Synthetic Turf Versus Natural Turf for Playing Fields

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Summary

This report describes research we performed for the San Francisco Department of the Environment (SFE) to assist in decisionmaking regarding the purchasing of synthetic turf. Synthetic turf is becoming increasingly popular as a surface for playing fields. The products have improved and many competing brands are now available, offering a range of choices of materials. These fields offer a number of advantages over natural turf, the most important of which in most instances is playability. Many questions have been raised about the health and environmental impacts of these playing fields, and although research is beginning to explore these questions the conclusions are based on incomplete information and lead to contradictory results.

Originally, the scope of this project was to be a full cost comparison between synthetic and artificial turf, putting the various pros and cons into a common currency (i.e. monetizing) so that total impacts could be calculated and compared. We did not find any other studies that had done this, although one study has compared the global warming implications of each lifecycle. That study found a natural turf field to have a negative carbon footprint (-16.9 tons $C0_2$ equivalent over ten years) due mainly to the carbon sequestration potential of the grass. The chosen synthetic turf field, on the other hand, emitted +55.6 tons of CO_2 equivalent over ten years. This figure would have been almost twice as high (108.2 tons CO_2) if the authors had not assumed that the field would be recycled at the end of life (which gave a carbon credit of 52.6 tons CO_2 equivalent). Recycling of synthetic turf is theoretically possible but apparently beyond the state of the art at the current time due to difficulties separating the various components. Assuming that the field is eventually recycled, its greenhouse gas emissions (GHG) relative to those of natural turf (which are negative) could be offset over ten years by planting 1861 trees. If the field lifecycle had not received the recycling credit, the required offset would increase to 3209 trees.

A recurring concern in a number of studies is the potential for leaching of toxic substances from turf components, particularly infill material that is derived from reused rubber tires (not all turf products use this material, but many do). Rubber contains several components of potential water quality concern, such as zinc, polycyclic aromatic hydrocarbons, and nonylphenol. Studies have not reached consistent conclusions regarding the seriousness of any potential problems, but a risk assessment for the Norwegian government concluded that “artificial turf that contains rubber from recycled tyres may give rise to local environmental risk.” The predicted environmental concentrations of zinc, PAH, and alkylphenols exceeded no-effect concentrations for aquatic life. In comparison, natural turf cannot be considered free of risk if fertilizers or pesticides are used. The use of water-soluble nutrients, and certain fungicides, insecticides, or selective herbicides would also likely result in measurable concentrations of nitrogen, phosphorus, and various pesticide active ingredients in leachate. A

comparison of water quality impacts from natural turf versus synthetic turf would require a detailed analysis of maintenance methods.

Over the course of this project, the scope was narrowed considerably by SFE to focus mainly on determining whether brominated flame retardants, especially polybrominated diphenyl ethers (PBDEs), are used in synthetic turf products. Although we had no evidence that PBDEs were used in these products, we had the opportunity to screen several products for the presence of bromine with a portable X-ray fluorescence spectrometer. The results of that testing are detailed in a separate report entitled *Occurrence of bromine, lead, and zinc in synthetic turf components*. In general, we found little or no bromine in the products tested, although one shock pad contained in the range of 0.1-0.4% bromine, and some bromine (hundreds of parts per million) was detected in some rubber infill material. We also identified roughly 2000 ppm lead in one turf product, but this was a product intended for landscape use rather than for playfields.

As a result of this work, we make the following recommendations regarding synthetic turf:
1. If the greenhouse gas emissions study is correct and broadly applicable synthetic turf, it strongly suggests that, unless the greenhouse gas emissions can be offset, the use of synthetic turf should be minimized and confined to the sites where its other benefits are maximized. It should not become the default standard surface for playfields.

2. When synthetic turf is purchased, SFE should continue to request full ingredients disclosure from manufacturers. Particular elements of concern that should be asked about include lead, bromine, and zinc. SFE should also inquire about the availability of alternatives to PVC pipe for field drainage when these products are installed.

3. SFE should stay abreast of developments regarding eventual recycling of synthetic turf fields as currently installed products come to the end of their useful life. If manufacturers begin to recycle their fields, SFE should investigate to be certain these claims can be verified and, if so, end of life field management could become an important selection criterion.

4. It would still be worthwhile to have SFE staff or an intern interview playfield managers to assess and compare potential impacts resulting from specific maintenance activities, such as pesticide use, gasoline consumption, etc. Even without a full cost comparison, it might be possible to identify ways to reduce the impacts of field maintenance for both natural turf and synthetic turf fields.

1.0 Introduction

Synthetic turf has become increasingly popular for sports fields in recent years due in large part to improvements in the products. So-called second- or third-generation surfaces look much more like natural turf and less like carpet. They utilize various infill materials on top of the base to mimic the feel of natural turf, reducing injuries and making the field more acceptable to athletes. The advantages of a synthetic turf playing field are obvious and have been written about extensively.[1,2,3] For the owner or manager, the most important advantage is playability: these fields can be used virtually every day, while natural turf fields must be closed part of the time to let the turf recover. Additional advantages are zero fertilizer use, greatly reduced pesticide use, greatly reduced water use, and no need for mowing. These advantages are balanced somewhat by a higher initial installation cost, warmer surface temperatures, lack of carbon sequestering or supporting beneficial soil life, the need to perform some grooming operations, and potentially high cost of repairs, ultimate replacement, and disposal. Other issues of interest that bear investigation are the identity of ingredients in synthetic turf, recycled content and recyclability, potential water quality issues from leachate, and reported drug resistant skin infections in athletes.

SFE initially requested a full-cost comparison between synthetic turf and natural turf in order to better understand the relative costs and benefits of each to support future decisions on playing surfaces. Full cost, as defined here, is intended to include monetary costs, labor costs, environmental and safety hazards, and disposal costs. After an initial literature search was conducted to determine what work has already been done (see Section 2 below), the scope of this project was scaled back to a more modest project. The results described here merely report the results of the literature found but do not attempt to monetize and aggregate the impacts. One study did, however, calculate and compare greenhouse gas emissions from natural and synthetic turf fields over their lifecycle.[4] That study gave a clear win to natural turf. We also tested several samples of synthetic turf with an X-ray spectrometer to determine bromine, lead, and zinc content.

2.0 Literature Search

Research was conducted to find out what literature exists on comparisons between artificial turf and natural turf. In addition, information on current artificial turf products was gathered from manufacturer websites, personal interviews, and printed information provided by manufacturers.

A literature search was performed using databases available through the University of Washington Libraries. The following databases shown in Table 2.1 were queried using the search terms “synthetic turf, “synthetic grass,” “artificial turf,” and artificial grass.” Because relatively few articles were recovered, it was not necessary to narrow the search with additional modifiers. In addition, Internet searches using the search engine Google was performed using the same search terms. The Internet searches were further narrowed with modifiers such as “comparison” and by including both “synthetic” and “natural” or “artificial” and “natural” as modifiers in the same search.

Table 2.1 Databases utilized for literature search

Garden, Landscape, Horticulture Index
ISI Web of Science
Agricola
Expanded Academic ASAP
ProQuest
Environmental and Engineering Abstracts
Science Direct
Water Resources Abstracts

National Technical Information Service (NTIS)

These searches yielded much less information than expected. In addition, a few papers or articles were located that discussed the relative merits of both types of surfaces. Papers written before 1995 were rejected on the basis that they were not dealing with the newest generation playing surfaces. Interest in this subject has skyrocketed in the last year or two, and a number of papers and reports have come to our attention after the formal literature search was performed. We have included those documents as well.

The following papers and articles were selected as being most relevant to our purposes. It should be noted that few of these are from peer-reviewed journals. Many are from trade publications and some are from industries with a financial interest in promoting either synthetic or artificial turf.

<u>Overview papers and articles</u>

Boehland, Jessica. 2004. *Which grass is greener? Comparing natural and artificial turf*. Environmental Building News 13(4): 1-15.

McNitt, AS. 2005. *Synthetic turf in the USA – Trends and issues*. International Turfgrass Society Research Journal 10 (Part 1): 27-33.

Brookline GreenSpace Alliance (BGSA). 2005. Artificial turf: Information compiled by Brookline GreenSpace Alliance. www.brooklinegreenspace.org/PDF/Artificial%20Turf.pdf

Francese, Frank, Gretchen Reison, et al. 2004. Athletic field turf committee. Report to the [Chappaqua] Board of Education. www.sau70.org/spotlight/athletic_fields/Supporting_documents/ChappaquaSchoolTurf.pdf.

Skindrud, Erik. 2005. *Turf wars: How do grass and artificial turf compare?* Landscape Contractor National, June 2005.

Turfgrass Producers International (TPI). 2004. *Serious questions about the new-generation artificial turf that require answers.* http://www.turfgrasssod.org/webarticles/articlefiles/139-Serious%20Questions.pdf

West Coast Turf (WTC). *Artificial turf: Separating fact from fiction.* http://www.westernsod.com/pdfs/w914-0046c_1-11.pdf

_____. 2004. *Comparing apples to oranges.* International Sports Turf. Horticulture & Crop Science in Virtual Perspective. Ohio State University.

American Recycler. 2003. *Recycled tires level the playing field.* http://www.americanrecycler.com/june2003/recycled.html

<u>Articles on specific health or environmental impacts</u>

Liu, HS, JL Mead, and RG Stacer. 1998. *Environmental impacts of recycled rubber in light fill applications: summary and evaluation of existing literature.* Technical report #2. Chelsea Center for Recycling and Economic Development, University of Massachusetts.

Williams, C Frank, and Gilbert E Pulley. undated. *Synthetic surface heat studies.* http://new.turfgrasssod.org/pdfs/Surface_Comparison_Heat_Study_F.pdf

Levin, Mark M. 2001. FieldTurf International, Inc. *Air Monitoring Report Quartz Silica*.

Miguel, AG, GR Cass, J Weiss, and MM Glovsky. 1996. Latex allergens in tire dust and airborne particles. Environ Health Perspect 104(11): 1180-1186.

Humphrey, DN and LE Katz. 2001. *Field study of water quality effects of tire shreds placed below the water table.* Proceedings of the Conference on Beneficial Use of Recycled Materials in Transportation Applications, Air and Waste Management Association, Pittsburgh. November 2001.

Hammer, C and TA Gray. 2004. *Designing building products made with recycled tires.* Report to California Integrated Waste Management Board. June 2004.

Meil, J and L Bushi. undated. *Estimating the required global warming offsets to achieve a carbon neutral synthetic field turf system installation.* Athena Institute.

Stephensen E, M Adolfsson-Erici, M Celander, Mats Hulander, J Parkkonen, T Hegelund, J Sturve, L Hasselberg, M Bengtsson, and L Forlin. 2003. Biomarker responses and chemical analyses in fish indicate leakage of polycyclic aromatic hydrocarbons and other compounds from car tire rubber. Environ Tox & Chem 22(12): 2926-2931.

Kallqvist T. 2005. Environmental risk assessment of artificial turf systems. Norwegian Institute for Water Research. Report for the Norwegian Pollution Control Authority.

Wik A and D Goran. 2005. Environmental labeling of car tires — toxicity to Daphnia magna can be used as a screening method. Chemosphere 59: 645-651.

Smolders E and F Degryse. 2002. Fate and effect of zinc from tire debris in soil. Environ Sci Technol 36: 3706-3710.

Andersen ME, KH Kirkland, TL Guidotti, and C Rose. 2006. A case study of tire crumb use on playgrounds: risk analysis and communication when major clinical knowledge gaps exits. Environ Health Persp 114(1): 1-3.

Birkholz D, K Belton, and T Guidotti. 2003. Toxicological evaluation for the hazard assessment of tire crumb for use in public playgrounds. J Air Waste Manag Asoc 53: 903-907.

Brown D. 2007. Exposures to recycled tire rubber crumbs used on synthetic turf fields, playgrounds and as gardening mulch. Report prepared by Environment and Human Health Inc. http://www.ehhi.org/reports/turf/turf_report07.pdf

Mattina MI, M Isleyen, W Berger, and S Ozdemir. 2007. Examination of crumb rubber produced from recycled tires. The Connecticut Agricultural Experiment Station. Report AC005. http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/examinationofcrumbrubberac005.pdf

Norwegian Institute of Public Health and the Radium Hospital. Artificial turf pitches — an assessment of the health risks for football players. January 2006. http://www.isss.de/conferences/Dresden%202006/Technical/FHI%20Engelsk.pdf

Office of Environmental Health Hazard Assessment. 2007. Evaluation of health effects of recycled waste tires in playground and track products. Contractors report to the California Integrated Waste Management Board. http://www.ciwmb.ca.gov/Publications/Tires/62206013.pdf

Articles on costs

Brakeman, L. 2005. *Natural turf or synthetic turf: The numbers game.* Athletic Turf. March 21, 2005. (Synopsis with tables from "Natural vs. Synthetic Fields: Comparing the Costs" by AJ Powell, University of Kentucky, presented at the 16th Annual STMA Conference, Phoenix AZ, January 2005.)

Brakeman, L. 2005. *Experts spell out the true cost of synthetic turf maintenance.* Athletic Turf. May 24, 2005.

Means, M. 2005. *Artificial turf has hidden costs, MU researcher warns.* Columbia Daily tribune, Columbia Missouri, December 7, 2005.

Articles on injuries

Seppa, N. 2005. *Football abrasions can lead to nasty infections.* Science News 167(6): 85-86.

Hitti, M. 2004. *Turf burns may spread dangerous infection.* WebMD Medical News.

Meyers, MC and BS Barnhill. 2004. *Incidence, causes and severity of high school football inuries on FieldTurf versus natural grass.* American Journal of Sports Medicine 32(7):1626-1638.

3.0 Product composition

Information on the materials used in artificial turf was obtained from several manufacturer websites, interviews with manufacturer representatives, and additional information supplied by manufacturers after the interviews. While all of the products utilize similar materials, there are differences between which materials are selected for particular products, the amounts used per unit of surface area, and the sourcing of the materials. The sections that follow give a capsule description of each turf system, followed by a summary comparison in Table 3.0.

3.0.1 FieldTurf™(www.fieldturf.com)

The FieldTurf system is illustrated schematically in Figure 3.0. The fibers in this system are made of virgin polyethylene. The backing material is made of polyurethane without a pad underneath. The infill consists of three parts: virgin silica sand, pelletized rubber made from automobile tires (cryo-rubber), and processed waste material from athletic shoes (Nike Grind). According to the company, the Nike Grind was originally produced from used athletic shoes, but now the source is manufacturing waste materials (Gill 2006). The company claims that their special infill, with sand and rubber in similar size particles, provides stability, long life resiliency, and proper playing characteristics.

3.0.2 SprinTurf™(www.sprinturf.com)

SprinTurf makes three versions of their synthetic turf, all with the same materials but in different quantities.[*] In order of decreasing weight, the three brands are SprinTurf Ultrablade, SprinTurf XPS, and SprinTurf MP. The blade material is polyethylene. There

[*] Note: The information in this paragraph was obtained from the SprinTurf website in 2006. The samples we received for testing were identified as Ultrablade, Ultrablade M, and Ultrablade DF. In addition, a new rubber-coated sand infill is now available as an alternative to the all-rubber infill.

are two backings, the primary being a triple layered material of woven and non-woven fabrics called Stabilon™ (composition?) and secondary backing of polyurethane. The infill material is 100% rubber, sourced from whole processed tires, then cleaned, recompressed, and granulated. The rubber granules (50% passing ASTM E-11 sieve number 16) are said to be much larger than sand granules. For warmer climates, a light colored rubber called CoolFill™is available to reduce surface temperatures of the playing field.

3.0.3 Sofsport™ (www.usaturf.com/hummerturf/ss_general_info.cfm)
Sofsport is a product of Hummer Sports Surfaces. It features blades made from polyethylene and a dual backing of polypropylene and polyurethane. There is also a base pad of 10 mm porous rubber. The infill is 80% coarse rounded sand on top of 20% crumb rubber.

3.0.4 SmartGrass™ (www.foreverfields.com)
SmartGrass is a product of Forever Green Athletic Fields, Inc. It features polyethylene grass blades, 100% cryogenic rubber infill, and a polyurethane backing.

3.0.5. ProGreen™ (www.betterthangrass.com)
ProGreen artificial turf is made of polyethylene with a cryo-rubber infill.

3.0.6 Sportexe™ (www.sportexe.com)
Sportexe produces four different artificial turf systems, all of which can be used for either soccer or football, as well as other sports. SportBlade™, the top of the line product, features polyethylene grass fibers, a rubber/sand infill, and a four-layer backing. Omnigrass™ is similar but with a 100% rubber infill material. FastGrass™ incorporates nylon fibers and a SBR rubber infill with a two-layer backing. Finally, VictoryTurf™ utilizes a polyethylene fiber with a nylon “SpikeZone” to reduce movement of the SBR rubber infill.

3.0.7 AstroTurf™ (www.astroturf.com)
The originator of artificial turf is still in the game today, with a variety of products including both infill and traditional types. AstroPlay™ is a polyethylene fiber with rubber infill over a “paved” or foam pad. AstroGrass™ and PureGrass™ are both nylon fiber products that can be used either with or without an infill. AstroGrass is available with a sand infill, while PureGrass can be infilled with either SBR rubber or EPDM rubber.

3.0.8 SafePlay™ (www.safeplayturf.com)
SafePlay International offers two artificial turf surfaces of polyethylene fibers infilled with recycled SBR rubber. SafePlay Plus is a heavier product (50 oz/yd with 4 lb infill/sq ft), while SafePlay Select II is 40 oz/sq yd and 3.3 lb/sq ft. A third turf system, SafePlay 2012, is not infilled.

3.0.9 A-Turf™ (www.aturf.com)
A-Turf offers two infilled polyethylene turf systems, each in a variety of weights. Premier-RS is infilled with SBR rubber and silica sand, while SportFlex-R has only SBR rubber as infill.

3.0.10 ProPlay™ (www.armsbm.com)
ProPlay is the product of ARMS Building & Maintenance, Inc. The product is available in several grades, made of polyethylene fibers with an infill material of unknown composition resting on a polyethylene foam base.

3.0.11 24/7 Artificial Field Turf (www.themotzgroup.com)
The Motz Group offers both natural and artificial turf surfaces, as well as a product that combines the two. The infilled synthetic turf system is 24/7 Artificial Field Turf, a product featuring polyethylene fibers with a choice of either a sand/rubber blend infill or a single component rubber infill. A rubber shock pad is optional.

3.0.12 GameDay™ (www.generalsportsturf.com)
General Sports Turf Systems offers its GameDay synthetic turf system in three versions: MP, HD, and XPe. All are manufactured with polyethylene yarn and are available with an infill of either 100% SBR rubber or rubber plus up to 10% DiaFill, described as "a naturally occurring siliceous sedimentary mineral compound."

Table 3.1 Composition of selected artificial turf products

Company	**Brands**	**Fiber Material**	**Infill Material**	**Backing Material**
FieldTurf	FieldTurf	polyethylene (PE)	silica sand cryo-rubber (3lb/sq ft) Nike Grind	polyurethane (PU)
SprinTurf	Ultrablade XPS MP	PE (44 oz/sq yd) PE (40 oz/sq yd) PE (36 oz/sq yd)	rubber or FlexSand rubber-coated silica sand	Stabilon (10oz/sq yd) PU (28 oz/sq yd) Stabilon (10oz/sq yd) PU (20 ox/sq yd) Stabilon (10oz/sq yd) PU (20 ox/sq yd)
Sofsport	Sofsport	PE (40 oz/sq yd) total wt 70 oz/sq yd	rubber (1.5 lb/sq ft) sand (3.5 lb/sq ft)	polypropylene (2 layer) PU (18-20 oz/sq yd) rubber pad (recycled content?) 10 mm
Forever Green	SmartGrass 5020 XPS 4020L	polyethylene 80 oz/sq yd total wt 70 oz/sq yd total wt	cryo-rubber	Fibrolock™ polyurethane
ProGreen	ProGreen	polyethylene	cryo-rubber	
Sportexe	SportBlade Omnigrass FastGrass VictoryTurf	polyethylene polyethylene nylon Thiolon XPL	50%rubber/50% sand 100% ground rubber SBR rubber SBR rubber	4-layer backing (???) 4-layer backing 2-layer backing 2-layer backing

		polyethylene/nylon		
AstroTurf	AstroPlay AstroGrass PureGrass	polyethylene nylon nylon	rubber no infill or sand infill no infill, SBR rubber, or EPDM rubber	"paved" or foam pad "closed cell" or foam "paved" or foam pad
SafePlay	SafePlay Plus SafePlay Select II	PE (50 oz/sq yd) PE (40 oz/yd)	recycled SBR rubber (4lb/sq ft) with DuraBond additives recycled SBR rubber (3.3lb/sq ft) with DuraBond additives	Tribond (10.66 oz/yd) Urethane (24-36 oz/yd) Tribond (10.66 oz/yd) Urethane (24-36 oz/yd)
A-Turf	Premier-RS SportFlex-R	PE (40-50 oz/sq yd) PE (40-50 oz/sq yd)	SBR rubber, silica sand SBR rubber	polypropylene, polyester, fiber, urethane polypropylene, polyester, fiber, urethane
ARMS Building & Maintenance	ProPlay	polyethylene	EnviroFill coated silica sand	polyethylene foam
The Motz Group	24/7 Artificial Field Turf (PE/nylon turf for landscape ue)	polyethylene (Thiolon XPS, 41 oz)	coarse sand/rubber or just rubber	granulated rubber (optional)
General Sports Turf	GameDay MP, HD, or XPe	polyethylene	100% SBR rubber or rubber + <10% DiaFill	3-part woven backing + urethane (26 oz0

3.1 Recycled content

None of the companies surveyed uses recycled materials for either the grass blades or the backing materials. The rubber infill material used in some of the systems is processed from used tires, but even though this material is often referred to as "recycled," in reality it is "downcycled" because it will not be remade into tires again. The Nike Grind material used in FieldTurf infill is also downcycled and is not currently being made from post-consumer waste.

4.0 Ingredients of concern

As detailed above, the principal constituents of synthetic turf products can include polyethylene, polypropylene, rubber, silica sand, nylon, urethane, and various adhesives. These are the bulk materials, but most of them can contain various additives that may or may not be problematic. Rubber, for example typically contains at least several percent zinc, around 20% naphthenic/aromatic oil, and various other compounds.[5] Plastics may contain brominated flame retardants,[6] and PVC vinyl may contain a host of plasticizers and stabilizers such as lead[7] and phthalates.[7,8] (Note that although the vinyl industry states that lead is now principally in vinyl wire and cable insulation,[9] recent warnings about lead in vinyl miniblinds,[10] lunch boxes,[11] and baby bibs[12] demonstrate that the use is more widespread.) We reviewed the literature sources listed earlier for discussion on particular components of concern in synthetic turf or rubber tires. We also used a portable X-ray spectrometer to screen selected samples for bromine, lead, and zinc. As described in the accompanying report on this X-ray testing, because the materials tested are not homogeneous in nature, the reported concentrations should not be taken as quantitatively definite, but only as qualitative screening values.

Most of the toxicological assessments on turf components have centered on the crumb rubber that is used as infill in most of these products. A number of analyses have been published that detected potentially toxic metals or organic compounds in the air or in leachate from recycled rubber. Mattina et al.[13] detected four prominent compounds off-gassed from tire crumbs at 60 °C: benzothiazole, butylated hyroxyanisole, n-hexadecane, and 4-(t-octyl) phenol. The same four compounds were seen in different relative amounts in leachate from tire crumbs soaked in water for seven weeks. Zinc was also prominent in leachate, while selenium, lead, and cadmium were detected at much lower concentrations. The Norwegian Institute for Water Research reported zinc, 16 PAHs, 8 phthalates, and three alkylphenols in leachate from artificial turf fiber and rubber granules.[14] The California Office of Environmental Health Hazard Assessment (OEHHA) reviewed 49 chemicals identified in laboratory or field studies where recycled tires were used.[15] The Norwegian Institute of Public Health and the Radium Hospital (NIPH) also evaluated a large number of chemicals.[16] Using different assumptions and methodologies, neither the OEHHA nor the NIPH studies found significant human health concerns related to recycled rubber use on sports fields or playgrounds. However, both studies suffer from a lack of complete toxicology information for the chemicals considered, and both tend to use a chemical by chemical approach that ignores potential additive or synergistic effects. Both reports studied only the single application of rubber under investigation, ignoring other types of exposures. A recent report from the non-profit Human Health and Environment, Inc. reviewed the current literature, including the two just-mentioned studies, and recommended, among other things, that there be a moratorium on installing any new fields or playgrounds using ground-up rubber tires until additional research is undertaken.[17]

4.1 Zinc

Zinc has relatively low human toxicity but is fairly toxic to aquatic life. Concerns have been raised about the possible leaching of zinc from rubber infill or pad material.[18] Given the high zinc content of rubber, this is certainly a concern, but evaluation of the risks must be done under realistic conditions. For example, Humphrey and Katz[19] found virtually undetectable concentrations of metals and organic compounds in wells at least 0.6 meters downgradient from tire shards buried in trenches either above or below the water table, although some concentrations were detectable in the trenches themselves. Tire shards are much larger than the rubber pellets used in synthetic turf infill and have correspondingly much lower surface area per unit of volume or weight, thus reducing leaching proportionally. The experimental geometry is very different from turf fields.

More relevant is the Norwegian study[14] in which measured concentrations of zinc, PAHs, phthalates, and alkylphenols in leachate from synthetic turf fibres and rubber granules were used to calculate predicted environmental concentrations (PECs) from a hypothetical turf pitch of 7200 square meters and annual precipitation of 800 mm (31.5 inches). These PECs were compared to estimated Predicted No Effect Concentrations (PNECs), which represent the highest concentration that does not result in harm to the environment. PNEC values for water and sediment were taken from EU risk assessment documents for the chemicals of interest. The analysis assumes that leachate from the turf pitch drains into a small stream with a dilution factor of 10. The risk quotient PEC/PNEC was highest for zinc of all the substances evaluated, with values of 40 for water and 341 for sediment. These numbers indicate a potential concern that the authors characterize as follows: “The risk assessment shows that the concentration of zinc poses a significant local risk of environmental effects in surface water which receives runoff from artificial turf pitches.”

In our X-ray analysis, we found zinc content of 6.8%, 9.3%, and 4-7% in three of four brands of infill material tested. One brand (ARMS ProPlay infill), which was not a rubber-based material, contained no measurable zinc.

4.2 PAHs

Ruber tires contain a considerable amount of PAHs in the form of softener oils, typically in the range of about 20%, although some new tires are now being made with aromatic-free oils. Many PAHs are carcinogenic and are toxic to aquatic organisms. Stephenson et al.[20] submerged whole tires, but with and without highly aromatic (HA) oils, in fish tanks containing juvenile rainbow trout. They searched for sublethal rather than lethal effects. A range of biochemical disturbances were seen in fish from both exposed groups, indicating metabolism of PAHs and “responses indicating oxidative stress symptoms and other metabolic disturbances in fish exposed to rubber tires.” The effects were generally greater for the fish exposed to HA oil leached from tires, but some effects were also seen in the exposed group. The authors do not speculate on what adverse effects these biochemical changes might cause over time.

The Norwegian environmental risk assessment referred to above[14] did not find risk quotients >1 for any of the individual PAHs investigated, but the sum PEC/PNEC for 16 PAHs was 1.132 in water, dominated by contributions from fluoranthene (0.551) and pyrene (0.493).

Wik and Dave[21] exposed Daphnia magna to water containing ground up rubber from car tires at different dilutions in order to measure EC50 (immobility) toxicity levels. They also exposed surviving (mobile) daphnids to a 2 hour UV exposure in the leachate. Some PAHs, including fluoranthene and pyrene, exhibit phototoxicity, in which the compounds become more toxic after exposure to UV light exites the compounds to a more toxic state. EC50 at 24 hours ranged from 0.29 to 32 g/L; EC50 at 48 hours ranged from 0.125 to 2.41 g/L, indicating a toxicity increase for various tire samples that ranged from 2.2 to 18.7 times at the longer exposure. After the UV treatment the toxicity of about have the tire samples remained the same, but the other half increased by factors ranging from 1.2 up to 38.6.

On the human health side, the OEHHA risk assessment[15] did not find significant non-cancer risks from rubber playground fill, but did calculate a risk of 2.9 per million (nearly three times the standard *de minimus* risk level) for chronic hand-to-mouth ingestion of chrysene, the only carcinogen detected in wipe samples taken from the rubber. The analysis assumed daily use of a playground from age 1 to 12 as the lifetime exposure period. Direct oral exposure to carcinogens was assumed to occur only via a single event. Inhalation exposure was not considered.

4.3 Lead

We did not see any literature indicating that lead would be found in synthetic turf materials. Lead is sometimes added to PVC vinyl, but vinyl was not said to be a component in any of these systems (except possibly in draining pipes). However, when we tested the samples with the X-ray fluorescence spectrometer, we did find lead in some products even though our testing confirmed that they were not made of PVC. The highest levels (1950 and 1990 ppm) were found in two separate tests of the Motz 24/7 PE/nylon turf. The ARMS ProPlay pad backing gave results of 534 and 692 ppm in two tests. Several other tests indicated the presence of lead but at levels below 100 ppm.

The toxicological significance of lead in these materials is unknown. Levels below about 100 ppm are comparable to those often seen in urban soil and probably do not pose an increase in human health risk over that posed by natural turf. The bioavailability of lead in these materials is unknown, and some of the turf components would not be in direct contact with athletes using the surfaces. Of most concern to us was the one sample that showed nearly 2000 ppm. Again, while the bioavailability is an open question, one must also ask why the use of lead would be needed in such a product. No threshold for adverse effects from lead in young children has been demonstrated,[22] and blood lead levels below the current 10 ug/dl action level have been associated with loss of mental capacity.[23] It has been argued that no level of exposure to lead is safe.[24]

4.4 Bromine

Because we found no literature on bromine in synthetic turf nor any mention of it in manufacturer literature, we decided to use the X-ray spectrometer to test samples. The portable XRF analyzer is a quick, non-destructive method to test for a variety of elements, including bromine, in many kinds of products. Our testing indicated no detectable bromine in any of the pure turf materials. We did find some bromine in some infill and pad samples, however. The ARMS ProPlay pad gave different readings depending on exactly where we aimed the X-ray beam. The pad itself is an aggregate material made up of several distinctly different materials, with a separate backing. Test results ranged from 994 to 4340 ppm bromine. Manufacturer literature admits that less than 1% of a flame retardant is present in this material. Lower levels (all less than 100 ppm) were found in the infill. No bromine was detected in the infill from ARMS, which is reported to be a silica rather than rubber product. On the basis of this limited testing, it does not appear likely that manufacturers of turf systems are deliberately adding brominated flame retardants to their products. However, the fact that we did find some scattered detections of bromine (and one rather high one), SFE could state absence of bromine as a selection criterion.

5.0 Lifecycle greenhouse gas assessment

Although we did not identify any other studies that have attempted a full-cost analysis of synthetic turf, we did find one study that compared the global warming implications of the lifecycles of synthetic and natural turf.[25] That study found a natural turf field to have a net negative carbon footprint (-16.9 tons $C0_2$ equivalent over ten years) due mainly to the carbon sequestration potential of the grass itself. The modeled synthetic turf field, on the other hand, emitted +55.6 tons of CO_2 equivalent over ten years. This figure would have been almost twice as high (108.2 tons CO_2) if the authors had not assumed that the field would be recycled at the end of life (which gave a carbon credit of 52.6 tons CO_2 equivalent). Recycling of synthetic turf is theoretically possible but apparently beyond the state of the art at the current time due to difficulties separating the various components. Assuming that the field is eventually recycled, its greenhouse gas emissions (GHG) relative to those of natural turf (which are negative) could be offset over ten years by planting 1861 trees according to the analysis. If the field lifecycle had not received the recycling credit, the required offset would increase to 3209 trees.

The description of the field modeled in the Athena Institute study includes a polyethyene turf yarn, Thioback Pro primary backing material (a blend of fiberglass, polypropylene/polyester layer and a fiber fleece layer), polyurethane secondary backing, “recycled” rubber granule infill, and PVC drainage piping. We cannot determine from the available information exactly how closely the modeled field matches each of the specific turf systems described above, but in general the components seem generally similar. The largest modeled GHG emissions arise from the production of polyethyene and polyurethane, components that are shared by virtually all of the turf systems. A considerably smaller GHG emission is modeled for the rubber granules, used by most but not all of the turf systems. Transport impacts could vary somewhat depending on the sourcing of raw materials. Although there would certainly be some variation in the actual GHG emissions for the lifecycles of the various synthetic turf products, it seems unlikely that the overall conclusions of the study would be materially different for any specific product brands.

6.0 Conclusions and recommendations

The analysis we did falls far short of what was originally envisioned before the scope was curtailed. We did not look at specific field maintenance practices for either natural or synethetic turf surfaces in San Francisco, nor did we attempt to monetize the various impacts to a common set of units to allow comparisons. On the other hand, we did read the literature retrieved from our search and did test selected products for bromine, lead, and zinc.

Our work leads us to the following recommendations:

1. If the greenhouse gas emissions study is correct and broadly applicable synthetic turf, it strongly suggests that, unless the greenhouse gas emissions can be offset, the use of synthetic turf should be minimized and confined to the sites where its other benefits are maximized. It should not become the default standard surface for playfields.

2. When synthetic turf is purchased, SFE should continue to request full ingredients disclosure from manufacturers. Particular elements of concern that should be asked about include lead, bromine, and zinc. SFE should also inquire about the availability of alternatives to PVC pipe for field drainage when these products are installed.

3. SFE should stay abreast of developments regarding eventual recycling of synthetic turf fields as currently installed products come to the end of their useful life. If manufacturers begin to recycle their fields, SFE should investigate to be certain these claims can be verified and, if so, end of life field management could become an important selection criterion.

4. It would still be worthwhile to have SFE staff or an intern interview playfield managers to assess and compare potential impacts resulting from specific maintenance activities, such as pesticide use, gasoline consumption, etc. Even without a full cost comparison, it might be possible to identify ways to reduce the impacts of field maintenance for both natural turf and synthetic turf fields.

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