Athletic Playing Fields

Choosing Safer Options for Health and the Environment

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Athletic Playing Fields: Choosing Safer Options for Health and the Environment

Introduction

Municipalities, universities, schools and other institutions frequently need to make decisions about maintenance and installation of athletic playing fields. This may include choosing between natural grass and artificial turf (also referred to as synthetic turf). Factors that may be considered include cost of installation and maintenance, number of days the field can be used, likelihood of player injuries, temperature of the playing environment, and athletes' exposure to chemicals.

A number of communities have requested technical assistance from TURI in evaluating the questions they face as they make these decisions. In response to these requests, TURI has conducted research on individual materials used in artificial turf. TURI has also worked with municipalities and other institutions to facilitate the adoption of athletic field management practices that are cost-effective and preferable for human health and the environment. This area of work has included projects to help communities eliminate or reduce the use of pesticides and facilitate the adoption of organic grass management practices.

This document provides information based on TURI's research on selected materials used in artificial turf. It also includes information on organic management of natural grass. TURI has identified organically managed natural grass as a safer alternative for sports surfaces. Additional educational documents and video resources are available on TURI's website.[1]

Principles of Toxics Use Reduction

TURI's work is based on the principles of toxics use reduction (TUR). The TUR approach focuses on identifying opportunities to reduce or eliminate the use of toxic chemicals as a means to protect human health and the environment. Projects to reduce the use of toxic chemicals often have additional benefits, such as lower life-cycle costs.

Children's Environmental Health

People of all ages benefit from a safe and healthy environment for work and play. However, special concerns exist for children. Children are uniquely vulnerable to the effects of toxic chemicals because their organ systems are developing rapidly and their detoxification mechanisms are immature. Children also breathe more air per unit of body weight than adults, and are likely to have more hand-to-mouth exposure to environmental contaminants than adults.[2] For these reasons, it is particularly important to make careful choices about children's exposures.

Artificial Turf Components

Artificial turf generally has several components, including a base layer made from gravel or stone; an artificial grass carpet, including a backing material and artificial grass fibers; and one or more infill materials, used to hold the grass fibers upright and provide cushioning, among other functions. Infill is the portion of the artificial turf that mimics the role of soil in a natural grass system. Many artificial turf fields also include a shock pad below the carpet for additional cushioning.[3] Depending on the infill type, this shock pad may be an optional component of the turf system, or may be required in order to provide a sufficiently resilient playing surface.

This document provides information on several infill materials. It is important to note that the materials available on the market may change frequently and the information presented here is not comprehensive. It is also important to understand that infill is just one component of an artificial turf system. This document focuses primarily on infill, but in evaluating the health and environmental impact of artificial turf, it is also important to consider the impacts of all the components, including the artificial grass blades, shock pad, and lower structural layers.

Regulatory/Testing Standards

There is no comprehensive regulatory or testing regimen specifically for artificial turf.

The standard cited most frequently by vendors is European Standard EN 71-3 – "Safety of Toys Part 3: Migration of certain elements" (the European Toy Safety Standard). For communities applying this standard, it is important to understand that it focuses only on metals. It does not cover other compounds that may be found in artificial turf materials, such as volatile organic compounds (VOCs), polyaromatic hydrocarbons (PAHs), phthalates, and others. The standard includes three different safety levels, so it is important to understand which level has been applied. Detailed information on this regulation is available in another TURI publication, *Chemicals in Artificial Turf Infill: Overview*.[4]

Other standards sometimes applied by researchers to artificial turf include regulatory standards for contamination of soil (e.g., comparing lead levels to those considered by the US EPA to pose a "soil-lead hazard" in play areas);[5] and checking metals in artificial turf runoff against federal and state regulatory levels for drinking water, surface waters and groundwater.[6] Studies in Europe have checked chemical levels in infill against a variety of regulatory standards for soil, sediment, and building materials, among other standards.[7] Germany has developed a regulation specifically for artificial turf, including requirements related to leaching of certain metals and organic compounds.[8]

Another relevant standard is California’s Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65). This law requires disclosure of the presence of chemicals that are identified by the state of California as causing cancer or reproductive harm.

Artificial Turf: Chemicals in Infill

TURI has received many queries from communities and institutions that are working to understand the health and safety profiles of a variety of infill types. Therefore, TURI has reviewed existing literature on these infill types, with a focus on chemicals found in the materials. Additional detail on selected individual infills can be found on TURI's website.[9]

It is important to note that chemicals in infill are just one piece of the picture. The artificial grass blades pose concerns as well. Toxic chemicals such as lead are found in the artificial grass blades in some cases.[10] It is also important to understand and research the materials used in any pad or underlayment used in the layers below the infill.

Overview

Crumb rubber made from recycled tires, also referred to as **tire crumb** or as styrene butadiene rubber (SBR), is present in a large number of artificial turf fields.

A number of materials are currently marketed as alternatives to recycled tires. Some are based on synthetic materials, while others are mineral- or plant-based, or contain a mixture of natural and synthetic materials. Alternative synthetic infills include **ethylene propylene diene terpolymer (EPDM)**, **thermoplastic elastomer (TPE)**, and **waste athletic shoe materials**, among others. **Mineral-based** and **plant-derived** materials used in infill can include sand, zeolite, cork, coconut hulls, olive cores, and walnut shells, among other materials. Infill can also be made with acrylic-coated sand.

Some vendors may also offer an option of tire crumb coated with polyurethane. Limited information is available on the chemicals in the coating, the ability of the coating to reduce exposure to chemicals in the tire crumb, or the durability of the coating.[11]

Relatively little information is available on the chemicals present in, or emitted from, alternative infills. Some of them may pose less of a concern than tire crumb, but some may introduce serious hazards. Some available information on these materials is provided here, but there is a need for more research on all of these materials. Some of these materials have also been evaluated in a 2017 review by the Norwegian Environmental Agency[12] and in a 2018 review by the National Institute for Public Health and the Environment (RIVM) in the Netherlands.[13]

This overview is not comprehensive. New infills are introduced to the market frequently. It is important to understand that any synthetic material used as infill will pose some concerns related to introduction of rubber or plastic particles into the environment, as well as whatever specific chemicals may be found in the material. Mineral- and plant-based infills can pose hazards as well. In addition to any issues associated with infill, all artificial turf introduces synthetic materials into the environment through the other components, including breakdown over time of the artificial grass carpet.

Understanding rubber and plastic products: terminology

For those interested in understanding more about rubber and plastic products, the following terminology may be useful.

Thermosets vs. thermoplastics. Both natural and synthetic rubbers are **thermosets**. A key characteristic of a thermoset is that although heat is used in the initial manufacture of the material, once the material has been formed, it cannot be melted. For this reason, tires and other products made from thermosets cannot be melted and re-formed into new products. Among the materials used in artificial turf infills, SBR, EPDM and shoe sole materials are all thermosets.

Thermoplastics, in contrast, are materials that can be melted and re-formed into new shapes. Thermoplastic elastomers (TPEs) are one broad category within the larger category of thermoplastics.

Curing/crosslinking/vulcanization. Thermosets gain their stability through a process of **curing**, also referred to as crosslinking or vulcanization. Curing is a process of creating links among polymer strands in order to create a stable, three-dimensional structure. In the case of a thermoset, these links are composed of irreversible chemical bonds.

A variety of chemicals can be used in the curing process. These include chemicals that become part of the crosslinking bond, as well as chemicals that catalyze or accelerate the crosslinking process. The term "vulcanization" is often used specifically to refer to crosslinking with sulfur.

In contrast to the large molecules of a polymer, the molecules added in the curing process are often relatively small. Some of these molecules may remain present as free molecules in the final material, and these may be released during product use.

Plasticizers. Plasticizers are added to stiff or rigid materials to make them more pliable. One important category of plasticizers is the phthalate esters, also commonly referred to simply as phthalates. Mineral oil can also be used as a plasticizer. The specific plasticizers used in a given product are frequently not disclosed.

Other additives. A variety of other additives may be used in rubber and plastic products. **Fillers** such as carbon black or silica can be used to attain specific material properties or simply to extend the volume of the material. **Stabilizers** can be added to decrease the effect of light, heat or other environmental conditions on the material. Other additives that may be used include **pigments** and **antimicrobial agents**.

Tire crumb

A large number of chemicals are found in tire crumb. Many of these have adverse effects on human health or the environment. In a literature review, the US Environmental Protection Agency (EPA) identified just over 350 chemicals or chemical categories that were discussed in existing literature on tire crumb.[14] The presence and amount of a given chemical can vary depending on the sample of tire crumb.

Table 1 shows the categories of chemicals considered by EPA, with examples of individual chemicals in each category.[15] As shown in the table, these include metals, such as lead and zinc; volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs); and a variety of uncategorized chemicals including vulcanization compounds (chemicals used in rubber curing). The broad category of SVOCs includes PAHs, phthalate esters, and chemicals that may be applied to the crumb rubber as biocides during the life of the artificial turf.

Some of the chemicals found in tire crumb are endocrine disrupters (e.g., phthalate esters); some are known or suspected carcinogens (e.g., arsenic, cadmium, benzene, styrene); and some are associated with other human health effects.[16] A recent study evaluated the potential carcinogenicity of 306 chemicals found in tire crumb and found that 197 of them met certain carcinogenicity criteria, while 58 were actually listed as carcinogens by a government agency.[17]

Table 1: Selected categories of chemicals found in tire crumb

Category[a]	Subcategory	Examples
Metals		Aluminum, arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc
VOCs		Benzene, benzothiazole, hexane, naphthalene, styrene, toluene, xylenes
SVOCs	PAHs	Anthracene, benz(a)anthracene, fluoranthene, naphthalene, phenanthrene, pyrene
	Phthalate esters	Benzylbutyl phthalate, di(2-ethylhexyl)phthalate [a.k.a. bis(2-ethylhexyl)phthalate]
	Biocide product ingredients	May include quaternary ammonium compounds such as alkylbenzyldimethyl ammonium chloride, alcohol ethoxylate 6, or others[b]
Other[c]		4-tert-(octyl)-phenol [a.k.a. 4-t-octylphenol], butylated hydroxytoluene

Sources:
Thomas K, Irvin-Barnwell E, Giuseppi-Elie A, Ragin-Wilson A. August 2016. *Research Protocol: Collections Related to Synthetic Turf Fields with Crumb Rubber Infill.* US EPA, CDC and ATSDR. Accessed at https://www.epa.gov/sites/production/files/2016-08/documents/tcrs_research_protocol_final_08-05-2016.pdf, January 2, 2017.
US EPA. December 2016. *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds: Status Report.* EPA/600/R-16/364. Accessed at https://www.epa.gov/chemical-research/december-2016-status-report-federal-research-action-plan-recycled-tire-crumb, March 21, 2017.
[a] Note: Categorization shown here follows categories used in EPA's August 2016 publication.
[b] Thomas et al. note these have been identified by the California Office of Environmental Health Hazard Assessment (OEHHA) as "potential turf biocides."
[c] As organized by Thomas et al., this category includes "potential rubber curatives, antioxidants/antiozonants, and other chemicals reported in literature."

Exposure to low doses of multiple chemicals can have health effects that may not be predicted based on the expected effects of each exposure individually. For this reason, some studies have considered the mix of chemicals in tire crumb, rather than looking at each individually. A study of a tire shredding facility in Taiwan tested airborne particulates from the facility for mutagenicity, and found that they showed "a substantial presence" of mutagens.[18] Another study considered the mutagenicity of dust and fumes at two tire-shredding facilities; they found "high mutagenic activity" of dust and fumes at one facility and "almost no mutagenic activity" at the other, a difference they attributed both to choices of chemicals and to the way in which each facility operated.[19]

EPDM

EPDM rubber is a specialty elastomer that can be mixed with high levels of additives and oils while retaining its desirable physical properties, including strength and resistance to tearing. Additives can include oil, carbon black, and other materials. EPDM may be manufactured with anywhere from 15 to 100 parts of oil per 100 parts of polymer.[20] Like tire crumb, EPDM is a vulcanized (cured) rubber product, so it can be expected to contain vulcanization compounds. Not all EPDM infills are necessarily the same, so it is important to find out what chemicals are present in any given EPDM product.

There has been limited examination of EPDM granules to evaluate their suitability from a public health and environmental perspective. In one study published in 2004, the Norwegian Building Institute (NBI) examined levels of selected chemicals in one sample of EPDM infill, comparing these levels with those found in three samples of recycled tires. The study found that the EPDM rubber contained more chromium than the tire material, similar amounts of zinc, and lower concentrations of PAHs, phthalate esters, and phenols. Polychlorinated biphenyls (PCBs), which were found in one sample of recycled rubber, were not found in the EPDM. The authors state that "with the exception of chromium and zinc, the EPDM rubber contains lower concentrations of hazardous substances than the recycled rubber types overall."[21] A 2008 study by the Danish Ministry of the Environment also included tests of one sample of EPDM.[22] A study supported in part by the tire industry in France found that EPDM emitted larger amounts of VOCs than tire crumb.[23]

In reviewing pros and cons of EPDM infill, the Norwegian Environmental Agency notes possible concerns about VOC emissions at indoor fields, introduction of microplastics into the environment, and aquatic toxicity from leachate, among other factors.[24]

RIVM reviewed the limited existing literature on EPDM infill as well as conducting limited testing of its own. RIVM concludes that EPDM infill is likely to contain PAHs but at lower levels than tire crumb; carbon black may be a concern in black EPDM, but not in EPDM of other colors; and phthalate esters such as diethylhexyl phthalate (DEHP), an endocrine disrupter, may be present in the material. Nonyl- and octylphenols, also endocrine disrupters, are detected at low levels in both EPDM and tire crumb. RIVM also notes that leaching of zinc from EPDM could potentially pose a concern similar to the level of concern posed by tire crumb.[25]

In summary, EPDM may pose some of the same health and environmental concerns posed by tire crumb, although it may contain lower levels of some important categories of chemicals of concern and a smaller number of chemicals of concern, compared with tire crumb. Additional detail on EPDM infill is available on TURI's website.[26]

TPE

Thermoplastic elastomer[27] (TPE) is a general term that can encompass a variety of materials. TPEs are composed of two materials: one that is hard at room temperature and one that is soft and rubbery at room temperature. The two materials can be either chemically bonded or blended together.

TPEs generally do not require curing or vulcanization during manufacturing. However, some products marketed as TPE do contain a vulcanized material as one part of the mix, further complicating the distinctions among material types.

As with EPDM infill, TPE infill has not been studied extensively. Based on the limited information available on TPE used in artificial turf infill materials, it appears to contain lower levels of many toxic chemicals than tire crumb. In particular, measurements indicate that TPE infill emits fewer VOCs. Furthermore, since TPE does not require vulcanization (curing), it is generally expected to be free of the vulcanizing agents that are used in crumb rubber made from tires.[28] However, TPE infill can contain and emit some chemicals of concern, and since individual TPE products may vary widely, it is important to obtain information on the chemicals found in any individual product that is under consideration.

Although the term TPE encompasses a broad category of materials, TURI examined details about one TPE infill to better understand the chemical composition. Using information obtained from Safety Data Sheets and the US National Library of Medicine's database (ChemID*plus)*, the TPE sample was found to be composed of styrene block copolymer, polyethylene, paraffin oil, calcium carbonate (chalk), carbon black, and unspecified stabilizers/antioxidants. Carbon black is identified by the International Agency for Research on Cancer as a possible human carcinogen (Group 2B), and many forms contain a variety of adsorbed compounds, including PAHs.[29]

A 2006 study by the Norwegian Pollution Control Authority compared three indoor fields: two containing crumb rubber (SBR) infill made from tires, and one containing TPE infill.[30] In measurements of airborne dust, the quantity of fine particulate matter ($PM_{2.5}$) was elevated for the two SBR fields, while quantities were in the expected ranges for an indoor setting for the TPE field. The researchers also noted that the dust generated by the TPE field was free of the vulcanization compounds, preservative compounds, and carbon black found in the SBR fields. Dust from all locations contained PAHs, but the levels in the dust generated by the TPE field were lower than those in the SBR dust. Total VOCs measured at the TPE field were also lower than those measured at the tire crumb fields. Phthalate esters were present at comparable levels at all locations; phthalate esters measured in airborne dust during one time period were slightly lower at the TPE field, but were higher at the TPE field during another time period.

RIVM's literature review suggests that little information is available on TPE infills, but that they are likely to contain lower levels of metals and VOCs than tire crumb or EPDM, lower or comparable levels of PAHs, and comparable levels of phthalate esters.[31]

In summary, based on the limited information that is available, TPE infill is likely to contain fewer chemicals of concern than tire crumb, but is still likely to contain some chemicals of concern. Communities considering purchasing a TPE infill product may wish to request additional information from the vendor on the specific type of TPE used. Additional detail on TPE infill is available on TURI's website.[32]

Waste shoe material

Infill made from post industrial waste shoe material can be made from a single brand of shoe product, or from several mixed together. For example, the Sole Revolution brand of infill may draw materials from a variety of shoe manufacturers, while Nike Grind is made from Nike® shoe material.[33]

Shoe manufacturing uses a wide variety of materials, and manufacturers' choices about these materials vary over time. Factors relevant to the environmental, health and safety characteristics of athletic shoe materials include the polymers used in shoe soles, the additives that impart key performance characteristics to those polymers, and the mandatory and voluntary testing protocols used to limit toxics in shoe materials.

Some shoe materials are governed by Restricted Substances Lists (RSLs) developed by shoe manufacturers to minimize or eliminate the use of certain chemicals that pose particularly high concerns. For example, Nike has an RSL that "restricts approximately 350 substances that have been regulated or voluntarily phased out of [their] manufacturing processes,"[34] and Nike Grind materials are governed by the RSL.[35]

According to Nike's RSL, certain VOCs (such as benzene or toluene) are subject to tight control in the manufacturing process. Thus, these substances are not necessarily absent from Nike products but they are used in the minimum quantity possible to achieve the desired effect. Nike also limits the levels of other categories of chemicals of concern, such as specific PAHs and specific phthalate esters.[36]

Waste shoe material can contain some of the same chemicals of concern as other rubber infills, although it offers the advantage that levels of some of the chemicals of highest concern may be regulated by an RSL. Neither of the recent assessments by European government agencies considered waste shoe material in detail as an alternative to tire crumb. TURI has not identified detailed independent studies of waste shoe material as used in infill.

Acrylic-coated sand

TURI was able to gather information on one acrylic-coated sand product that is currently marketed for use in artificial turf.[37] According to the manufacturer, this product is composed of well-rounded sand, a proprietary (undisclosed) acrylic, a Microban® antimicrobial, and a pigment.[38]

The specific acrylic used in the product is a proprietary component of the manufacturer's production process, so no other information was available on its health and environmental properties. According to the manufacturer, it does not contain any additives beyond the pigment and antimicrobial.[39] Laboratory test results provided by the manufacturer show that all PAHs for which tests were conducted were below the detection limit.[40] The manufacturer also states that the product was below the detection limit for all VOCs for which tests were conducted.[41]

The antimicrobial helps to protect the acrylic coating from deterioration. The company currently uses ZPTech®, a zinc-based antimicrobial. According to the Microban website, "ZPTech is a broad-spectrum antimicrobial."[42] According to Microban, the product "encapsulates zinc pyrithione in customized carriers." Zinc is released when the material is exposed to water.[43] The product is also available without the antimicrobial.

According to the manufacturer, the antimicrobial product originally used in the product was triclosan, but the transition to the zinc-based antimicrobial has been complete since the end of 2016.[44] Triclosan poses concerns based on bioaccumulation and adverse health and environmental effects.[45]

Test data are available both for presence of metals in the material and for leaching of metals from the material. The metal that appears in the largest quantity is zinc (18 and 57 mg/kg in two samples respectively). Tests show that the material leaches 0.82 mg/L of iron and 0.13 mg/L of zinc.[46]

Many of the categories of organic chemicals of concern that are present in the other synthetic infills may be lower, or absent, in acrylic-coated sand. On the other hand, there may be a need for more research on the environmental implications of the broad use of sand coated with an antimicrobial-infused polymer.

Mineral- or plant-based materials

A growing list of mineral- or plant-based materials is marketed for use in infill. At least one of these options, zeolite, poses serious health concerns. The other materials have generally not been studied in depth. As with the other materials discussed in this report, it is essential to gather detailed information on these materials to understand their potential health or environmental impacts. This section mentions a few areas of concern, but is not comprehensive.

Zeolite. Zeolite poses a respiratory hazard. Animal studies suggest that exposure to some types of zeolites may be associated with increased risk of developing mesothelioma.[47] Erionite, one type of zeolite, poses particular concerns; its health effects can be similar to those of asbestos.[48]

Cork. Respiratory disease has been documented in cork workers exposed to cork dust. For example, a 1973 study concluded that workers in the cork industry may suffer from various complaints related to the inhalation of cork dust. It states that "workers in factories where cork is processed and transformed into commercial products may acquire incapacitating disease of the respiratory tract."[49] Respiratory disease associated with cork dust exposure is known as suberosis. Fungi that frequently colonize cork appear to play some role in the disease, although the disease is not fully understood.[50]

Coconut fiber. Some individuals are allergic to coconut, although coconut allergies are relatively rare. The American College of Allergy, Asthma & Immunology notes that "coconut is not a botanical nut; it is classified as a fruit, even though the Food and Drug Administration recognizes coconut as a tree nut. While allergic reactions to coconut have been documented, most people who are allergic to tree nuts can safely eat coconut."[51]

Walnut shells. Nut shells may pose concerns related to allergies if nut allergens are present on the shells. Walnut shells are used as an alternative to silica in sand blasting, and there is one report of an individual developing an allergic reaction in that context.[52] According to the manufacturer, USGreentech, the shells used in Safeshell[53] (a proprietary infill made from walnut shells) are processed to remove allergens to "below 2.5 parts per million."[54]

Fibers. A variety of respirable plant-based fibers can cause disease and disability. For example, cotton dust is a well-known source of respiratory disease.[55] TURI has not identified any studies that consider possible hazards related to plant-based fibers in infill.

Comparing infills

As noted above, infills are just one part of an artificial turf system and all portions of the system should be evaluated as part of the decision making process. Table 2 provides comparative information on selected chemicals or chemical categories in infill materials.

Most infill vendors are able to provide test results for a number of metals. The information on metals in this table is drawn primarily from one set of tests on individual infill products provided by a vendor of multiple infill types. The table shows specific information on lead because it is a particular concern for children's health, and zinc because it has been flagged as a possible environmental concern associated with artificial turf. However, other metals may be equally or more important. Communities working to make a decision should request the most up-to-date results on metals present in the specific product they are considering.

Information on other chemicals may not be as readily available from vendors. Communities may wish to request information on organic chemicals, such as VOCs or PAHs, found in any specific product. Note that the term "organic" in this context refers to any chemical that is based on carbon. This is not the same as the use of "organic" to describe pesticide-free management of natural grass systems.

As shown in the table, vulcanization compounds are likely to be found in tire crumb, EPDM, and shoe materials. VOCs have been measured in many of the materials, but are higher in some than in others. Similarly, PAHs may be present in varying quantities depending on the material. There may be some increased predictability when purchasing waste shoe materials if they are subject to an RSL. Mineral- and plant-based materials are unlikely to pose concerns related to the four broad categories of synthetic chemicals listed in the table, but some pose other significant concerns. It is important to note that even in cases where the chemicals listed below may be absent, infills may pose other hazards.

In the course of TURI's research, a number of data gaps were identified. For example, not all vendors were able to provide information on PAHs in infill products. To help address this data gap and better understand the presence of PAHs in these materials, TURI contracted with the Icahn School of Medicine at Mount Sinai to conduct limited testing on samples of commercial infill products. As shown in Table 2, the tire crumb sample contained the largest total PAH concentration, with over 500 mg/kg. Waste athletic shoe material and EPDM had the next largest total PAH concentrations, although they were both an order of magnitude lower than tire crumb (55 and 20 mg/kg respectively).[56]

Table 2: Comparing infills: Selected categories of chemicals of concern

Category	Tire crumb	EPDM	Shoe materials[a]	TPE	Acrylic-coated sand	Mineral- or plant-based
Lead[b]	Present	Present	Present	Present	Below detection limit[c]	Absent in some cases
Zinc[b]	Present	Present	Present	Present	Present[c]	Present in some cases
Other metals[b]	Present	Present	Present	Present	One additional metal present[c]	Present
Vulcanization compounds[d]	Present	Present	Present	Generally absent	Expected to be absent	Zeolite, when present, poses serious respiratory hazard. Plant-based materials can pose concerns related to dust, fungi, or allergens. Vulcanization compounds and phthalates are expected to be absent; VOCs and PAHs are expected to be low or absent.[h]
Phthalates	Present[e]	Present (lower)[f]	May be present, but subject to RSL	Present[g]	Expected to be absent	
VOCs	Present[e]	Present (lower in some cases, higher in others)[f]	Expected to be present, but subject to RSL	Present (lower)[g]	Expected to be absent	
PAHs	Present[e]	Present (lower)[f]	May be present, but subject to RSL	Present (lower)[g]	Below detection limit[c]	
PAHs (TURI sample)[i]	Present (highest) (548 mg/kg)	Present (20 mg/kg)	Present (55 mg/kg)	Present (below 10 mg/kg)		

[a] Some information in this column is drawn from Nike's RSL. *VOCs:* Nike's RSL restricts benzene to 5 ppm and a number of other VOCs to a total of 1,000 ppm. *PAHs:* Nike's RSL restricts certain PAHs to 1 ppm each and sets a 10 ppm total for all PAHs on the list. *Phthalate esters:* Certain phthalate esters are listed on the Restricted Substances Lists (RSLs) of major shoe manufacturers. Specifically, Nike restricts all ortho-phthalates to a total of 1,000 ppm.

[b] Except where otherwise noted, information is drawn from Labosport. 2014. *Technical Report: Toxicological Analysis of Performance Infill for Synthetic Turf Fields according to EN 71-3 Standard – Safety of Toys Part 3: Migration of Certain Elements.* Report #R14565CAN-A1, provided to Jason Smollett, FieldTurf.®

[c] AIRL, Inc. 2018. Lab report #304074, provided to Ross Vocke, US Greentech. Detection limit 10 µg/Kg for PAHs, 0.25mg/Kg for metals.

[d] By definition, the vulcanized rubber products (tire crumb, EPDM and shoe materials) may contain residual vulcanization compounds. TPE is not vulcanized; however, in some cases, products marketed as TPE are a blend that also contains vulcanized rubber.

[e] US EPA. 2016. *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds: Status Report.* EPA/600/R-16/364. Viewed on October 23, 2018, at https://www.epa.gov/sites/production/files/2016-12/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf.

[f] Norwegian Building Research Institute (NBI - BYGGFORSK). 2004. "Potential Health and Environmental Effects Linked to Artificial Turf Systems: Final Report." Report prepared for the Norwegian Football Association. Project no. 0-10820. September 10, 2004. Authors: Thale S.W. Plesser, Ole J. Lund. Moretto R. 2007. *Environmental and health assessment of the use of elastomer granules (virgin and from used tires) as filling in third-generation artificial turf.* Report prepared for ADEME/ALIAPUR/Fieldturf Tarkett. Note: The terms "lower" and "higher" refer to the comparison with tire crumb.

[g] Dye, Christian, A. Bjerke, N. Schmidbauer, S. Manø. 2006. *Measurement of Air Pollution in Indoor Artificial Turf Halls.* Trondheim, Norway: Norwegian Pollution Control Authority/Norwegian Institute for Air Research. Report #NILU OR 03/2006. TA number: TA-2148/2006. ISBN number 82-425-1716-9. Note that in this study, phthalates measured in airborne dust at a TPE field were found to be lower at one time, and higher at another time, compared with levels measured at a tire crumb field.

[h] Plants can produce some substances that are classified as VOCs. However, based on currently available information, the plant-based materials used in infill are not expected to pose concerns related to VOCs. PAHs can be taken up by plants from ambient pollution in some cases.

[i] Toxics Use Reduction Institute. 2019. "Artificial Turf Infill: Laboratory Testing Results: PAHs." Fact sheet available at www.turi.org/Our_Work/Community/Artificial_Turf/PAH_Test_Results. TURI contracted with the Icahn School of Medicine at Mount Sinai to conduct limited testing to supplement information available in existing literature.

When researching turf options, communities should evaluate materials carefully and may wish to require additional testing to ensure they have considered the full range of chemicals. Existing tests generally apply only to the sample on which they were conducted, so it is important to obtain data on the specific product in question.

Environmental Concerns

Environmental concerns include loss of wildlife habitat and contaminated runoff into the environment. A study by the Connecticut Department of Environmental Protection identified concerns related to a number of chemicals in stormwater runoff from artificial turf fields. These include both metals and organic compounds. They noted high zinc concentrations in stormwater as a particular concern for aquatic organisms. They also noted the potential for leaching of high levels of copper, cadmium, barium, manganese and lead in some cases. The top concerns identified in the study were toxicity to aquatic life from zinc and from whole effluent toxicity (WET).[57] WET is a methodology for assessing the aquatic toxicity effects of an effluent stream as a whole.[58] In another example, a study found that leachate from several artificial turf systems was toxic to aquatic organisms.[59]

Another environmental concern is migration of synthetic particles into the surrounding environment. Both infill particles and broken synthetic grass fibers do not stay limited to the boundaries of the artificial turf field. Photographic evidence collected by community members in Massachusetts show broken pieces of artificial grass fibers widely dispersed in environments surrounding artificial turf fields. Field maintenance protocols provide for periodic addition of infill to replace infill lost from the field in the course of play, further demonstrating that not all infill particles remain in place within the field. With growing concern about global microplastic pollution, some communities are working actively to reduce the amount of plastic they introduce into the environment. Little or no research has been conducted on ways in which dust and broken particles from artificial turf fields may contribute to microplastic pollution in the environment.

Acrylic-coated sand particles, according to the manufacturer, pose less risk of migrating into waterways compared with other infills because they do not float; however, they could still generate dust that may move offsite. To the extent that particles migrate off the original field site and enter water resources, there could be concerns about whether sedimentary organisms could incorporate these materials and whether they could enter the food chain in this way.

Disposal of the synthetic materials, including the infill and the shock pad, poses an additional concern. Some synthetic materials may be reusable one or more times, while others may have to be disposed of in a landfill or through incineration when the field is due for replacement. RIVM notes that it may be possible to use waste material from a replaced artificial turf field in some other sporting applications, but also notes that due to the degradation of the material over time, this will not always be possible. RIVM also notes that the substructure elements of an artificial turf field may need to be cleaned prior to recycling, if they are contaminated with any chemicals that have leached from infill. For the limited set of infills it analyzes, RIVM assumes an average 10 year service life for artificial turf fields and assumes that the infill materials are not reused on additional fields.[60]

Artificial Turf and Heat Stress

In sunny, warm weather, artificial turf can become much hotter than natural grass, raising concerns related to heat stress for athletes playing on the fields.[61] Research indicates that all artificial turf reaches higher temperatures than natural grass,[62] although some infill materials may reach higher temperatures than others.

A report by the New York State Department of Environmental Conservation found that surface temperatures on an artificial turf field were 35°F to 42°F higher than those on natural grass.[63]

Another study found that the highest temperature measured on artificial turf was 60.3°F greater than that observed on natural grass.[64]

In another study, artificial turf fibers reached temperatures of 156°F under direct sunlight, while the crumb rubber infill reached 101°F.[65]

Measurements taken by sports managers at Brigham Young University found that the surface temperature of artificial turf was 37°F higher than asphalt and 86.5°F hotter than natural turf. The hottest surface temperature recorded during the study was 200°F on a 98°F day. Even in October, the surface temperature reached 112.4°F.[66]

Irrigation can lower field temperature for a short time. A study by Penn State's Center for Sports Surface Research found that frequent, heavy irrigation reduces temperatures on artificial turf, but temperatures rebound quickly under sunny conditions.[67] Another study found that irrigation could lower temperatures by 10 to 20 degrees for a period of at least 20 minutes.[68] Another found that irrigation lowered the surface temperature from 174°F to 85°F; however, the temperature rebounded to 164°F after 20 minutes.[69]

Heat-related illness can be a life-threatening emergency. Experts note that athletic coaches and other staff need to be educated about heat-related illness and understand how to prevent it, including cancelling sport activities when appropriate.[70] In one example, a number of students developed heat-related illness after band practice on a new artificial turf field.[71]

Heat can also affect chemical emissions. For example, one study expressed concern about PAH emissions from tire crumb at elevated temperatures.[72]

Additional information on heat is available in TURI's website.[73]

Injuries

Injury rates can be affected by a variety of factors, including the type and condition of the playing surface as well as equipment used and type and level of sport. Studies show variable outcomes in the rates and types of injuries experienced by athletes playing on natural and on artificial turf.[74]

One particular concern is increased rates of turf burns (skin abrasions) associated with playing on artificial turf. For example, a study by the California Office of Environmental Health Hazard Assessment found a two- to three-fold increase in skin abrasions per player hour on artificial turf compared with natural grass turf.[75] These study authors noted that these abrasions are a risk factor for serious bacterial infections, although they did not assess rates of these infections among the players they studied.

Additional information on injuries is available in TURI's website.[76]

Current Federal and State Studies on Artificial Turf and Tire Crumb

As noted above, a number of existing studies have examined the chemicals present in artificial turf, with a particular focus on tire crumb. Some of these studies include a risk assessment, in which an effort is made to estimate the number of cases of disease that could result from exposure to a subset of the chemicals found in tire crumb.

After reviewing the studies, federal and state officials have identified a need for additional information. Two current studies are described here.

California Office of Environmental Health Hazard Assessment

In 2015, the California Office of Environmental Health Hazard Assessment (OEHHA), an office within the California Environmental Protection Agency, began a new study of the potential health effects of exposure to artificial turf as well as playground mats made from recycled waste tires. The study includes analyses of samples of new and used artificial turf and playground mats; the development of exposure scenarios; and the development of a risk assessment based on this information. OEHHA has sampled more than 30 fields in a range of climate regions within California, including both new and old fields.[77] OEHHA is also examining the range of routes by which players and bystanders can be exposed to chemicals found in the artificial turf materials, including through skin contact, breathing, and ingestion. As part of this effort, OEHHA has conducted a survey of both child and adult athletes to learn more about whether they report getting infill materials on their skin, in their eyes, and/or in their mouths during the course of play.[78]

In the future, OEHHA may also examine people's actual exposures through measurement of biological specimens or use of personal monitors.[79]

Research by federal agencies

Three federal agencies are also engaged in an assessment of potential health effects of exposure to artificial turf. The agencies working on the study are the US EPA, the Consumer Product Safety Commission (CPSC), and the Agency for Toxic Substances and Disease Registry (ATSDR) within the Centers for Disease Control. As background on the need for this study, EPA noted that "limited studies have not shown an elevated health risk from playing on fields with tire crumb, but the existing studies do not comprehensively evaluate the concerns about health risks from exposure to tire crumb."[80] EPA further states, "While this effort won't provide all the answers about whether synthetic turf fields are safe, it represents the first time that such a large study is being conducted across the U.S."[81]

In this project, the federal agencies are working to identify chemicals of concern found in tire crumb, and gain a better understanding of how people are exposed to tire crumb on playing fields and in playgrounds. The study has four components: a literature review and analysis of gaps in current knowledge; a tire crumb characterization study; a sports turf exposure characterization study; and a playground study.[82]

The agencies have issued summary documents based on the work they completed in 2016, including a summary of all the literature that was reviewed and a detailed spreadsheet showing information on which chemicals were examined in each study.[83] These are useful resources for people interested in learning more about the studies that have been conducted to date.

Among other information, the federal agencies' preliminary report on their work provides an overview of knowledge gaps about tire crumb used in playing surfaces. For example, with regard to characterizing tire crumb materials, there are gaps related to chemical characterization, emissions assessments, microbial assessments, bioaccessibility, and variability.[84] For example, EPA notes that there is a lack of studies that measure a wide range of tire crumb samples and consider the full range of chemicals that can be found in tires. Regarding emissions, EPA notes that "few laboratory-based studies have investigated VOC and SVOC emissions from synthetic fields and playgrounds under different temperature conditions," and those studies that do exist have considered only a limited set of chemical emissions. Regarding bioaccessibility (the likelihood that the human body will take up the chemicals present in the material), there is a lack of studies that "systematically measure a wider range of metal and organic chemical constituents, using multiple simulated biological fluids, and across a large range of tire crumb rubber samples." Finally, EPA notes that "most studies characterizing tire crumb rubber from synthetic fields and playgrounds in the United States have been relatively small, and restricted to a few fields or playgrounds. Measurements for samples collected from a wider range of tire recycling plants, synthetic fields, and playgrounds across the United States is lacking."

Additional gaps exist with regard to other important areas of study. For example, with regard to characterizing exposure and risk, there are gaps related to exposure factors, dermal or ingestion exposures, exposure through broken skin or through eyes, and more. EPA notes that while a number of studies have examined possible exposures through inhalation, "more limited information is available for understanding dermal and ingestion exposures." EPA also notes that "little information is available on the potential for increased exposures via broken skin (i.e., due to cuts and scrapes) and through ocular fluids," and that few studies have examined the potential cumulative effects of exposures through multiple routes, including inhalation, ingestion, and skin exposure.

Other parts of the federal agencies' work are still in progress at the time of publication of this report. EPA and CDC/ATSDR have completed the collection and analysis of samples for the exposure and tire crumb characterization parts of the study, and the draft report is now undergoing technical peer review, according to EPA's website, updated September 2018.

In addition, CPSC has completed a study of how children interact with recycled tire materials on playgrounds. CPSC used a combination of focus groups, field observations, and a national survey of parents and child-care providers to collect information on children's behavior when playing on playground surfacing made from recycled tires or other materials. CPSC focused in particular on the behavior and experience of toddlers on playgrounds. Among other findings, CPSC noted that children "may be commonly exposed to rubber surfacing materials in various ways, such as chewing the materials and being scraped by them." They noted concerns including children mouthing and chewing rubber surfacing materials; stains from rubber surfacing left on children's skin and clothing; children picking up rubber mulch; children being exposed through bare feet; and children eating snacks at playgrounds. The CPSC found that the study findings raise concerns that deserve further investigation.[85]

What is a Risk Assessment?

Many existing studies on the use of tire crumb in artificial turf are quantitative risk assessments. Risk assessment is a methodology used by researchers to estimate the number of cases of disease that could result from anticipated exposure. To develop a risk assessment, researchers may bring together information on chemical toxicity, level of exposure, route of exposure, expected ages at which exposure may occur, expected duration of exposure, and expected ways in which the body may absorb and process the chemicals. Since risk assessments often consider just a subset of the chemicals present in artificial turf, they may not present a complete picture. In addition, a number of assumptions have to be made in the course of the assessment, and the final result is an estimated number of cases of disease (e.g., an expected number of cancer cases per million people exposed). This number may be used in discussions about levels of risk that are considered acceptable.

The Toxics Use Reduction approach does not rely on quantitative risk assessments; rather, the focus is on reducing or eliminating toxic chemical use when possible.

New Regulatory Initiatives in Europe

The European Union regulates chemicals under its Registration, Evaluation and Authorisation of Chemicals (REACH) regulation. The Netherlands has developed a proposal under REACH to regulate the presence of PAHs in sports turf infills.[86] Specifically, the proposal would limit the level of eight PAHs in sports turf infills, as well as in materials used in loose form on playgrounds. The proposed restriction is based on a finding that the EU's current exposure limits for these materials are not sufficiently protective. The proposed restriction would limit the sum of the eight PAHs to 17 mg/kg in granules or mulches used as infill or as playground surfacing in order to reduce the estimated cancer risk for exposed individuals to 2.6×10^{-6} (2.6 per million).[87] The proposed restriction was developed in response to concerns about PAHs in waste tires but would apply to any alternative material as well. This is the first step in a multi-stage regulatory and consultation process. If there is agreement on the restriction, the estimated timeline is that it would be adopted in 2020.[88]

Laboratory Testing of Artificial Turf

A number of communities have asked TURI what types of information they should gather as they make decisions about artificial turf fields. All the issues noted above are relevant for decision making, but confusion often arises around the testing that may be conducted on turf infill and grass blades.

In general, manufacturers are able to provide test data covering a number of metals of concern. Manufacturers often provide a comparison between this information and the standards provided in the European Toy Safety Standard. Communities may choose to order their own tests on metal contents as well.

Less information tends to be available on other, non-metal chemicals that may be present in either the infill or the grass blades. Therefore, communities may wish to either conduct their own testing or request test results from the vendor on these other chemicals. For example, it may be useful to ask the vendor for data on VOCs, SVOCs, and PAHs present in the product.

Safer Alternative: Natural Grass

Natural grass fields can be the safest option for recreational space, by eliminating many of the concerns noted above. Grass fields may be maintained organically or with conventional or integrated pest management (IPM) practices. Organic turf management eliminates the use of toxic insecticides, herbicides and fungicides.

Photo credit: Adam Anulewicz

Forest Park, Springfield, MA, 2018.

Natural grass can reduce a field's overall carbon footprint by capturing carbon dioxide. A natural grass field can also provide a number of ecosystem services, such as providing habitat for invertebrates and microorganisms, reducing the heat island effect in urban areas, and helping to control flooding, among others.

Table 3 shows a broad comparison between artificial turf and natural grass, including conventionally and organically managed grass. As shown in the table, artificial turf can pose chemical hazards related to chemicals either present in the surfacing material or applied to the surface. Cleaners, disinfectants and even herbicides may sometimes be applied to the artificial turf surface as well. Natural grass, on the other hand, only contains whatever is already in the ambient environment and generally does not include polymers, rubber and plastic additives, or respiratory hazards such as zeolite. Conventionally managed natural grass may be treated with synthetic pesticides or fertilizers; organically managed natural grass builds soil health, making it unnecessary to apply chemical treatments.

Table 3: Comparing artificial turf with natural grass				
Category	**Subcategory**	**Artificial turf**	**Natural grass – conventional**	**Natural grass – organic**
Chemicals	**Present in surface**	Polymers, additives; respiratory hazards, e.g., zeolite	Ambient environmental exposures only	
	Applied to surface	Cleaners, disinfectants, herbicides	Synthetic pesticides, fertilizers	Soil health built through aeration, proper mowing practices, organic soil amendments, and other approaches
Other health hazards	**Heat**	Higher	Lower	
	Risk of skin abrasions and infections	Higher	Lower	
	Other injuries	Variable injury patterns		
Other environmental considerations	**Ecosystem services**	None	Habitat for a range of organisms; carbon fixation; water/flood control; reduction of heat island effect in urban areas	
	Migration of materials	Particles of infill & artificial grass blades can migrate into environment	Possible fertilizer runoff or pesticide drift	n/a
	Water use	Irrigation may be used to lower temperature	Irrigation may be used to support grass growth	Irrigation may be used to support grass growth; organic management reduces irrigation needs by supporting root development

Organic Management of Recreational Field Space

Organic management of a recreational field space requires a site-specific plan to optimize soil health and minimize long-term costs. Over time, a well-maintained organic field is more robust for recreational use due to a stronger root system than that found in a conventionally managed grass field. Water needs also decrease over time. Key elements of organic management include the following steps.[89]

- **Field construction**: Construct field with appropriate drainage, layering, grass type, and other conditions to support healthy turf growth. Healthy, vigorously growing grass is better able to outcompete weed pressures, and healthy soil biomass helps to prevent many insect and disease issues.

- **Soil maintenance**: Add soil amendments as necessary to achieve the appropriate chemistry, texture and nutrients to support healthy turf growth. Elements include organic fertilizers, soil amendments, microbial inoculants, compost teas, microbial food sources, and topdressing as needed with high-quality finished compost.

- **Grass maintenance**: Maintain turf health through specific cultural practices, including appropriate mowing, aeration, irrigation, and over-seeding. Address trouble spots through composting and re-sodding where necessary.

It is important to note that organic turf management requires proper training. Conventional turf management may follow a similar protocol each year; organic turf managers make adjustments based on changing conditions.

Installation/Maintenance Costs: Comparing Artificial Turf with Natural Grass

In analyzing the costs of artificial vs. natural grass systems, it is important to consider full life cycle costs, including installation, maintenance, and disposal/replacement. Artificial turf systems of all types require a significant financial investment at each stage of the product life cycle. In general, the full life cycle cost of an artificial turf field is higher than the cost of a natural grass field.

Cost information is available through university entities, turf managers' associations, and personal communications with professional grounds managers. Information is also available on the relative costs of conventional vs. organic management of natural grass.

Installation

According to the Sports Turf Managers Association (STMA), the cost of installing an artificial turf system may range from $4.50 to $10.25 per square foot. For a football field with a play area of 360x160 feet plus a 15-foot extension on each dimension (65,625 square feet), this yields an installation cost ranging from about $295,000 to about $673,000. These are costs for field installation only, and full project costs may be higher. Costs for a larger field would also be higher. A range of choices in materials and underlayments can influence the total cost of the field.

In one site-specific example, information provided by the town of Natick, Massachusetts, shows that the full project budget for the installation in 2015 of a new artificial turf field (117,810 square feet), along with associated landscaping, access and site furnishings, totaled $1.2 million.[90]

For natural grass, installation of a new field may not be necessary. For communities that do choose to install a new field, costs can range from $1.25 to $5.00 per square foot, depending on the type of field selected. For the dimensions noted above, this would yield an installation cost ranging from about $82,000 to about $328,000.[91]

Maintenance

Maintenance of artificial turf systems can include fluffing, redistributing and shock testing infill; periodic disinfection of the materials; seam repairs and infill replacement; and watering to lower temperatures on hot days. Maintenance of natural grass can include watering, mowing, fertilizing, replacing sod, and other activities. In both cases, specialized equipment is needed. Communities shifting from natural grass to artificial turf may need to purchase new equipment for this purpose. According to STMA, maintenance of an artificial turf field may cost $5,000 to $8,000 per year for materials and 300 to 500 hours of labor per year. These estimates are higher for artificial turf fields used for multiple sports. Maintenance of a natural grass field may cost $4,000 to $14,000 per year for materials plus 250 to 750 hours of labor.[92]

Organic turf maintenance can be cost-competitive with conventional management of natural grass. One study found that once established, an organic turf management program can cost 25% less than a conventional turf management program.[93]

Fifteen acres of playing fields in Marblehead, MA are managed organically. Annual maintenance costs are $2,400–$3,000 per 2-acre playing field, not including mowing costs. Mowing costs for a 2-acre field were estimated in 2010 to be $10,000 annually. Thus, total maintenance costs per 2-acre field are $12,400 to $13,000 annually (or $0.14 to $0.15 per square foot per year).[94]

Disposal/replacement

Artificial turf also requires disposal at the end of its useful life. STMA estimates costs of $6.50 to $7.80 per square foot for disposal and resurfacing.[95] Those estimates yield $426,000 to $512,000 for a

65,625 square foot field and $552,000 to $663,000 for an 85,000 square foot field.

Annualized costs

In 2008, a Missouri University Extension study calculated annualized costs for a 16-year scenario. The calculation included the capital cost of installation; annual maintenance; sod replacement costing $25,000 every four years for the natural fields; and surface replacement of the synthetic fields after eight years. Based on this calculation, a natural grass soil-based field is the most cost effective, followed by a natural grass sand-cap field, as shown in Table 5.[96] Another study, conducted by an Australian government agency, found that the 25-year and 50-year life cycle costs for artificial turf are about 2.5 times greater than those for natural grass.[97]

Planning over time

Each municipality or institution will face its own considerations as it works to develop plans for athletic fields. Some municipalities are working from a baseline of an existing, poorly-maintained grass field, or a field with poor drainage, and may wish to research options for upgrading these existing resources. In planning for the medium term, it is necessary to have a maintenance plan, whether the field is grass or artificial. For an artificial turf field, the community also needs to plan for disposal.

Summary

In summary, when the full product life cycle is taken into account, natural grass is likely to be more cost effective than artificial turf. Organic management of natural grass can further lower costs over time by building healthy soil and robust root systems. When assessing the cost of any option, whether natural grass or artificial turf, it is also important to note that there can be cost gradations depending whether a basic or a premium field is needed. More detailed cost information is also available on TURI's website.[98]

Organic Management of Playing Fields: Springfield, MA


Forest Park, Springfield, MA, 2018.

The city of Springfield, Massachusetts, manages many of its sports fields organically. According to the Springfield Parks Department, organic management has improved the overall condition of these fields. Many hours of both formal and informal sports play occur on these fields, and there are few or no cancellations due to weather-related field conditions.[99]

The consultant working with Springfield was able to provide TURI with cost figures for the first three years of organic management. The cost was $1,740/acre in the first year, $1,245/acre in the second year, and $1,110/acre in the third year. Thus, maintenance costs decreased each year as the health of the soil and vegetation improved.[100]

The consultant was also able to provide an estimate of the hours of play on one of the organically managed fields. The field has 650 scheduled hours annually. In addition to this, physical education classes are held on the field and there is an estimated 100 hours of non-programmed use. The consultant estimated that this adds up to a total of about 1,000 hours of field use per year.[101]

Conclusions

Artificial turf poses a number of health and environmental concerns. Those communities that have decided to install artificial turf are encouraged to make careful choices among the materials available to them. This is likely to include requiring some additional testing to get information on organic compounds as well as metals. Communities should bear in mind that existing tests apply only to the sample on which they are conducted, and materials used in artificial turf may vary widely in composition. From an environmental and health standpoint, organically managed natural grass is a safer choice for sports fields. When the full product life cycle is considered, organically managed natural grass also offers lower costs over time.

Glossary of Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
CPSC	Consumer Product Safety Commission
EPA	US Environmental Protection Agency
EPDM	Ethylene propylene diene terpolymer
FDA	US Food and Drug Administration
IPM	Integrated pest management
NBI	Norwegian Building Institute
OEHHA	California Office of Environmental Health Hazard Assessment
PAHs	Polyaromatic hydrocarbons
$PM_{2.5}$	Particulate matter with diameter less than 2.5 micrometers
REACH	European Union's Registration, Evaluation and Authorisation of Chemicals
RIVM	National Institute for Public Health and the Environment (Netherlands)
RSLs	Restricted Substances Lists
SBR	Styrene Butadiene Rubber
STMA	Sports Turf Managers Association
SVOCs	Semi-volatile organic compounds
TPE	Thermoplastic elastomer
TUR	Toxics Use Reduction
TURI	Massachusetts Toxics Use Reduction Institute
TVOCs	Total volatile organic compounds
VOCs	Volatile organic compounds
WET	Whole effluent toxicity

[1] Toxics Use Reduction Institute. 2018. "Artificial Turf: Selecting Safer Alternatives for Athletic Playing Fields." Available at www.turi.org/artificialturf. Also see Toxics Use Reduction Institute. 2018. "Organic Lawn Care Projects," available at https://www.turi.org/Our_Work/Community/Topic_Areas/Organic_Lawn_Care_Projects, and "Organic Lawn Care," available at https://www.turi.org/Our_Work/Community/Organic_Lawn_Care.

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