[65] Arda, D. R., and Mackley, M. R. (2005). The effect of die exit curvature, die surface roughness and a fluoropolymer additive on sharkskin extrusion instabilities in polyethylene processing. *Journal of Non-Newtonian Fluid Mechanics* 126(1), 47-61.

[66] EP1672020A1 at 0014.

[67] For example, FIFA Test Method 08 and ASTM F1015 are standard test methods used to measure the coefficient of friction for artificial turf.

[68] For example, the use of softer polyolefin yarns in the 1990s was a replacement for the harder more abrasive polyamine yarns from the first-generation artificial turf products, see Tay, S. P., Fleming, P., Hu, X., and Forrester, S. (2017). Skin friction related behaviour of artificial turf systems. *Journal of Sports Sciences* 35(15), 1500-1507.

[69] Ebnesajjad, S. (2017). Introduction to fluoropolymers. In *Applied Plastics Engineering Handbook* (pp. 55-71). William Andrew Publishing.

decades,[70,71] in part because processing aids are used at such small amounts that only "a negligible amount of PFAS is capable of migrating" from materials made with them.[72]

PFAS in the Environment

Certain properties and characteristics contribute to a substance's behavior in environmental and biological systems. For example, solubility in water is a contributing factor to a substance's ability to move, or not move, into and through the environment. Further, solubility in water and other substances impacts the likelihood of a substance bioaccumulating, such as in the fatty tissues of organisms (such as large fish) instead of being eliminated through normal bodily waste. Other characteristics that may be important to a substance's behavior in these contexts are molecular size/weight, vapor pressure, melting and boiling point, acidity, and resistance towards chemical, thermal, and biological degradation.[73] Because PFAS include molecules with widely varying chemical structures and properties, it is important to consider the properties of specific PFAS when attempting to predict or explain the behavior of that substance in environmental and biological systems.

Small Molecule PFAS

Because they have been widely used in products and processes for decades, small-molecule PFAS have been introduced into the environment in many ways. In any particular environmental sample (such as water or soil), the presence of an individual PFAS compound may include contributions from multiple sources, which may have been introduced at multiple times, and its fate in the environment may be affected by mobility, chemical transformations, and degradation processes, as well as other factors.[74] Because of the resistance of certain PFAS toward chemical and biological degradation, PFAS may persist over long periods of time in environmental systems, though the estimated half-lives of specific PFAS differ based on their chemical structures. To date, measurable levels of certain small-molecule PFAS have been detected in environmental samples worldwide.[75]

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[70] Daikin PPA DA-310ST complies with United States FDA regulation 21 CFR 177.1520 when used at levels not to exceed 0.21% for food content, see Daikin PPA DA-310ST, Technical Data Sheet, 4/29/16.

[71] 3M Dynamar FX 9613 complies with United States FDA regulation 21 CFR 176.170(c) when used at levels up to 2000 ppm for food content, see 3M Dynamar Polymer Processing Additive FX 9613, Technical Data Sheet, Issued 12/16.

[72] U.S. FDA. Authorized Uses of PFAS in Food Contact Applications. Available at: https://www.fda.gov/food/process-contaminants-food/authorized-uses-pfas-food-contact-applications, accessed December 19, 2022.

[73] National Research Council. (2014). Physicochemical Properties and Environmental Fate. *A Framework to Guide Selection of Chemical Alternatives*. Available at: https://www.ncbi.nlm.nih.gov/books/NBK253965/pdf/Bookshelf_NBK253965.pdf, accessed December 19, 2022.

[74] Prevedouros, K., Cousins, I. T., Buck, R. C., and Korzeniowski, S. H. (2006). Sources, fate and transport of perfluorocarboxylates. *Environmental Science & Technology* 40(1), 32-44.

[75] Abunada, Z., Alazaiza, M. Y., and Bashir, M. J. (2020). An overview of per-and polyfluoroalkyl substances (PFAS) in the environment: source, fate, risk and regulations. *Water* 12(12), 3590.

In soils, surveys have demonstrated widespread distribution of certain PFAS, even in rural areas.[76] In California specifically, certain PFAS have been found in a large number of groundwater samples. Like the larger dataset, groundwater sampling data from Los Angeles County, collected between January 2017 and September 2022, demonstrate this fact. In over 4,900 collected samples, PFOA was measured in over 2,500 of those samples at concentrations ranging from 0.002 ng/L to 29,000 ng/L (29 ppb).[77]

Certain fluorosurfactants came under regulatory scrutiny in the early 2000s, and the U.S. Environmental Protection Agency (EPA) promulgated significant new use rules (SNURs), which restricted the manufacturing and importation of specific chemicals, with certain exemptions for specific ongoing uses. PFAS targeted in the two SNURs in 2002 were variants of the eight-carbon–based sulfonic acid PFOS.[78] Following that initial regulation, subsequent SNURs focused on other perfluorinated sulfonates and small-molecule PFAS with seven or more perfluoroalkyl carbons.[79] In 2009, EPA established provisional health advisory levels for PFOA and PFOS in drinking water at 400 parts per trillion (ppt) and 200 ppt, respectively.[80] In comparison, PFOA concentrations measured in Los Angeles County groundwater (29 ppb) are over one thousand times higher than these advisory levels. The EPA health advisory levels were lowered in 2016 to 70 ppt individually or combined, and then again in 2022 to 0.004 ppt and 0.02 ppt for PFOA and PFOS, respectively.[81] In 2022, two additional small-molecule fluorosurfactants, perfluorobutane sulfonic acid (PFBS) and hexafluoropropylene oxide dimer acid (HFPO-DA, also known as "GenX") were issued lifetime health advisory levels in drinking water at 2,000 ppt and 10 ppt, respectively.[82] Although many PFAS have been studied for risk assessment purposes, today at the federal level, these four molecules are the only PFAS with sufficient evidence to support limits on their presence in the environment.

Fluoropolymers

Because the characteristics of fluoropolymers that are relevant to behavior in biological and environmental systems are measurably different from those of fluorosurfactants (and other small-molecule PFAS), fluoropolymers are often considered to be distinct types of PFAS.[83] Polymers are generally considered lower risk because of molecular size, and this is also true for

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[76] Zhu, W.; Khan, K.; Roakes, H.; Maker, E.; Underwood, K.L.; Zemba, S.; and Badireddy, A.R. (2022), *J. Haz. Mat.* 438: 129479.

[77] Data for PFOA in Los Angeles County wells where available downloaded from: https://gamagroundwater.waterboards.ca.gov/gama/gamamap/public/, accessed November 18, 2022.

[78] 40 CFR 721 March 11, 2002; 40 CFR 721 December 9, 2002.

[79] 40 CFR 721 October 9, 2007; 40 CFR 9 and 721 October 22, 2013.

[80] CRS. 2022. PFAS and Drinking Water: Selected EPA and Congressional Actions. Congressional Research Service. R45693. July 18, 2022.

[81] CRS. 2022. PFAS and Drinking Water: Selected EPA and Congressional Actions. Congressional Research Service. R45693. July 18, 2022.

[82] CRS. 2022. PFAS and Drinking Water: Selected EPA and Congressional Actions. Congressional Research Service. R45693. July 18, 2022.

[83] Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., and van Leeuwen, S.P.J. (2011). *Int. Env. Assess. and Management* 7(4): 513-541.

fluoropolymers (often >100,000 daltons).[84] Concern is also reduced for inert substances like fluoropolymers, compared to substances with functional groups that interact with water, such as small molecule fluorosurfactants. Many have assessed fluoropolymers for risk in the context of medical devices and food contact, as described above, as well as in the context of the Organisation for Economic Co-operation and Development's (OECD) designation "polymers of low concern," defined as "those deemed to have insignificant environmental and human health impacts."[85,86,87,88] As with any assessment, molecules are not interchangeable, but generally, studies have found fluoropolymers to be of low concern for PFAS exposure unless they contain over a certain amount of residual fluorosurfactants(s) from the manufacturing process. [89]

Established Guidelines and Systems for Evaluating Environmental and Health Risk from PFAS

Various regulatory bodies have established guideline levels for the assessment of risk associated with the presence of specific PFAS in drinking water, environmental samples, and in some types of products. These guidelines take many forms, such as environmental screening levels, maximum contaminant levels (MCLs), and limits on the content of PFAS in products. The concentrations that these guidelines identify vary based on the type of sample and the specific type of PFAS, to account for the distinct properties of different chemicals in specific environments, and may change over time.

As there are currently no regulatory guidelines for artificial turf, specifically, screening levels for residential soil have been used for risk assessments related to substances contained in artificial components. For example, the EPA has compared metals and other substances present in artificial turf to residential soil screening levels in a previous crumb rubber study,[90] and compared the metal concentrations that may leach from crumb rubber to drinking water standards, as the State of

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[84] Henry, B.J.; Carlin, J.P.; Hammerschmidt, J.A.; Buck, R.C.; Buxton, L.W.; Fiedler, H.; Seed, J.; and Hernandez, O. (2018). *Int. Env. Assess. and Management* 14(3): 316-334.

[85] OECD Task Force on New Chemicals Notification and Assessment. Data Analysis of the Identification of Correlations between Polymer Characteristics and Potential for Health or Ecotoxicological Concern; Paris, 2009.

[86] For a discussion of fluoropolymers in the context of the OECD's polymers of low concern framework, see: Henry, B.J.; Carlin, J.P.; Hammerschmidt, J.A.; Buck, R.C.; Buxton, L.W.; Fiedler, H.; Seed, J.; and Hernandez, O. (2018). *Int. Env. Assess. and Management* 14(3): 316-334.; Lohmann, R.; Cousins, I.T.; DeWitt, J.C.; Gluge, J.; Goldenman, G.; Herzke, D.; Lindstrom, A.B.; Miller, M.F.; Ng, C.A.; Patton, S.; Scheringer, M.; Trier, X.; and Wang, Z. (2020). *Env. Sci. Tech.* 54: 12820-12828.; Korzeniowski, S.H.; Buck, R.C.; Newkold, R.M.; El Kassmi, A.; Laganis, E.; Matsuoka, Y.; Dinelli, B.; Beuchet, S.; Adamsky, F.; Weilandt, K.; Soni, V.K.; Kapoor, D.; Gunasekar, P.; Malvasi, M.; Brianti, G.; and Musio, S. (2022). *Int. Env. Assess. and Management.* https://doi.org/10.1002/ieam.4646.

[87] Henry, B. J; Carlin, J. P; Hammerschmidt, J. A; Buck, R. C; Buxton, L W.; Fiedler, H.; Seed, J.; Hernandez, O. A Critical Review of the Application of Polymer of Low Concern and Regulatory Criteria to Fluoropolymers. *Integr. Environ. Assess. Manage*. 2018, 14(3), 316−334.

[88] U.S. EPA. Premanufacture Notification Exemption for Polymers; Amendment of Polymer Exemption Rule to Exclude Certain Perfluorinated Polymers, 2010; Vol. 75.

[89] Lohmann, R.; Cousins, I.T.; DeWitt, J.C.; Gluge, J.; Goldenman, G.; Herzke, D.; Lindstrom, A.B.; Miller, M.F.; Ng, C.A.; Patton, S.; Scheringer, M.; Trier, X.; and Wang, Z. (2020). *Env. Sci. Tech.* 54: 12820-12828.

[90] EPA. 2009. A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds. EPA/600/R-09/135. November, at p. vi.

California has done in a previous crumb rubber study.[91] With respect to soils, the EPA and the state of California have established or proposed residential soil screening levels for certain PFAS (Table 1). These screening levels are intended to be used to "determine whether levels of contamination found at the site may warrant further investigation or site cleanup, or whether no further investigation or action may be required."[92]

Table 1. EPA and California State screening levels for certain PFAS in residential soil.

Analyte	EPA Residential Soil Screening Level[93] (ppb)	California Residential Soil Screening Level[94] (ppb)
PFOA	190	3.8
PFNA[95]	190	
HFPO-DA[96]	230	
PFBS	19,000	
PFHxS	1,300	
PFOS	130	12

With respect to PFAS in products, there are fewer guidelines and regulations. However, California's Assembly Bill 1817 imposes a limit of 50–150 ppm total organic fluorine[97] (see below for further discussion of this method) on various textile-based products. Organizations that set limits for compostable goods use a similar limit of 100 ppm total organic fluorine.[98]

Experimental Test Methods for PFAS Identification and Quantification

The presence of PFAS in a product, like artificial turf, is one factor that may be considered in an assessment of environmental risk related to that product. As a result, product testing may be conducted to identify the identity and quantity of fluorine-containing components, including PFAS, in the product. However, available test methods have certain limitations, which are described in more detail below, and test results must be interpreted in the context of the test

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[91] OEHHA. 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. January, at p. 95.

[92] Regional Screening Levels (RSLs) - User's Guide. U.S. EPA (2022). Available at: https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide, accessed December 14, 2022.

[93] U.S. EPA. Regional Screening Levels. Accessible at https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables.

[94] RWQCB. 2020. PFAS ESL Memorandum. Available at: https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/ESL/PFAS_ESL_Memo.pdf.

[95] Perfluorononanoic acid (PFNA).

[96] Hexafluoropropylene oxide-dimer (HFPO-DA).

[97] Total organic fluorine (TOF) is distinct from a targeted PFAS measurement, as TOF is a nominal measure of all carbon-bound fluorine in a sample that may include non-PFAS sources. However, as both the TOF and TOP assays serve as proxies for total PFAS content, TOF regulatory limits are relevant to the discussion.

[98] Biodegradable Products Institute, https://bpiworld.org/fluorinated-chemicals, accessed November 18, 2022.

method and the product itself. Further, it is important to note that the *presence* of PFAS in a product does not directly equate to the *release* of PFAS from that product into the environment. To assess the potential risks associated with PFAS in a specific product, additional factors should be considered, including the specific substances that are present, and the properties of these substances relevant to its behavior in environmental and biological systems.

Testing a product or environmental sample for PFAS is challenging given the limitations of testing methods that are currently available, and this can be important when reviewing test reports seeking to describe the presence or absence of PFAS in an environmental sample. As described above, there are thousands of different PFAS that demonstrate widely different chemical and physical properties, of which less than 100 are included in currently available standardized methods.[99] Therefore, many of the methods used to detect and quantify PFAS are nonstandard, custom methods that differ between laboratories and may not provide equivalent information. Further, the trace levels at which detection of certain PFAS is required (as low as parts per trillion, in the case of drinking water samples) and the ubiquity of PFAS in products and the environment can lead to quality-related laboratory issues because of sample or instrument contamination. To understand the PFAS content of a product or environmental sample, then, it is necessary to interpret test results carefully in the context of many factors, including the sample type, the specific sample collection or preparation processes used, the details of the analytical method itself, and quality-control data generated alongside the test results of interest.

Current analytical methods for the detection of PFAS include targeted and nontargeted methods, which are directed at either finding a specific set of pre-identified PFAS or finding chemical signals associated with any PFAS. Targeted methods detect and quantify a relatively small number of specific PFAS chemicals with a high degree of accuracy. Nontargeted analyses detect a wider set of chemistries, but do not provide verified identification and quantification of these substances. For example, elemental analysis-based methods that detect fluorine in any form may provide a total concentration of fluorine or extractable fluorine contained in a sample, but do not confirm the presence of PFAS or identify specific substances present because they also detect other types of fluorine that may be present in the samples.

Targeted Analysis

The few standardized methods that are currently available include targeted methods established by the EPA for use with drinking water and certain environmental samples. These methods allow for the detection of 29 specific PFAS analytes, all of which are small-molecule fluorosurfactants, in drinking water samples.[100] The presence of 40 small-molecule PFAS analytes are detectable in nonpotable water and soil, biosolids, sediment, landfill leachate, and fish tissue according to an

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[99] United States Government Accountability Office (GAO). (2022). Persistent Chemicals: Technologies for PFAS Assessment, Detection, and Treatment. Accessed at https://www.gao.gov/products/gao-22-105088.

[100] These methods leverage solid phase extraction (SPE) liquid chromatography-tandem mass spectrometry (LC-MS/MS) to decipher the presence and specific concentrations of at least 25 PFAS analytes. U.S. EPA (2019). Method 533: Determination of Per- and Polyfluoroalkyl Substances in Drinking Water by Isotope Dilution Anion Exchange Solid Phase Extraction and Liquid Chromatography/tandem Mass Spectrometry. U.S. EPA (2020) Method 337.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS).

additional draft EPA method.[101] While the EPA has indicated that additional test methods will be released for environmental samples, none are currently published.[102] Further, no standardized methods are generally accepted for the evaluation of samples other than environmental media, such as consumer product samples.

Targeted analysis on other types of samples requires sample preparation, including an extraction step that can influence the results of the targeted PFAS analysis. For example, consumer products such as textiles must be extracted using solvents or solutions, such as ammonium hydroxide and methanol, to isolate fluorine-containing materials in a form that can be analyzed using methodology similar to the above-described EPA methods. These extraction conditions are intended to extract and measure a wide variety of different PFAS that might be present in a sample, for the purpose of determining the sample's composition. This type of extraction method is not intended to mimic the conditions a product might experience during use, and should not be used as an indication of the leachability or availability of PFAS in the sample unless extraction conditions are chosen appropriately.

Targeted analyses report concentrations of the specific PFAS that the method detects, at or above certain concentration limits. Analytical methods have certain levels of sensitivity that depend on the techniques used, the sample type, the analyte, and other factors. The lowest concentration detectable by the method is typically called the "detection limit," below which, the analyte could be present but would not be identified by that method. However, at this low concentration, the specific level of an analyte may not be reliably determined. Therefore, the "practical quantitation limit" is the concentration at which reproducible quantification can be determined for an analyte using the method. These limits may be specified in standardized methods, or may be determined by a specific laboratory for their particular method and equipment. The "reporting limit" can be defined in different ways. The reporting limit is a concentration threshold that is often set in relation to the practical quantitation limit, as a threshold level below which results should be considered approximate.[103]

A common way in which targeted methods are used with products is the "Total Organic Precursors" (TOP) method, which consists of two targeted analyses in combination.[104,105] In the

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[101] U.S. EPA. (2021). Method 8327: Per- and Polyfluoroalkyl Substances (PFAS) by Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). U.S. EPA. (2022). Draft Method 1621: Screening Method for the Determination of Adsorbable Organic Fluorine (AOF) in Aqueous Matrices by Combustion Ion Chromatography (CIC). U.S. EPA. (2022). 2nd Draft Method 1633: Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolid, and Tissue Samples by LC-MS/MS.

[102] "PFAS Analytical Methods Development and Sampling Research." Available at: https://www.epa.gov/water-research/pfas-analytical-methods-development-and-sampling-research, accessed December 13, 2022.

[103] California's Surface Water Ambient Monitoring Program. Quantitation and Reporting Limits 101. (2011). Available at: https://mywaterquality.ca.gov/monitoring_council/collaboration_network/docs/bvanbuuren_jan2012.pdf. accessed December 14, 2022.

[104] For example, see https://cswab.org/wp-content/uploads/2018/05/Total-PFAS-Testing-Benefits-and-Potential-2017.pdf, accessed December 14, 2022.

[105] Several published methods for TOP analysis are based on a method described in 2012. *See*: Houtz, E. F., & Sedlak, D. L. (2012). Oxidative conversion as a means of detecting precursors to perfluoroalkyl acids in urban runoff. *Environmental science & technology*, 46(17), 9342-9349.

TOP method a sample of product is first prepared by extraction with solvent to isolate small-molecule PFAS that may be present in the product. Next, the resulting extract is analyzed[106] using targeted analysis to quantify the presence of specific PFAS analytes in the initial sample ("pre-TOP"). A second sample of the product is then exposed to oxidizing and basic conditions intended to digest any bound PFAS or PFAS precursors, and the resulting solution is analyzed using targeted analysis ("post-TOP"). TOP method conditions vary, and the conditions can affect the specific PFAS and quantities detected in the experiment. Generally, the TOP method is expected to convert various potential precursors (which may be PFAS of other types) into perfluorinated carboxylic acids (PFCAs).[107,108] As a result, many types of precursors are reduced to a set of PFCAs in the TOP method, which makes it difficult or impossible to derive direct information about the identity of the precursors that originally existed in the sample, prior to exposure to oxidizing conditions.[109] This ambiguity can complicate analysis of the detected substance's source in the sample.

Nontargeted Analysis

Nontargeted analyses for PFAS and methods such as "total fluorine" and "total organic fluorine" methods detect a wider set of chemical substances, including fluoropolymers, but do not provide the reliable identification and quantification of the above-described standardized methods for targeted analysis. Total fluorine methods detect the amount of fluorine, compared to other types of elements (such as carbon and oxygen) present in a sample. Total fluorine can be used as a screening tool for the presence of PFAS, because it will detect any of the thousands of PFAS present in a sample along with many other substances. Importantly, not all fluorine that is measured in environmental or materials samples is a "PFAS" chemical and the level of fluorine in a sample can, therefore, be very different than the amount of PFAS present in that sample.

For example, fluorine is a naturally occurring element that is present in the environment as inorganic fluoride in minerals and dissolved in water, as well as in certain organic compounds that may or may not be considered PFAS. All of these types of fluorine would be detected and included in the results of a total fluorine analysis, but are significantly different in the physical and chemical properties that are relevant to their behavior in biological and environmental systems. Total organic fluorine methods are similar to total fluorine methods, but include an extraction step intended to remove inorganic fluorine from the sample prior to analysis.[110]

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[106] Analysis is typically conducted using liquid chromatography-mass spectrometric (LC-MS) analysis, similar to the EPA methods for drinking water analysis described above.

[107] PFCAs are a group of PFAS containing a fluorinated alkyl chain and a carboxylate end group, of which PFOA is one of the most well-known examples. PFCAs are structurally different and chemically distinct from other PFAS of similar chain lengths, such as PFOS, another well-known PFAS.

[108] Some ether-containing PFAS are stable and may be only partially oxidized during the TOP process, reducing the likelihood or extent of their detection in the assay. Zhang, C., Hopkins, Z.R., McCord, J., Strynar, M.J., Knappe, D.R.U., *Environmental Science & Technology Letters* (2019), 6(11), 662-668.

[109] Göckener, B., Lange, F.T., Lesmeister, L., Göcçe, E., Dahme, H.U., Bandow, N., Biegel-Engler, A., Digging deep—implementation, standardisation and interpretation of a total oxidisable precursor (TOP) assay within the regulatory context of per- and polyfluoroalkyl substances (PFASs) in soil. *Environ. Sci. Europe* (2022), 34:52.

[110] Al Amin, M., Sobhani, Z., Liu, Y., Dharmaraja, R., Chadalavada, S., Naidu, R., ... and Fang, C. (2020). Recent advances in the analysis of per-and polyfluoroalkyl substances (PFAS)—A review. *Environmental Technology & Innovation* 19, 100879.

However, even this approach has limitations because it has been demonstrated that methods for total organic fluorine analysis can also detect inorganic fluoride.[111,112,113] In summary, total fluorine and total organic fluorine measurements are a potential indicator of PFAS that may be present within a sample, but are not a definitive determinant. Using total fluorine as a measurement of the concentration of PFAS may significantly overstate the concentration of PFAS in the sample.

Why Are PFAS Associated with Artificial Turf Systems?

As described earlier, artificial turf is manufactured by extrusion, exposed to outdoor conditions, and expected to provide certain characteristics related to friction and abrasion potential in order to mimic the playing experience of a grass field. Each of these attributes is served by the introduction of a small amount of a fluoropolymer additive into the turf fiber formulation.[114,115,116,117,118,119] These additives, as noted above, are large molecules with nonreactive chemistries that contain fluorine and demonstrate significant differences from small-molecule PFAS in the properties that are relevant to environmental impact and human exposure.

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[111] Jones, J. L., Burket, S. R., Hanley, A., & Shoemaker, J. A. (2022). Development of a standardized adsorbable organofluorine screening method for wastewaters with detection by combustion ion chromatography. *Analytical Methods*, 14(36), 3501-3511.

[112] Shoemaker, J. A. and Jones, J. L. Development of Adsorbable Organic Fluorine (AOF) Screening Method with Detection by Combustion Ion Chromatography (CIC). Executive Meeting, Board of Scientific Counselors, September 29-30, 2021, at slide 3. Available at: https://www.epa.gov/system/files/documents/2021-09/cq1_br1_shoemaker.pdf, accessed December 20, 2022.

[113] EPA Draft Method 1621, Screening Method for the Determination of Adsorbable Organic Fluorine (AOF) in Aqueous Matrices by Combustion Ion Chromatography (CIC) at p. 3. Available at: https://www.epa.gov/system/files/documents/2022-04/draft-method-1621-for-screening-aof-in-aqueous-matrices-by-cic_0.pdf, accessed December 20, 2022.

[114] Bigio, D., Meillon, M. G., Kharchenko, S. B., Morgan, D., Zhou, H., Oriani, S. R., ... and Migler, K. B. (2005). Coating kinetics of fluoropolymer processing aids for sharkskin elimination: The role of droplet size. *Journal of Non-Newtonian Fluid Mechanics* 131(1-3), 22-31.

[115] Dubrocq-Baritaud, C., Darque-Ceretti, E., and Vergnes, B. (2014). Fluoropolymer processing aids in linear-low density polyethylene extrusion: How to improve their efficiency? *Journal of Non-Newtonian Fluid Mechanics* 208, 42-52.

[116] Arda, D. R., and Mackley, M. R. (2005). The effect of die exit curvature, die surface roughness and a fluoropolymer additive on sharkskin extrusion instabilities in polyethylene processing. *Journal of Non-Newtonian Fluid Mechanics* 126(1), 47-61.

[117] EP1672020A1 at 0014.

[118] For example, FIFA Test Method 08 and ASTM F1015 are standard test methods used to measure the coefficient of friction for artificial turf.

[119] For example, the use of softer polyolefin yarns in the 1990s was a replacement for the harder more abrasive polyamine yarns from the first-generation artificial turf products, see Tay, S. P., Fleming, P., Hu, X., and Forrester, S. (2017). Skin friction related behaviour of artificial turf systems. *Journal of Sports Sciences* 35(15), 1500-1507.

Synthetic turf has recently been the subject of attention related to component materials that may be considered PFAS, and the potential for release of PFAS into the environment.[120,121,122] However, public comments related to PFAS in artificial turf have, in some cases, relied on incomplete information about the source of PFAS in environmental and artificial turf samples and flawed assumptions related to the data provided by specific test methods, discussed in detail below. In order to accurately assess the environmental impact of PFAS that may be contained in artificial turf, it is important to consider the specific type of fluorinated substance(s) present, the level(s) at which these substances are present, and the potential for interactions between these substances and the environment, among other factors.

In some instances, the detection of fluorine is the basis for concluding that artificial turf fibers and backing materials contain PFAS.[123,124] However, as described earlier, testing methods that detect fluorine in product samples have certain limitations, including potential detection of non-PFAS substances. Fluorine is an element that may be present in many chemical forms, and the literature provides examples of numerous fluorine-containing substances that have been well characterized and described to offer acceptable and beneficial attributes (for example, fluoride in toothpaste). Even if present as organic fluorine, not all fluorinated compounds will be considered "PFAS" according to different definitions. And within the group of compounds that may be considered "PFAS," different compounds have different properties, all of which matter in the assessment of environmental risk from a product such as artificial turf.

At present, there appears to be only one study in the peer-reviewed literature that discusses the presence of PFAS in artificial turf systems. In that work, the authors conclude that the PFAS identified in artificial turf is polymeric organofluorine, stating "these results point toward polymeric organofluorine (e.g., fluoroelastomer, polytetrafluoroethylene, and polyvinylidene fluoride);" therefore, "[t]he combination of poor extractability and recalcitrance towards advance oxidation suggest that the fluorine in AT [artificial turf] does not pose an imminent risk to users."[125] The authors further emphasize the differences between the detection of total fluorine content from the emission or extraction of nonpolymeric PFAS from the artificial turf during its intended use, which is estimated to be an order of magnitude lower.[126]

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[120] Lerner, S. (2019). Toxic PFAS chemicals found in artificial turf, *The Intercept*, pp. 1-13.

[121] Glüge, J., Scheringer, M., Cousins, I. T., DeWitt, J. C., Goldenman, G., Herzke, D., ... and Wang, Z. (2020). An overview of the uses of per-and polyfluoroalkyl substances (PFAS). *Environmental Science: Processes & Impacts* 22(12), 2345-2373.

[122] Ng, C., Cousins, I. T., DeWitt, J. C., Glüge, J., Goldenman, G., Herzke, D., and Wang, Z. (2021). Addressing urgent questions for PFAS in the 21st Century. *Environmental Science & Technology* 55(19), 12755-12765.

[123] Dr. Graham Peaslee and Kristen Mello, NEWMOA Conference, April 6, 2022.

[124] Synthetic Turf Laboratory Testing and Analysis Summary Report Martha's Vineyard Regional High School (MVRHS), Horsley Witten Group, March 1, 2021.

[125] Lauria, M. Z., Naim, A., Plassmann, M., Fäldt, J., Sühring, R., and Benskin, J. P. (2022). Widespread Occurrence of Non-Extractable Fluorine in Artificial Turfs from Stockholm, Sweden. Environmental Science & Technology Letters 9(8), 666-672 (quote at the abstract).

[126] Lauria, M. Z., Naim, A., Plassmann, M., Fäldt, J., Sühring, R., and Benskin, J. P. (2022). Widespread Occurrence of Non-Extractable Fluorine in Artificial Turfs from Stockholm, Sweden. *Environmental Science & Technology Letters* 9(8), 666-672.

Further public discussion of PFAS in artificial turf relies on poorly controlled experimental conditions and inaccurate assumptions. For example, surface water samples taken from bodies of water adjacent to artificial turf fields generally do not allow for contributions from sources other than the turf field to be identified, even though other sources may be relevant. Thus, a report of ppm levels of PFAS detected in surface water near a turf field[127] does not provide reliable information about the likely source or sources of the PFAS.

Overall, the potential for artificial turf materials to release PFAS into the environment should be assessed by considering not only whether PFAS are present in the turf at any level, but by a consideration of (1) the specific substances present, (2) the amounts at which these substances are detected, and (3) the potential for environmental mobility of these substances.

PFAS Testing of Vertex CORE 2.5 Turf Carpet

FieldTurf artificial turf carpet products, including the specific components proposed for use in the Project, have been evaluated on at least four occasions for the presence of PFAS.[128] Undetectable[129] to very low levels[130,131,132] of small-molecule PFAS were identified in the materials. These studies were performed on multiple FieldTurf products,[133] at different laboratories,[134] at the request of different parties (including the City of Portsmouth, NH).

The specific components proposed for use in the Project,[135] were evaluated using two targeted methods (i.e., a targeted PFAS analysis paired with a Total Oxidizable Precursor (TOP) assay[136]) to evaluate the samples for the presence of 68 small-molecule PFAS and additional precursors.[137]

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[127] Dr. Graham Peaslee and Kristen Mello, NEWMOA Conference, April 6, 2022.

[128] Information relevant to the sampling of the Core Vertex 2.5 material are described in: Letter to Mr. Mike Harden, Environmental Science Associates RE: Testing of FieldTurf Cryogenic Crumb Rubber for Total CAM 17 Metals and FieldTurf Core Vertex 2.5 Fiber for Total PFAS Using the Total Oxidizable Precursor Assay, dated November 22, 2022.

[129] Analytical report on "Field Turf Sample," Eurofins Sacramento, dated February 25, 2022.

[130] Letter to Mr. Darren Gill, "RE: FieldTurf Synthetic Turf Carpet PFAS Testing Results," dated November 26, 2019.

[131] TRC Technical Memorandum, "Evaluation of PFAS in Synthetic Turf," dated June 7, 2022.

[132] Analytical report on "Cryogenic Rubber 14-30" and "Core Vertex 2.5" samples. Eurofins Sacramento, dated September 28, 2022.

[133] Tested products included FieldTurf Core Vertex 2.5, Classic HD, Core, Revolution, Revolution 360, XM6, and XT with Mattex.

[134] Testing was conducted at: ALS Environmental of Kelso, Washington; Eurofins of Sacramento, California; and Eurofins in Lancaster, Pennsylvania.

[135] Information relevant to the sampling of the Core Vertex 2.5 material are described in: Letter to Mr. Mike Harden, Environmental Science Associates RE: Testing of FieldTurf Cryogenic Crumb Rubber for Total CAM 17 Metals and FieldTurf Core Vertex 2.5 Fiber for Total PFAS Using the Total Oxidizable Precursor Assay, dated November 22, 2022.

[136] The test report from Eurofins refers to the U.S. EPA Method 537 as the basis for the targeted analysis of the pre- and post-oxidized samples, though deviations from that method are necessary, as EPA 537 is for the testing of drinking water and not solid samples like artificial turf.

[137] The term "PFAS" in the context of this testing report, refers to the list of 68 small molecule fluorinated chemicals targeted by Eurofins in their analyses.

The PFAS that were targeted in this analysis include small-molecule fluorinated surfactants, such as PFOS and PFOA, that are the focus of certain regulatory activity. Fluoropolymers would not be detected by this method, or by other targeted analysis methods currently available.

These tests allow for screening assessments and provide a foundation for specifying additional testing to understand risks associated with detected substances. This screening approach underlies the environmental screening levels published by regulatory agencies for assessing potential environmental risk from specific substances in different types of media. As discussed earlier, the presence of a substance is not enough to know how it may impact environmental or biological systems. The detected level, as well as factors such as availability from a matrix (such as the plastic composition of the turf) and the potential for transport away from the source (e.g., due to size and solubility) are important.

Overall, the results of testing on the Vertex CORE 2.5 turf carpet indicated that, prior to oxidation, very low levels of small-molecule PFAS were present in the product. Specifically, only one fluorinated substance was detected in the original extracted conditions, and this was detected below the reporting limit[138] of 1 ppb. After oxidation and extraction of the sample, two substances were detected above the reporting limit of 1 ppb. The results of the testing are provided in Table 2 below, followed by a more detailed analysis of the information, including factors indicating that the quality of the data is uncertain regarding the identification of substances over background levels not from the sample.

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[138] Reporting limits represent concentrations at which quantification of the substance can be performed at an acceptable level of accuracy and repeatability. Reporting limits vary based on the type of sample as well as the method and equipment used. For example, while drinking water methods published by the EPA are able to achieve reporting limits in the parts-per-trillion concentration range, these methods cannot be used to analyze product samples without modification. The modifications made for product samples and other types of media often result in less precision and accuracy because the samples are more challenging to test and methods involve additional steps that introduce uncertainty, such as the extraction and oxidation steps of the TOP method used in the Eurofins investigation of the Core Vertex 2.5 product.

Table 2. Table of PFAS analytes detected before and after chemical digestion via a Total Oxidizable Precursor (TOP) assay and residential soil screening levels established by EPA and proposed by California. PFAS with EPA and/or California screening levels are listed first, followed by other detected PFAS.

ANALYTE[139]	**VERTEX CORE 2.5 ANALYSIS RESULTS**				**RESIDENTIAL SOIL SCREENING LEVELS**	
	Pre-TOP (ppb)	Post-TOP (ppb)	Reporting Limit (detection limit) (ppb)	Notes	EPA[140] (ppb)	California[141] (ppb)
PFOS	ND	ND	1.0 (0.22)		130	12
PFBS	ND	ND	1.0 (0.19)		19,000	
PFHxS	ND	ND	1.0 (0.15)		1,300	
PFOA	ND	0.35*	1.0 (0.27)		190	3.8
PFNA	ND	0.17*	1.0 (0.11)		190	
HFPO-DA	ND	ND	1.0 (0.21)		230	
PMPA	0.38	ND	1.0 (0.15)			
MTP‡	ND	5.9	1.0 (0.50)	Matrix Interference		
PFPrA†	ND	0.7*	1.0 (0.15)	Present in blank		
PFBA	ND	1.7	1.0 (0.23)	Present in blank		
PFPeA	ND	0.34*	1.0 (0.21)			
PFHxA	ND	0.87*	1.0 (0.16)			
PFHpA	ND	0.50*	1.0 (0.19)			
PFTrDA	ND	0.11*	1.0 (0.11)			

* The measured concentration is below the reporting limit, but above the detection limit, and should be considered approximate.

† PFPrA is referred to as "PPF Acid" in the Eurofins report.

‡ MTP exhibited poor recoveries in the laboratory control sample (ca. 4%), indicating significant matrix interference. Measured concentrations should be considered approximate until the nature of the interference is understood.

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[139] Perfluoro-2-methoxypropanoic acid (PMPA); 2,2,3,3-tetrafluoro-3-methoxy-propanoic acid (MTP); Perfluoropropionic acid (PFPrA); perfluorobutanoic acid (PFBA); Perfluoropentanoic acid (PFPeA); Perfluorohexanoic acid (PFHxA); Perfluoroheptanoic acid (PFHpA); Perfluorooctanoic acid (PFOA); Perfluorononanoic acid (PFNA); Perfluorotridecanoic acid (PFTrDA); Perfluorobutanesulfonic acid (PFBS); Perfluorohexanesulfonic acid (PFHXS); Hexafluoropropylene oxide-dimer acid (HFPO-DA).

[140] U.S. EPA. Regional Screening Levels. Available at https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables, accessed December 15, 2022.

[141] RWQCB. 2020. PFAS ESL Memorandum. Available at: https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/ESL/PFAS_ESL_Memo.pdf.

The data in Table 2 demonstrate the following:

- A single PFAS analyte was detected in the Vertex CORE 2.5 sample: perfluoromethoxy propanoic acid (PMPA) at 0.38 parts per billion (ppb). This value is below the reporting limit, but above the method detection limit, and is therefore an approximate value.

- Several 3- to 13- carbon PFCAs were identified in the sample after subjecting it to oxidation, but these substances were detected below the reporting limit of 1.0 ppb. These data provide a reasonable basis for identifying compounds, but do not provide exact quantification information because the detected concentrations are below those reliably quantified by the method.

- Perfluorobutanoic acid (PFBA) was detected in the post-oxidation sample, and this was above the reporting limit of 1.0 ppb. However, PFBA was also identified in the method blank (*i.e.*, a sample that is run as a control, using the carrier solvents and other method components but not containing artificial turf extracts) at 1.05 ppb, indicating that contamination of the instrument or other interference likely contributed to the result.[142] These data do not provide a reliable identification or quantification of PFBA in the Vertex CORE 2.5 material.

- Perfluoro-2-methoxypropanoic acid, (MTP) was identified in the post-oxidation sample at 5.9 ppb (above the 1.0 ppb reporting limit). However, based on poor control sample recovery, it is likely that matrix interference[143] has introduced inaccuracy to this measurement. These data provide a reasonable basis for identifying the presence of MTP in the oxidized sample, but do not provide reliable quantification information.

The values of all detected PFAS analytes are in the single-digit ppb range or lower, and substantially lower than levels used for regulatory guidance about soils. For the two substances associated with regulatory guidance (i.e., PFOA and PFNA in residential soils), the values are hundreds of times lower than the EPA environmental screening levels and at least ten times lower than the proposed California screening level. While the EPA and California screening levels are associated with soils rather than products, this comparison can help frame a risk assessment.

Further, the detected levels of PFAS in this assay are several orders of magnitude below the levels being discussed in various regulations that apply to polymer or fiber-based products, although the regulatory limits are set in relation to a different test method (total organic fluorine) that detects a wider range of fluorinated substances. As a more direct comparison, a study by Lui and colleagues found that carpets tested for specific PFAS exhibited levels of small molecule surfactants (fluorotelomer alcohols) up to approximately 330 ppm—an approximate 100,000-fold higher

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[142] Negation of the result is based on a factor-of-two multiple of the level found in the method blank compared to the level found in the sample. Because the levels found in both the blank in the sample are so close to one another, contamination is a likely cause for the signal and the result should not be accepted.

[143] Matrix interference is the term used to describe an analytical issue where materials and substances present in the sample, that are not the analyte of interest, cause inaccuracies in the method's ability to detect and quantify an analyte.

concentration of PFAS than the PFCAs detected in the post-TOP sample reported above for the Vertex CORE 2.5 product.[144]

What Are Metals?

In addition to addressing the questions related to PFAS in artificial turf, described above, Exponent has also been asked to consider the potential for certain metals to be present in the crumb rubber infill material proposed for use in the Project. This section provides a description of certain metals and their presence in the environment, a discussion of test methods that can be used to understand the metallic elements in a material and the mobility of the metals contained in it, and a description of test results relevant to the measured metals content of the crumb rubber infill material proposed for use in the Project.

Metals account for the majority of the known elements in the periodic table. They occur naturally in many forms, including as pure elements (*e.g.*, gold) as well as in combinations or alloys (*e.g.*, steel), in salts and minerals (*e.g.*, calcium carbonate/"limestone"), and in organometallic compounds (*e.g.*, hemoglobin). Metals are also frequently used in various forms in human-engineered materials, such as zinc oxide used as a UV-blocking component in sunscreen,[145] or the calcium cation in gypsum drywall and in hand soap products.[146]

Unlike other types of substances, metals are not created or destroyed by chemical or biological activity. However, the chemical and physical environment of a metal can change its form—for example, by changing its oxidation state or converting between inorganic and organic forms. The form of the metal influences its properties and characteristics—for example, its bioaccessibility, bioavailability, fate, and effects.[147]

Metals in the Environment

Metals occur naturally in both the earth's crust and in bodies of water. Metals are loosely grouped in the scientific literature by their abundance, with aluminum, calcium, iron, magnesium, potassium, sodium, silicon, and titanium classified as "major" elements, while "trace metals" include elements having less than 0.1% abundance in the earth's crust.[148] The natural levels of metals in soil vary by location, and can be affected by human activities including mining,

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[144] Liu, X., Guo, Z., Folk, E.E., Roache, N.F., *Chemosphere* (2015), 129, 81-86.

[145] National Center for Biotechnology Information (2022). PubChem Compound Summary for CID 14806, Zinc oxide, available at https://pubchem.ncbi.nlm.nih.gov/compound/Zinc-oxide, accessed November 14, 2022.

[146] Dove Care & Protect Antibacterial Hand Wash, https://www.dove.com/us/en/washing-and-bathing/hand-wash/care-protect-antibacterial-hand-wash.html, accessed November 18, 2022.

[147] Framework for Metals Risk Assessment. 2007. EPA 120/R-07/001, at p. 1-10. Available at: https://www.epa.gov/sites/default/files/2013-09/documents/metals-risk-assessment-final.pdf.

[148] Bradford, G.R., Change, A.C., Page, A.L., Bakhtar, D., Frampton, J.A., Wright, H., *Kearney Foundation of Soil Science Division of Agricultural and Natural Resources* (1996), p. 4. Available at https://ucanr.edu/sites/poultry/files/297094.pdf.

agriculture, and transportation.[149] A study that measured the concentration of metals in California soil samples found that the most abundant metals were the same as generally found in the earth's crust, though the relative abundance of potassium and magnesium is reversed. Metals also occur naturally in the ocean—sodium, magnesium, calcium, and potassium being the most abundant—though other metals such as strontium are also commonly present at lower levels.[150]

Metals are also naturally present in biological systems, and are necessary for human and plant health.[151] Iron, copper, cobalt, sodium, and zinc ions play a vital role in enzyme structure and catalysis.[152] Unsurprisingly, then, deficiencies in certain minerals, including iron, zinc, iodine, and others, are reported to have a negative impact on public health.[153,154,155] Zinc and other metals are reported as being essential for the growth of certain plants.[156]

While metals share certain common characteristics, the properties of individual metals that are relevant to an environmental assessment or exposure estimate vary depending on the particular metal and its form.[157] Individual metals are found, and used, in different contexts because each has a unique electronic structure, which results in specific properties and chemical reactivity in different types of environments. These properties lead to different behaviors in environmental systems (e.g., solubility and mobility in water) as well as different effects on biological systems.[158] An assessment of potential environmental impacts from the presence of a particular metal at a specific concentration should consider the identity of the metals present, the metals' form (i.e., the specific compound or substance present), the concentration at which these substances or compounds are present, the ability of the substances or compounds to enter the environment, as well as other factors.

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[149] Bradford, G.R., Change, A.C., Page, A.L., Bakhtar, D., Frampton, J.A., Wright, H., *Kearney Foundation of Soil Science Division of Agricultural and Natural Resources* (1996), p. 4. Available at https://ucanr.edu/sites/poultry/files/297094.pdf.

[150] Duxbury, Alyn C. , Mackenzie, Fred T. and Byrne, Robert Howard. "seawater". Encyclopedia Britannica, 28 Apr. 2022, https://www.britannica.com/science/seawater, accessed December 7, 2022.

[151] Framework for Metals Risk Assessment. 2007. EPA 120/R-07/001, at p. 1-10. Available at: https://www.epa.gov/sites/default/files/2013-09/documents/metals-risk-assessment-final.pdf.

[152] Voet, D., Voet, J.D., and Pratt, C.W.; Fundamentals of Biochemistry, Third Edition, 2008, p. 335.

[153] Anuraj H Shankar. Mineral Deficiencies. Hunter's Tropical Medicine and Emerging Infectious Disease (Ninth Edition) 2020, pp. 1054.

[154] Allen. et al. Guidelines on food fortification with micronutrients. WHO Library Cataloguing-in-Publication Data. 2006. pp 3-86.

[155] Afshin, A., Sur, P.J., Fay, K.A., Cornaby, L., Ferrara, G., Salama, J.S., Mullany, E.C., Abate, K.H., Abbafati, C., Abebe, Z., et al. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*. (2019).

[156] Bradford, G.R., Change, A.C., Page, A.L., Bakhtar, D., Frampton, J.A., Wright, H., *Kearney Foundation of Soil Science Division of Agricultural and Natural Resources* (1996), p. 4. Available at https://ucanr.edu/sites/poultry/files/297094.pdf.

[157] Framework for Metals Risk Assessment. 2007. EPA 120/R-07/001, at p. 27-32. Available at: https://www.epa.gov/sites/default/files/2013-09/documents/metals-risk-assessment-final.pdf.

[158] Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Molecular, clinical and environmental toxicology*, 133-164.

Established Guidelines and Systems for Evaluating Environmental and Health Risk from Metals

Similarly to the guidelines in place for PFAS, regulatory bodies and other organizations have published guidelines for evaluating environmental and health risks related to the presence of metals in environmental media. The U.S. EPA has published a framework for risk assessment,[159] as well as regional screening levels for environmental samples, including residential soils (EPA screening levels).[160] This process is better established for metals than for PFAS, but both incorporate many of the same concepts.[161] Screening levels vary based on the specific metal considered and the medium in which it is present, reflecting differences in the properties of different metals and their relative availability in different types of samples. These screening levels indicate "whether levels of contamination found at the site may warrant further investigation or site cleanup, or whether no further investigation or action may be required."[162] The California Regional Water Quality Control Board has also established environmental screening levels for metals in environmental media, such as residential shallow soils (California screening levels).[163] The EPA and California screening levels for residential soil samples are summarized for certain metals in Table 3

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[159] Framework for Metals Risk Assessment. 2007. EPA 120/R-07/001, at p. 1-10. Available at: https://www.epa.gov/sites/default/files/2013-09/documents/metals-risk-assessment-final.pdf

[160] Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1) November 2022, available at https://semspub.epa.gov/work/HQ/403628.pdf, accessed November 28, 2022.

[161] Leaching Environmental Assessment Framework (LEAF) How-To Guide. U.S. EPA (2019) Revision 1. Available at: https://www.epa.gov/sites/default/files/2019-05/documents/final_leaching_environmental_assessment_framework_leaf_how-to_guide.pdf, accessed December 15, 2022.

[162] Regional Screening Levels (RSLs) - User's Guide. U.S. EPA (2022). Available at: https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide, accessed December 15, 2022.

[163] San Francisco Bay Regional Water Quality Control Board. "Environmental Screening Levels." Available at https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/esl.html.

Table 3. As described above, the EPA and the State of California have both used residential soil screening levels for metals content to assess potential risks related to artificial turf, and specifically, to crumb rubber.[164,165]

These screening levels are expressed as concentrations of specific metals (occurring in any form), rather than concentrations of specific compounds, in certain media as a result of test method limitations. However, the potential for a metal to enter the environment depends on the specific compound present. To the extent that screening levels identify the need for further investigation, one of the important factors to consider is the type of chemical compound or substance actually present in the material and the properties of that compound or substance.

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[164] EPA. 2009. A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds. EPA/600/R-09/135. November, at p. vi.

[165] OEHHA. 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. January, at p. 95.

Table 3. Federal and California screening levels for certain metals in residential soil samples.

	EPA Regional screening level mg/kg (ppm)[166]	CA Environmental screening level mg/kg (ppm)[167]
Antimony	31	11
Arsenic	0.68	0.067
Barium	15000	390
Beryllium	160	5
Cadmium	7.1	1.9
Chromium[168]	Cr (III): 120,000 Cr (VI): 0.3	Cr (III): 120,000 Cr (VI): 0.3
Cobalt	23	23
Copper	3100	180
Lead	400	32
Mercury	11	13
Molybdenum	390	6.9
Nickel	1500	86
Selenium	390	390
Silver	390	390
Thallium	0.78	0.78
Vanadium	390	390
Zinc	23000	23000

To assist in evaluating risks, the Synthetic Turf Council also developed guidelines and recommended testing procedures leveraging knowledge developed from other recreation applications.[169,170] These guidelines recommend testing on infill be performed according to a

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[166] Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1) November 2022, available at https://semspub.epa.gov/work/HQ/403628.pdf, accessed November 28, 2022.

[167] San Francisco Bay Regional Water Quality Control Board. "Environmental Screening Levels." Available at https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/esl.html The lowest screening level between cancer risk and non-cancer risk for residential shallow soil exposure was selected.

[168] The Eurofins testing does not differentiate between the oxidation states of chromium.

[169] The Synthetic Turf Council (STC) is an organization founded in 2003. Membership includes builders, landscape architects, testing labs, maintenance providers, manufacturers, suppliers, installation contractors, infill material suppliers and other specialty service companies, see https://www.syntheticturfcouncil.org/page/AboutSTC, accessed December 14, 2022.

[170] Suggested Environmental Guidelines for Infill, August 2015, available at https://www.syntheticturfcouncil.org/store/viewproduct.aspx?id=17587425.

European Standard method[171] that involves extraction of soluble elements from a sample of infill using a simulated gastric fluid (to mimic conditions in the human stomach), followed by analysis of metals content in the extract. The guidance levels are shown in Table 4. These levels are for detected elements because the method does not capture information related to form (i.e., the rest of the substance), and therefore only provides a portion of the information necessary to assess risks that may arise from their presence.

Table 4. Industry suggested guidelines from the Synthetic Turf Council.

	STC Guidelines (mg/kg)
Aluminum	70,000
Antimony	560
Arsenic	47
Barium	18,750
Boron	15,000
Cadmium	17
Cobalt	130
Copper	7,700
Lead	160
Manganese	15,000
Mercury	94
Nickel	930
Selenium	460
Strontium	56,000
Tin	180,000
Zinc	46,000
Chromium III	460
Chromium VI	0.2

Experimental Test Methods for Metals Identification and Quantification

The metals content of crumb rubber can be experimentally quantified using several different methods. One method is to use an acid digestion coupled with inductively coupled plasma/mass

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[171] European Standard EN 71-3 – Safety of Toys Part 3: Migration of certain elements.

spectrometry (ICP/MS) analysis (described in EPA Method 6020),[172,173] which provides an overall concentration of certain metals in the sample, regardless of the form in which they occur.

The amount of a metal present in a sample can be a useful screening tool for some purposes. However, the presence of a metal in a sample does not mean that the metal will be released and enter the environment.[174,175,176] Different test methods than those used for basic quantification are used to assess the availability, or mobility, of metals in a sample under relevant conditions, such as bioavailability tests[177] and leaching tests (*e.g.*, the simulated precipitation leaching procedure (SPLP)).[178] For example, a metals bioaccessibility test could be used to quantify the amount of metal released from a material into a simulated bodily fluid (gastric, sweat with sebum, and saliva)[179] and could provide information relevant to the potential for exposure.[180] Similarly, SPLP tests are run according to a standard method (EPA SW-846 Method 1312) that attempts to measure the concentration of metals that might leach into rainwater.[181,182]

Importantly, the conditions used for extraction can influence the amount of metal that leaches out of a material. Extraction conditions are chosen to mimic certain types of biological or environmental conditions, and the results of a specific test may be more or less relevant in different contexts, depending on the similarities and differences between test conditions and the conditions experienced in the intended application. For example, the SPLP test conditions described above do not necessarily represent typical environmental exposure conditions for crumb rubber, and the New York State Department of Environmental Conservation (NYSDEC)

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[172] EPA/ORD and CDC/ATSDR, pp. 21, 66.

[173] Method 6020 Inductively Coupled Plasma-Mass Spectrometry. U.S. EPA. Available at https://www.epa.gov/sites/default/files/documents/6020.pdf, accessed December 15, 2022.

[174] Leaching Environmental Assessment Framework (LEAF) How-To Guide. U.S. EPA (2019) Revision 1. Available at: https://www.epa.gov/sites/default/files/2019-05/documents/final_leaching_environmental_assessment_framework_leaf_how-to_guide.pdf, accessed December 14, 2022

[175] EPA/ORD and CDC/ATSDR, p. xxxvi.

[176] Framework for Metals Risk Assessment. 2007. EPA 120/R-07/001, at p. 1-10, 2-7, 2-11. Available at: https://www.epa.gov/sites/default/files/2013-09/documents/metals-risk-assessment-final.pdf

[177] EPA/ORD and CDC/ATSDR, p. xxxvi.

[178] Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, pp. 1-2.

[179] EPA/ORD and CDC/ATSDR, p. 39.

[180] EPA/ORD and CDC/ATSDR, p. 15.

[181] For example, an SPLP test may measure the amount of metals leached from 100 g of sample in 2 L of water at a slightly acidic pH. It is noted that SPLP tests west of the Mississippi River are to be performed with pH 5 water, while tests east of the Mississippi River are to be performed with pH 4.2.

[182] Townsend, T.; Jang, Y.; Tolaymat, T. (2003). A Guide to the Use of Leaching Tests in Solid Waste Management Decision Making. Prepared for the Florida Center for Solid and Hazardous Waste Management. Available at https://semspub.epa.gov/work/09/1112378.pdf, accessed December 6, 2022.

considers this test to represent more aggressive conditions than are typically present.[183] As a result, NYSDEC designed a laboratory column test that "more closely represents field conditions," in which crumb rubber packed into a column is exposed to the equivalent of 48 inches of rain.[184]

Why Are Metals Associated with Crumb Rubber Infill?

Because crumb rubber is made from recycled tires, certain metallic elements that are used in the manufacturing of tires are expected to be found in crumb rubber. However, the specific metals and concentrations that are present depend on the source of the rubber, the life of the tire, the type of processing, and the crumb rubber location.[185] In order to understand the metals content of a specific material, the different analytical test methods described above can be employed.

The tires used to make crumb rubber are manufactured using a range of materials, including a natural or synthetic rubber, curing agents, reinforcing fillers (*e.g.*, carbon black or silica), cords, and other components.[186] Zinc oxide is often included in tire rubber as part of the cure system that is used to manufacture the finished tires.[187] Zinc oxide is a white, odorless solid,[188] which is also used in cosmetics as a colorant, skin protector, or UV absorber.[189] It has low solubility in water[190] and is listed on the FDA's Generally Recognized as Safe (GRAS) list.[191] The amount of zinc oxide added to a tire formulation is typically around 8,000–15,000 ppm for passenger car tires and 18,000–31,000 ppm for truck tires.[192] As a result, the amount of zinc found in crumb rubber

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[183] Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, pp. 7, 65.

[184] Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, pp. 18-19.

[185] EPA/ORD and CDC/ATSDR, p. 1, 21-22; Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, p. 12, 21.

[186] Sheridan M. F., *The Vanderbilt Rubber Handbook*, Fourteenth Edition, 2010, p. 704.

[187] EPA/ORD and CDC/ATSDR, p. 1.; Sheridan M. F., *The Vanderbilt Rubber Handbook*, Fourteenth Edition, 2010, p. 11.

[188] The National Institute for Occupational Safety and Health (NIOSH): Zinc oxide, October 30, 2019, available at https://www.cdc.gov/niosh/npg/npgd0675.html, accessed November 14, 2022.

[189] National Center for Biotechnology Information (2022). PubChem Compound Summary for CID 14806, Zinc oxide, available at https://pubchem.ncbi.nlm.nih.gov/compound/Zinc-oxide, accessed November 14, 2022.

[190] For example, zinc is soluble in pH neutral water at 0.0004 % (64 °F). The National Institute for Occupational Safety and Health (NIOSH): Zinc oxide, October 30, 2019, available at https://www.cdc.gov/niosh/npg/npgd0675.html, accessed November 14, 2022.

[191] Code of Federal Regulations (CFR) Title 21, Part 182 Substances generally recognized as safe, Sec. 182.8991 Zinc Oxide, see https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=182.8991#:~:text=(a)%20Product.-,Zinc%20oxide.,accordance%20with%20good%20manufacturing%20practice, accessed November 18, 2022.

[192] Sheridan M. F., *The Vanderbilt Rubber Handbook*, Fourteenth Edition, 2010, pp. 715, 731.

made by different producers can vary[193] depending on the tire source (automobile, truck, mixture of the two) and the method of grinding (cryogenic or ambient).[194] Generally, crumb rubber made from automotive tires and ground cryogenically will have lower zinc content than crumb rubber made from truck tires ground at ambient temperature.[195] The average measured zinc content of fresh crumb rubber (*i.e.*, not yet installed in a field[196]) measured by the EPA Method 6020 has been reported at 6,437–17,000 ppm while, after installation, fields are reported to be measured with 3,752–15,000 ppm of zinc by this method.[197]

Other metals, including cobalt, may also be used as salts in tire components that promote metal-rubber adhesion.[198] These components are added at low levels to improve the bonding of the rubber and tire cord.[199] A study measuring cobalt content in crumb rubber samples found an average cobalt content of 190 ppm, with a maximum of 440 ppm.[200] In addition to its use in rubber tires, cobalt is commonly encountered as part of biological systems and enzymes,[201] as part of high-strength or wear-resistant alloys,[202] in lithium ion batteries,[203] and in implantable medical and dental devices.[204]

Other metals may be introduced into tires during manufacture not as an intentionally added component, but as a contaminant from other ingredients. For example, carbon black (not a metal) is added to tires at concentration of approximately 27-30 wt%[205] and it is known that carbon black can contain metals such as arsenic, cadmium, lead, mercury, and nickel.[206] Similarly, the steel

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[193] EPA/ORD and CDC/ATSDR, pp. 1, 14, 32-33.

[194] Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, pp. 1, 10, and p. 3 Figures.

[195] Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf, pp. 1, 10, and p. 3 Figures.

[196] EPA/ORD and CDC/ATSDR, p. 12.

[197] EPA/ORD and CDC/ATSDR, p. 23.

[198] Clauwaert, E., Kamphuis, B.J., Cobalt Bearing Polymeric Compositions, U.S. Publication Number US 2011/0206879 A1, August 25, 2011.

[199] Mandal, N., Sajith, P., Agrawal, S. L., Bandyopadhyay, S., Mukhopadhyay, R., D'Cruz, B., and Deuri, A. S. (2005). Synthesis of cobalt adhesion promoters and their evaluation in a passenger radial-belt skim compound. *The Journal of Adhesion* 81(9), 911-923.

[200] EPA/ORD and CDC/ATSDR, p. 116.

[201] Yamada, K. (2013). Cobalt: its role in health and disease. *Interrelations between essential metal ions and human diseases*, 295-320.

[202] Uses of Cobalt. *Nickel, Cobalt, and Their Alloys.* ASM Specialty Handbook, ASM International, 2000.

[203] Li, M., and Lu, J. (2020). Cobalt in lithium-ion batteries. *Science*, 367(6481), 979-980.

[204] Disegi, J. A., Kennedy, R. L., and Pilliar, R. (1999). *Cobalt-base alloys for biomedical applications* (No. 1365). ASTM International.

[205] Sheridan M. F., *The Vanderbilt Rubber Handbook*, Fourteenth Edition, 2010, pp. 715, 731.

[206] Safety Data Sheet: Carbon Black, Birla Carbon, 10/198/2017, available at https://www.birlacarbon.com/pdf/SDS/01_Rubber_Products_SDS/NA-GHS%20RCB%20ENGLISH%2019%20OCTOBER%202017.pdf, accessed December 15, 2022.

cords used in tires are typically high-carbon-steel, and can contain additional components such as chromium, copper, manganese, and other elements.[207]

Because crumb rubber is made of recycled tires, its chemical composition, including metals content, includes both components used in the manufacture of tires, as well as substances absorbed during its lifetime of use as a tire.[208]

Several studies and risk evaluations have been performed to evaluate the levels of metals present in crumb rubber infill material,[209] the leachability of metals from crumb rubber,[210] and the risks that may be associated with those metals. A review of available studies, published in 2018, concluded that "recycled rubber infill in synthetic turf poses negligible risks to human health."[211] One recent study, published by Catia, et al., has been cited for reaching a different conclusion with respect to the lead and chromium content in crumb rubber.[212] However, this study was recently amended to correct flawed calculations, and its conclusions related to cancer risk were retracted. After correction of the methodology used in the study, the authors calculated this risk to be "within the acceptable values" for both adults and children.[213]

Cryogenic Rubber 14-30 Metals Content Analysis

Metals Content in Cryogenic Rubber 14-30

Recent test results of a sample of the fresh crumb rubber proposed for use in the Project's artificial turf field, Cryogenic Rubber 14-30, demonstrate that levels of the tested metals are consistent with, or lower than, the levels of metals reported in published studies of other fresh crumb rubber (i.e., crumb rubber after grinding, and before use in an application like infill).[214,215] In this recent testing, summarized in Table 5 and assessed in more detail below, most of the tested metals in Cryogenic Rubber 14-30 were detected at levels lower than published federal and state screening

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[207] Mark, J.E., Erman, B., Roland, C.M., *The Science and Technology of Rubber*, Fourth Edition, 2013, p. 673.

[208] EPA/ORD and CDC/ATSDR, p. 1.

[209] EPA/ORD and CDC/ATSDR, p. 23.

[210] Bocca, B., Forte, G., Petrucci, F., Costantini, S., & Izzo, P. (2009). Metals contained and leached from rubber granulates used in synthetic turf areas. Science of the total environment, 407(7), 2183-2190.

[211] Peterson, M. K., Lemay, J. C., Shubin, S. P., & Prueitt, R. L. (2018). Comprehensive multipathway risk assessment of chemicals associated with recycled (" crumb") rubber in synthetic turf fields. Environmental research, 160, 256-268.

[212] Cátia A.L. Graça, Filipe Rocha, Filipa O. Gomes, M. Rosário Rocha, Vera Homem, Arminda Alves, Nuno Ratola, (2022). Presence of metals and metalloids in crumb rubber used as infill of worldwide synthetic turf pitches: Exposure and risk assessment, *Chemosphere*, Volume 299, p. 5.

[213] Graça, C. A., Rocha, F., Gomes, F. O., Rocha, M. R., Homem, V., Alves, A., & Ratola, N. (2022). Corrigendum to" Presence of metals and metalloids in crumb rubber used as infill of worldwide synthetic turf pitches: Exposure and risk assessment"[Chemosphere 299 (July 2022) 134379]. *Chemosphere*, 305, 135446.

[214] Information relevant to the sampling of the Cryogenic Rubber 14-30 material are described in: Letter to Mr. Mike Harden, Environmental Science Associates RE: Testing of FieldTurf Cryogenic Crumb Rubber for Total CAM 17 Metals and FieldTurf Core Vertex 2.5 Fiber for Total PFAS Using the Total Oxidizable Precursor Assay, dated November 22, 2022.

[215] Analytical report on "Cryogenic Rubber 14-30" and "Core Vertex 2.5" samples. Eurofins Sacramento, dated September 28, 2022.

levels for residential soils. Cobalt and arsenic were identified as elements in excess of published screening level guidelines in the Cryogenic Rubber 14-30 and these results are analyzed in more detail below. The chromium results for Cryogenic Rubber 14-30 could not be directly compared against the screening levels, and this is also discussed in more detail in the following section.

EPA Method 6020 was used to analyze the content of 16 metals and was performed on a sample of Cryogenic Rubber 14-30 (Table 5). In addition, the crumb rubber sample was tested for mercury content using EPA Method 7471B, and no mercury was detected. The metals content in fresh Cryogenic Rubber 14-30 crumb rubber is either consistent with, or lower than, the composition of fresh crumb rubber samples described in published studies.

Table 5. Comparison of the metals concentration (ppm) in fresh Cryogenic Rubber 14-30 crumb rubber with reported levels in other fresh crumb rubber samples.[216] The literature values are reported as the average, with the number of samples indicated in the heading. A blank cell indicates that this metal was not measured. "ND" indicates that the metal was not detected in the Cryogenic Rubber 14-30.

	Cryogenic Rubber 14-30	EPA 2019 (n=9)	Cristy 2018 (n=2)	Marsili 2014 (n=5)
Antimony	0.48	1.2		
Arsenic	0.43	0.30	0.81	
Barium	4.2	7.4	5.2	
Beryllium	ND	0.015		
Cadmium	0.65	0.55	0.65	1.8
Chromium	1.5	1.8		7.0
Cobalt	130	190	145	
Copper	46	42	45	37
Lead	15	13	13	21
Molybdenum	0.21	0.22		
Nickel	2.7	3.2	5.9	11
Selenium	0.1			
Silver	ND			
Thallium	ND			
Vanadium	0.75	1.7		
Zinc	14000	17000	16800	6437

Comparison to Established Screening Levels

As described earlier, there are several systems in place by which risk from metals in environmental samples can be assessed, including the EPA and California screening levels for

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[216] EPA/ORD and CDC/ATSDR, p. 23.

soils. However, there is no similar regulatory guidance concerning the metals content of crumb rubber for use in artificial turf. Because the crumb rubber will be used in a similar context to soil, EPA and the State of California have used soil guidance levels as a screening tool to identify metals present in crumb rubber at levels that may require further analysis.[217,218] However, soil and crumb rubber are different materials with different physical and chemical properties that affect their behavior in the environment, including leaching behavior, and the presence of a metal in excess of soil screening levels does not necessarily mean that it will leach from the crumb rubber to enter the environment.

A comparison of the results of the Cryogenic Rubber 14-30 metals levels to the above-described screening levels[219] is presented in Table 6. The majority of the metals in Cryogenic Rubber 14-30 are below both sets of screening levels, indicating that soil with the same metal content would be considered acceptable under these risk assessment systems. The metals for which Cryogenic Rubber 14-30 was below both screening levels include: antimony, barium, beryllium, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc.

Zinc was the metal found in the samples at the highest concentration (14,000 ppm). The zinc in the crumb rubber is expected to be made up of primarily zinc oxide, which is used in tire manufacturing. Although the reported zinc content of the crumb rubber was higher than the concentrations of other metals detected, this concentration of zinc is below both the EPA and California screening levels. Additionally, to the extent that zinc is leached from the crumb rubber, literature demonstrates that the rock material typically used below the turf removes zinc from the water, decreasing the concentration of zinc in the water where it exits the rock material and enters the environment more generally.[220] This study, performed by scientists at Stanford University for Santa Clara Valley Water District, found that "rock materials supporting artificial turf fields attenuate Zn [zinc] discharge by storm runoff by strongly adsorbing dissolved Zn," indicating that the final zinc concentration entering the groundwater would be even lower than the concentration of zinc in water flowing off the crumb rubber material.

Three metals were detected in Cryogenic Rubber 14-30 at levels above soil screening levels, or in a manner that could not be directly compared against these levels: arsenic, chromium, and cobalt. Because metals content describes the total amount of metal in the crumb rubber, not the form of the metal or the amount of each metal that would be bioavailable or leachable (which could be lower), additional analysis of these metals is required to contextualize the metals content for the purposes of identifying and understanding the potential risks to humans and the environment.

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[217] EPA. 2009. A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds. EPA/600/R-09/135. November, at p. vi.

[218] OEHHA. 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. January, at p. 95.

[219] When multiple screening values were issued for different types of risk assessments, the lowest of the available values was reported in Table 6.

[220] Field, Pilot, and Laboratory Studies for the Assessment of Water Quality Impacts of Artificial Turf, Prepared by Hefa Cheng and Martin Reinhard at Stanford University, Prepared for Santa Clara Valley Water District, June 2010.

Arsenic was detected in Cryogenic Rubber 14-30 below the EPA screening level for soils, but above the California environmental screening level. To understand its potential contribution to arsenic levels in the environment around the Project, it is useful to compare the levels of arsenic in the crumb rubber sample to typical levels of arsenic in soil, rather than comparing only against the screening levels, which may not be representative of local arsenic levels. In the case of California soils, the reported background level of arsenic is several times higher than the concentration of arsenic in Cryogenic Rubber 14-30. Essentially, based on these measurements, using Cryogenic Rubber 14-30 in an artificial turf field would be unlikely to introduce higher levels of arsenic than would be present in the soil of a traditional grass playing field in California.

With regard to chromium, the total chromium level in Cryogenic Rubber 14-30 cannot be directly compared against the EPA and California screening levels. These screening levels specify different concentrations for different forms of chromium, one of which (Cr^{VI+}) is below the "total chromium" level measured for Cryogenic Rubber 14-30. Because a straightforward comparison cannot be made between the collected data and the EPA screening levels, additional analysis can be helpful to provide context for a risk assessment. Similar to arsenic, comparison to typical soil levels of chromium demonstrates that the level of total chromium in Cryogenic Rubber 14-30 is well below the reported soil background level in California (Table 7). Additionally, studies have shown that ground tire rubber can be used to *remove* chromium from water in remediation efforts.[221] Overall, it is unlikely that Cryogenic Rubber 14-30 would increase the presence of chromium in the environment of the Project, compared to the soil that would be present in a traditional grass playing field.

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[221] Entezari, M. H., Ghows, N., and Chamsaz, M. (2005). Combination of ultrasound and discarded tire rubber: removal of Cr (III) from aqueous solution. *The Journal of Physical Chemistry A* 109(20), 4638-4642.

Table 6. Testing done by Eurofins on Cryogenic Rubber 14-30 compared with the EPA regional screening levels and California environmental screening levels for metals in residential soils, as well as the background level of these metals in soils. ND indicates that the metal was not detected in Cryogenic Rubber 14-30.

	Cryogenic Rubber 14-30	EPA Regional screening level mg/kg (ppm)[222]	CA Environmental screening level, mg/kg (ppm)[223]	Background soil level—CA[224] mg/kg (ppm)
Antimony	0.48	31	11	0.60
Arsenic	0.43	0.68	0.067	3.5
Barium	4.2	15000	390	509
Beryllium	ND	160	5	1.28
Cadmium	0.65	7.1	1.9	0.36
Chromium[225]	1.5	Cr (III): 120,000 Cr (VI): 0.3	Cr (III): 120,000 Cr (VI): 0.3	122
Cobalt	130	23	23	14.9
Copper	46	3100	180	28.7
Lead	15	400	32	48.5
Mercury	ND	11	13	0.26
Molybdenum	0.21	390	6.9	1.3
Nickel	2.7	1500	86	57
Selenium	0.1	390	390	0.058
Silver	ND	390	390	0.8
Thallium	ND	0.78	0.78	0.56
Vanadium	0.75	390	390	112
Zinc	14000	23000	23000	149

The cobalt level measured in Cryogenic Rubber 14-30 were above both the EPA and California screening levels. However, as discussed above, the presence of cobalt in the samples does not mean that the cobalt will migrate out of the crumb rubber or otherwise become available for

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[222] Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1) November 2022, available at https://semspub.epa.gov/work/HQ/403628.pdf, accessed November 28, 2022.

[223] San Francisco Bay Regional Water Quality Control Board. "Environmental Screening Levels." Available at https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/esl.html The lowest screening level between cancer risk and non-cancer risk for residential shallow soil exposure was selected.

[224] Bradford, G.R., Change, A.C., Page, A.L., Bakhtar, D., Frampton, J.A., Wright, H., *Kearney Foundation of Soil Science Division of Agricultural and Natural Resources* (1996). Available at https://ucanr.edu/sites/poultry/files/297094.pdf.

[225] The Eurofins testing does not differentiate between the oxidation states of chromium.

environmental or human exposure.[226] As is described in more detail below, although leaching studies were not performed on this particular crumb rubber sample, previous studies of crumb rubber samples have demonstrated that cobalt (and other metals) leached from the crumb rubber at low levels – below the established guideline levels for metals content in drinking water.

One study that demonstrates the limited extent of cobalt leaching from crumb rubber (through SPLP methods) was performed by the New York State Department of Health.[227,228] In these studies, leachate from samples of 31 crumb rubber materials were analyzed for the presence of 24 metals (Table 7). Of these, 17 metals, including cobalt, were not detected at all in the leachate from the 31 crumb rubber samples.[229] As demonstrated in Table 5, crumb rubber typically contains cobalt at ppm levels similar to the level detected in Cryogenic Rubber 14-30. Therefore, it is likely that at least some (and possibly all) of the 31 samples of crumb rubber tested in this study contained cobalt. The fact that cobalt was not detected in any of the leachate samples in this study demonstrates that cobalt in a typical crumb rubber is not expected to migrate out of crumb rubber materials into water at significant concentrations.

For the metals that were detected in the crumb rubber leachate samples in this study, only low levels of metals were reported. In fact, the detected concentrations of these metals were below EPA maximum contaminant levels (MCLs) for drinking water, except for iron[230,231] (also listed in Table 7). It should be noted that the MCL for iron is established at 300 ug/L to avoid drinking water from exhibiting a rusty color and metallic taste and not due to health effects.[232]

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[226] EPA/ORD and CDC/ATSDR, p. xxxvi.

[227] Leaching studies were performed according to EPA Method 1312. Lim, L., and Walker, R. "An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields," New York State Department of Environmental Conservation, May 2009, available at https://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf.

[228] These tests were performed in New York, so the water pH was 4.2. If these studies were to be performed in California, the water pH would have been 5. Also, New York received 48 inches of rain, while Los Angeles receives ~13 inches of rain. These differences in the experimental setup would likely make the data collected by New York more conservative than environmental conditions in Los Angeles, and, as such, tests conducted using Los Angeles conditions should yield lower concentrations in the leachate.

[229] Aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, magnesium, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, and vanadium were not detected in any of the SPLP tests performed on 31 crumb rubber samples performed by New York State Department of Health.

[230] National Primary Drinking Water Regulations. Available at: https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

[231] Secondary Drinking Water Standards: Guidance for Nuisance Chemicals. Available at: https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals, accessed December 15, 2022.

[232] Secondary Drinking Water Standards: Guidance for Nuisance Chemicals. Available at: https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals, accessed December 15, 2022.

Table 7. SPLP leaching test results including the percentage of the 31 tested samples of crumb rubber in which a metal was detected, as well as the average detected concentration, reported in a study performed by the New York State Department of Health. The MCL is the drinking water maximum contaminant level established by the EPA.[233]

	% Detected	Average, µg/L*	Drinking water MCL (µg/L)
Zinc	100	1947.4 ± 419.3	5,000
Calcium	96.8	2443.5 ± 251.8	
Manganese	77.4	20.7 ± 1.8	50
Barium	19.4	30.4 ± 3.6	2,000
Iron	12.9	1704.8 ± 717.8	300
Copper	9.8	296.3 ± 120.7	1,000
Lead	9.7	12.8 ± 1.2	15
Aluminum	0	ND	50
Antimony	0	ND	6.0
Arsenic	0	ND	10
Beryllium	0	ND	4.0
Cadmium	0	ND	5.0
Chromium	0	ND	100
Cobalt	0	ND	
Magnesium	0	ND	
Mercury	0	ND	2.0
Molybdenum	0	ND	
Nickel	0	ND	
Potassium	0	ND	
Selenium	0	ND	50
Silver	0	ND	100
Sodium	0	ND	
Thallium	0	ND	2.0
Vanadium	0	ND	

* Average ± standard error for detected results only.

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[233] A blank value indicates that no MCL is established for a specific metallic element.

Summary and Conclusions

The River Park Project proposal includes an artificial turf playing field with materials sourced from FieldTurf, consisting of the Vertex CORE 2.5 carpet and Cryogenic Rubber 14-30 crumb rubber infill, which have been analyzed for the presence of PFAS and certain metals.

PFAS is a poorly-defined term that can encompass thousands of substances with widely different properties that influence their behavior in environmental and biological systems, and only certain PFAS are associated with regulatory limits supported by environmental and health risk assessments. Artificial turf utilizes low levels of fluoropolymer processing aids in the manufacturing of turf fibers, which are beneficial to the production and performance of the turf fibers. These fluoropolymer processing aids may be considered PFAS under some definitions of the term, but are often considered to be a distinct category of PFAS because of their large size and chemical inertness. These properties contribute to fluoropolymers' long history of use in applications such as medical devices, in which biocompatibility is an important characteristic.

The Vertex CORE 2.5 turf carpet was evaluated for the presence of 68 small-molecule PFAS using a total organic precursors (TOP) method. The TOP method demonstrated that after extraction, the sample included only one small-molecule PFAS and, further, that it was detected at levels below the reporting limit of the method. After oxidation of this extracted sample, additional PFAS were detected at low levels, with only one compound detected over the reporting limit of the method. While there are no regulatory screening levels for the specific PFAS in the FieldTurf samples after oxidation, the levels that were detected are significantly lower than proposed regulatory limits for PFAS content in products, and lower than residential soil screening levels for any form of PFAS issued by EPA and proposed by the state of California.

Metals of different types occur naturally in the environment and in biological systems, and the properties of the individual metal depend on its identify and its form. Crumb rubber infill materials are made from recycled end-of-life tires and are, as a result, associated with certain metals that are used in the tire manufacturing process as well as other metals that are taken up by the rubber during its use life as a tire. Evaluations of the potential for environmental and health impacts of the metals in crumb rubber consider both the amounts of specific metals that are present in the crumb rubber as well as the likelihood of leaching under typical outdoor conditions.

The Cryogenic Rubber 14-30 proposed for use in the Project was found to contain levels of metals similar to, or less than, levels reported for other crumb rubber samples. For the majority of metals detected, the concentrations were below, and in some cases far below, the environmental screening levels for residential soil issued by EPA and the state of California. Three metals, cobalt, arsenic, and chromium, were either above the soil screening levels or could not be directly compared against these levels. However, these three metals were found to either be comparable in concentration to background levels typically found in California soil, and/or to leach from the crumb rubber at only low levels compared to concentrations considered acceptable in drinking water.

Limitations

This memo is based on documents provided by Harvard-Westlake School and publicly available literature; the materials cited in this memo; and my education, training, and experience.[234] In the analysis, Exponent has relied on product composition information, testing data, and specifications provided to it by Harvard-Westlake School. While Exponent is relying on provided information, it has not independently assessed the underlying accuracy and rigor by which the information was collected (including, but not limited to, professional standards and care exercised by independent laboratories in the investigation of the aforementioned chemicals and compounds).

The guidance formulated during this assessment is based on observations and information available at the time of the investigation. Exponent's role is advisory in nature, and the opinions, analysis, conclusions, results, recommendations, and the like will be assessed by ESA with respect to its products, processes, or services. As such, no guarantee or warranty as to future life or performance of the reviewed artificial turf systems is expressed or implied. The scope of services performed during this investigation may not adequately address the needs of other users of this memo, and any reuse of this memo or its findings, conclusions, or recommendations presented herein are at the sole risk of the user.

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[234] For more details, see Dr. Sarah Parker's curriculum vitae in Appendix A and a comprehensive list of materials reviewed in Appendix B.

Appendix A

Curriculum Vitae of
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Professional Profile

Dr. Parker is a chemist who specializes in understanding how composition and formulation affect the performance of complex chemical systems and practical materials. She consults in the areas of fuel, oil, and lubricant formulations for automotive and industrial applications, as well as cosmetics and personal care products, pharmaceuticals, medical devices, paints and coatings, and industrial and specialty chemicals including fluorinated substances (PFAS). Dr. Parker has experience analyzing product composition and identifying potential contaminants through standardized and non-standard methods, and uses her expertise to help clients determine the source and potential impacts of chemical contamination in a range of products. Dr. Parker has also consulted for parties involved in intellectual property disputes, including trade secret and patent litigation.

Dr. Parker has investigated the quality and end-use performance of engine and machine lubricant formulations (oils and greases) and fuels, including gasoline, diesel fuel, biofuels, marine fuel, and fuel oil products. She is familiar with common quality specifications and guidelines for lubricants and fuels set by industry organizations, original equipment manufacturers (OEMs), and regulatory bodies. Dr. Parker has utilized a variety of chemical analysis methods in these investigations, including Fourier-transform Infrared spectroscopy (FTIR), gas chromatography-mass spectrometry (GC-MS), and two-dimensional gas chromatography-mass spectrometry (GCxGC-MS), as well as various elemental analysis and specialized chemical analysis methods. Dr. Parker is well-versed in ASTM and ISO methods for lubricant and fuel characterization including rheological and tribological testing related to friction and wear (tribology) issues. She is also familiar with surface characterization, profilometry, and microscopy techniques.

Dr. Parker helps clients investigate, assess, and mitigate contamination in formulated products. She is experienced in selecting appropriate sampling and analysis methods to accurately characterize the chemical composition of a product. Her expertise extends to the design and validation of new sampling and test methods utilized when appropriate standardized methods are not available. Dr. Parker uses this expertise to help clients analyze the potential past and future impacts of contamination, once identified, across a range of products including personal care products, pharmaceuticals, medical devices and assays, industrial and specialty chemicals, and petroleum products.

Dr. Parker has also worked in the area of polymeric materials and coatings, specializing in the interaction of material and coating formulations with their environments. Her experience includes the characterization and assessment of equilibrium processes such as absorption and off-gassing, as well as exposure to environmental stressors such as UV irradiation, temperature, and humidity. Dr. Parker's research experience also includes the synthesis and design of organic molecules and metal catalysts commonly used in the production of reinforced plastics and composite materials, inks and coatings, elastomers, and fine chemicals.

Prior to joining Exponent, Dr. Parker was a Senior Researcher at ExxonMobil Research & Engineering. In that role she developed new formulations for commercial vehicle (heavy-duty) engine oils and greases to meet API, ACEA, and automotive engine manufacturer specifications using a combination of industry standard bench tests, stationary fired-engine test stands, and field test programs. She explored new additives for lubricant applications including novel antioxidants, anti-wear additives, pour-point depressants, dispersants, and friction modifiers, and has contributed to patent applications related to this work. In addition, Dr. Parker provided failure analysis and lubricant product support to lubricant blenders, vehicle manufacturers, and end customers in the transportation, mining, construction, and agriculture industries. She was also involved in the technical validation and global deployment of new components and formulations with impact on product claims and specifications, the global supply chain, and product registration with foreign governments.

Academic Credentials & Professional Honors

Ph.D., Chemistry, Harvard University, 2014

B.A., Chemistry, Grinnell College, 2007

National Science Foundation Graduate Research Fellow, 2009-2012

Thomas J. Watson Fellow, 2007-2008

Archibald Prize for Highest Scholarship, Grinnell College, 2007

Chemistry Alumni Prize, Grinnell College, 2007

Barry M. Goldwater Scholar, 2005-2007

Trustee Honor Scholarship, Grinnell College, 2003-2007

Prior Experience

Senior Researcher, Industrial Lubricants & Greases, ExxonMobil Research & Engineering, 2016

Senior Researcher, Commercial Vehicle Lubricants, ExxonMobil Research & Engineering, 2014-2016

Professional Affiliations

American Chemical Society

ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants

Patents

Alessi ML, Jetter SM, Kennedy S, Parker SE, Burns RG. Lubricating oil compositions with oxidative stability in diesel engines. US Patent Application US16/171401, October 2018.

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Mobley TA, Parker SE. Synthesis and conformational characterization of Cp2WHSn(CN)Ph2. Poster presentation, American Chemical Society National Meeting, 2007.

Appendix B

Materials Reviewed

Project-specific and Materials Testing Documents

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Analytical report on “Field Turf Sample,” Eurofins Sacramento, dated 2/25/2022.

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