References and Resources for Turf Field Evaluation

WHS Athletic Improvements Stadium Complex

Wayland School Committee
Spring 2018

EPA Reference Guide

Federal Research on Recycled Tire Crumb Used on Playing Fields (FRAP)

https://www.epa.gov/chemical-research/federal-research-recycled-tire-crumb-used-playing-fields
In February 2016, the EPA launched a multi-agency effort called the Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds (FRAP) to study key environmental and human health questions.

See FRAP Link.

FRAP Status Report

https://www.epa.gov/sites/production/files/201612/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf
In December 2016, the agencies released a 169-page Status Report. This report provides a summary of activities to date, including the final peer-reviewed Literature Review/Gaps Analysis (LRGA). The LRGA was developed to provide a current summary of the available literature and capture the data gaps as characterized in those publications. The status report does not include any preliminary findings of the research.

See Status Report Link. See attached *Status Report Table of Contents and Executive Summary.*

FRAP Literature Review

Summary Spreadsheet of Literature Review/Gaps Analysis
A summary spreadsheet provides a listing of the scientific literature references included in the Literature Review and Gap Analysis Status Report and a brief description of each of the study's results.

See attached *EPA Literature Review Summary of Tire Crumb Rubber Studies #* 1-97
See attached *Appendix E – List of Literature Reviewed*

FRAP Status Report: State-of-the-Science Literature Review and Gap Analysis (LRGA). White Paper Summary of Results. Appendix B (See pp 39-91 FRAP Status Report link above)

Each of the 90 references identified in the analysis was reviewed and categorized. The objectives of the LRGA were to:

1) Identify the existing body of literature related to human exposure to tire crumb rubber through the use of synthetic turf athletic fields and playgrounds/
2) Characterize and summarize the relevant data from the scientific literature;
3) Review the summary information and identify data gaps
4) Build on the current understanding of the state of the science and inform the development of specific research efforts.

See attached *Appendix B – State of the Science Literature Review/Gaps Analysis Executive Summary.*

FRAP Data Gap Analysis

Table B-1 (pp 43-44 of the FRAP Status Report link above)
The table summarizes the important data gaps that remain in the characterization of tire crumb rubber material used in synthetic turf fields and playgrounds, assessing exposures for users of these fields and playgrounds, human and ecological risk assessment, and in health impact assessments.
See attached *Table B-1. Data Gaps for Research on Tire Crumb Rubber in Synthetic Fields and Playgrounds pp 43-44.*

FRAP Additional References

Center of Disease Control. CDC Review of 23 studies included in the Literature Review & Gap Analysis. Appendix B (pp 92-104 of the FRAP Status Report link above)

See attached *Appendix A – CDC Review of Published Literature and Select Federal Studies on Crumb Rubber and Synthetic Turf pp 92-104.*

Environmental Protection Agency. EPA Summary Reports of federal/state government studies included in the Literature Review and Gap Analysis. Appendix B (pp 107-110 of the FRAP Status Report).

See Attached *Appendix C – EPA-NCEA Summary of Available Exposure and health Risk Assessment Studies on Artificial Turf, Playgrounds and Tire Crumbs pp 107-110.*

Other Reports and References

Commonwealth of Massachusetts. Office of Health and Human Services, Department of Public Heath and Bureau of Environmental Health. Frequently Asked Questions: Artificial Turf Fields.
http://www.mass.gov/eohhs/docs/dph/environmental/exposure/faq-artificial-turf-0615.pdf
See attached.

Gale Associates Inc. (2015). Alternative Infills for Synthetic Turf.
http://www.galeasssociates.org/wp-content/uploads/2015/03/Alternative-Infills-for-Synthetic-Turf.pdf.
See attached.

UMass Lowell Toxics Use Reduction Institute (TURI). Fact Sheet.
Athletic Playing Fields and Artificial Turf: Considerations for Municipalities and Institutions.
https://www.turi.org/content/download/10990/179677/file/Turf%20Fact%20Sheet%20June%202016.pdf
Reference provided by Tom Sciacca.

Environment and Human Health, Inc (EHHI). Synthetic Turf Report.
http://www.ehhi.org/NewTurf_Final.pdf
EHHI reviewed 22 of the studies from the FRAP Literature Review (cited above) in its 112-page report, *Synthetic Turf: Industry's Claims Versus the Science. A Careful Analysis of Studies that Industry Uses to Justify Safety Claims.*

Reference provided by Tom Sciacca.

Grass Roots Environmental Education. Synthetic Turf.
http://grassrootsinfo.org/pdf/syntheticturfscience.pdf
Independent Science on Public Health Concerns Regarding Synthetic Turf. Citations with links of studies related to Crumb Rubber Chemicals, Bioaccessibility, Heat Effects, Injuries, Flame Retardants, Disinfectants and Sanitizers.

Reference provided by Tom Sciacca.

Delaware Riverkeeper Network. Alternative Infills for Artificial Turf Fact Sheet.
http://www.synturf.org/images/DRK3_Artificial_Turf_Alternative_Infill_Fact_Sheet_10.18.16_0.pdf
Reference provided by Tom Sciacca.

Big Sky Conference (2013). Determination of Microbial Populations in a Synthetic Turf System.
https://skyline.bigskyconf.com/cgi/viewcontent.cgi?referer=http://www.synturf.org/staphnews.html&httpsredir=1&article=1000&context=journal
Reference provided by Tom Sciacca.

EPA Reference Guide
Federal Research on Recycled Tire Crumb Used on Playing Fields (FRAP)

https://www.epa.gov/chemical-research/federal-research-recycled-tire-crumb-used-playing-fields

We've made some changes to EPA.gov. If the information you are looking for is not here, you may be able to find it on the EPA Web Archive or the January 19, 2017 Web Snapshot.

EPA United States Environmental Protection Agency

Federal Research on Recycled Tire Crumb Used on Playing Fields

Background

Concerns have been raised by the public about the safety of recycled rubber tire crumb used in synthetic turf fields and playgrounds in the United States. We know people are concerned and players and their families want answers. 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. We are committed to supporting more comprehensive efforts to assess risks from tire crumb.

That's why on February 12, 2016, the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (ATSDR), and the Consumer Product Safety Commission (CPSC) launched a multi-agency **Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds** to study key environmental and human health questions.

Federal Research

This coordinated *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds* includes outreach to key stakeholders, such as athletes and parents, and seeks to:

- Fill important data and knowledge gaps.

Public and Stakeholder Engagement

- 2017 International Society of Exposure Science Tire Crumb Study Presentations
- 2017 Federal Register Notice: Public Comment and Federal Responses
- 30-day Federal Register Notice: Comment on Information Collection Request for

- Characterize constituents of recycled tire crumb.
- Identify ways in which people may be exposed to tire crumb based on their activities on the fields.

The study has four parts:

- Literature Review/Gap Analysis (EPA and CDC/ATSDR)
- Tire Crumb Characterization (EPA and CDC/ATSDR)
- Exposure Characterization Study (EPA and CDC/ATSDR)
- Playground Study (Consumer Product Safety Commission)

Status

The collection of samples for the exposure and tire crumb characterization parts of the study are now complete. EPA and CDC/ATSDR are in the process of analyzing samples and drafting the report.

For the tire crumb characterization part of the study, tire crumb samples were gathered from tire crumb manufacturing/recycling plants and from indoor and outdoor fields across the country. Samples were gathered from nine tire crumb manufacturing/recycling plants and 40 fields.

For the exposure characterization part of the study, on August 2, 2017, the Office of Management and Budget (OMB) approved the Information Collection Request for the continuation of the exposure characterization study. With the OMB approval, the EPA and CDC/ATSDR team were able to complete the field work associated with the exposure characterization in the Fall of 2017. During the exposure characterization field work, EPA and CDC/ATSDR visited several fields to collect exposure information to better characterize people's exposure to tire crumbs. Activity information from field users who elected to participate in the study was also gathered.

Prior to the August 2017 OMB approval, the exposure characterization portion of the study as outlined in the Federal Research Action Plan was posted for public comment in February 2017. An additional requirement of a 30-day Federal Register Notice, along with the Information Collection Request package was published on June 12, 2017 .

On December 30, 2016, the agencies released a status report describing the progress of the research to date. The status report includes the final peer-reviewed Literature Review/Gaps Analysis report and describes the progress to date on other research activities that are part of the effort including: Characterization of the chemicals found in tire crumb; Characterization of the exposure scenarios for those who use turf fields containing tire crumb; Study to better understand how children use playgrounds containing tire crumb and; Outreach to key stakeholders. The status report does not include research findings. (See sidebar for links to the Federal Register Notices and 2016 Status Report).

Characterizatio of Exposure Potential during Activities Conducted on Synthetic Turf with Crumb Rubber Infill - Closed on July 12, 2017

- 60-day Federal Register Notice: Comment on proposed and/or continuing sample collections - Closed April 11, 2017
- 2016 Federal Register Notice: Public Comment and Federal Responses
- April 2016 Webinar Recording: Overview of the Federal Research Action Plan

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. The study will provide a better understanding of potential exposures that athletes and others may experience and will help answer some of the key questions that have been raised.

Timeline

The draft report will be sent to external peer-review in Spring 2018, with the expectation of releasing a final peer-reviewed report summarizing study results in mid-2018.

Existing Research and Information

Other federal, state, and local government agencies have conducted limited studies on artificial turf fields. For example, from 2009-2011, New York City and the states of New York, Connecticut and New Jersey conducted studies on tire crumb infill and synthetic turf.

Also, in 2008 and 2009 the Consumer Product Safety Commission and the Agency for Toxic Substances and Disease Registry evaluated synthetic turf "grass blades" in response to concerns about lead exposure. Their evaluations estimated that any potential releases of toxic chemicals from the grass blades, such as lead, would be below levels of concern. In 2008, EPA conducted a limited Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds. The purpose of the limited study was to test a method for measuring possible emissions from using synthetic turf on playgrounds and ball fields, not to determine the potential health risks of recycled tire crumb in playgrounds or in synthetic turf athletic fields.

Study Documents

- December 2016 Status Report: Federal Research Action Plan on Recycled Tire Crumb
- Research Protocol and Study Design
- Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds
- 2008 EPA Limited Scoping Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds

Related Links

- Tire Crumb Questions and Answers
- Government Organization Websites Related to the Use of Tire Crumb on Fields and Playgrounds

LAST UPDATED ON FEBRUARY 8, 2018

Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds

Background

Concerns have been raised by the public about the safety of recycled tire crumb used in playing fields and playgrounds in the United States. 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.

Federal Research

Because of the need for additional information, the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (ATSDR), and the U.S. Consumer Product Safety Commission (CPSC) are launching a multi-agency action plan to study key environmental human health questions. This coordinated federal action includes outreach to key stakeholders, such as athletes and parents, and seeks to fill important data and knowledge gaps, characterize constituents of recycled tire crumb, and identify ways in which people may be exposed to tire crumb based on their activities on the fields. The Federal Research Action Plan includes numerous activities, including research studies. While additional research questions may require evaluation beyond this year, the information will help answer some of the key questions that have been raised.

Objectives

The specific objectives of this research effort are to:

- Determine key knowledge gaps.
- Identify and characterize chemical compounds found in tire crumb used in artificial turf fields and playgrounds.
- Characterize exposures, or how people are exposed to these chemical compounds based on their activities on the fields.
- Identify follow-up activities that could be conducted to provide additional insights about potential risks.

Research Summary

Conduct Data and Knowledge Gap Analysis: The Agencies will evaluate the existing scientific information related to recycled tire crumb used in artificial turf fields and other types of playing fields to build on current understanding of the state-of-the-science and inform the research activities.

Outreach to Key Stakeholders, Including Parents and State Agencies: EPA, ATSDR, and CPSC will convene discussions with members of the public and organizations with an interest in studying tire crumb. These parties have ongoing tire crumb studies or can provide expertise to inform the federal study. The agencies will meet with:

- ***Athletes, parents, and coaches*** to get first-hand perspectives on potential exposures.

- ***Government agencies*** to discuss the federal research, share relevant information from state-level studies, request support, and identify current best practices for minimizing exposures. One important state partner is California. California's Office of Environmental Health Hazard Assessment has an in-depth tire crumb study underway. This study includes a series of scientific studies to determine if chemicals in tire crumb can potentially be released under various environmental conditions and what, if any, exposures or health risks these potential releases may pose to players who frequently play on artificial fields constructed with tire crumb. The evaluation includes expert solicitation and stakeholder participation to help guide the design and EPA and other federal agencies are actively engaged in that process.
- ***Industry representatives*** to better understand the manufacturing process and use parameters for recycled tire crumb used in artificial turf and for recycled tire-derived playground surface materials.

Testing of Tire Crumb to Characterize Chemicals, Potential Emissions, and Toxicity: The agencies will test different types of tire crumb. These tests – along with existing scientific information from the literature – will help us better understand the tire crumb materials. For example, this will help the scientists working on this effort to understand chemicals that are found in tire crumb and might be emitted from the material. It will also help us understand if chemicals can be released from tire crumb when a person comes into contact with them – for example, when tire crumb comes in contact with sweat on the skin or are accidentally ingested by athletes playing on turf fields. Once we better understand what chemicals are in tire crumb, we will also be able to search existing databases of information to understand the potential health effects of those chemicals. Some examples of research activities are listed below.

- Based on information obtained through the efforts described above, evaluate various manufacturing process (for example, the tire crumb manufacturing process and the tire-derived playground surface materials manufacturing process), including an analysis of the diversity of these processes, material blends, components of the material (metals, volatile and semi-volatiles, particulate matter).
- Conduct laboratory analyses to characterize components of the chemicals in newer and older (aged) tire crumb materials at different temperatures.
- Determine the rate at which tire crumb components are absorbed by the body using simulations of biological processes in the lab, for example simulations of activities in the stomach as well as salivating and sweating.
- Evaluate potential cancer and non-cancer toxicity of key tire crumb constituents based on existing databases of information.

Launch Pilot-Scale Study to Characterize Exposure Under Use Conditions: The agencies will conduct several activities to better understand potential exposures that may occur when individuals frequently use artificial turf fields. Scientists will identify various exposure scenarios (ways in which people may be exposed based on their activities on the fields) and then design and conduct a pilot-scale exposure study to characterize people's exposures on these fields. This work will consider possible ways that one may be exposed – including by breathing, accidentally ingesting, or physical contact with tire crumb. Some examples of research activities are listed below.

- Develop exposure scenarios, paying particular attention to high-end exposure scenarios.
- Identify activity patterns for athletes and other relevant populations.
    - Estimate nature, duration, and frequency of exposures.
    - Evaluate other relevant factors, such as the standard operation and maintenance of the fields (e.g., replacement of materials, use of biocides) and how the materials change over time.
- Design and conduct pilot-scale exposure study to characterize exposures on select playing fields, considering all relevant routes of exposure (inhalation, dermal, oral).

- Develop methods, as necessary, for measuring exposure to both targeted and non-targeted analytes.

Public Comment Opportunities: Some studies that are part of this research plan are posted for public comment through a Federal Register Notice (available at Regulation.Gov, search by docket number Docket No. ATSDR–2016–0002). For example, one study that is part of the Federal Register Notice will gather data from facilities with fields that contain tire crumb materials, and another study will gather activity data from persons who routinely perform activities on artificial turf fields with tire crumb. The number of fields that will be sampled as well as the number of field users who will be surveyed are described in the Federal Register Notice. We encourage you to review the Federal Register Notice and provide your comments.

Additional Research Activities: EPA, CDC/ATSDR, and CPSC have set an ambitious schedule for this effort in 2016. A number of additional activities may also be initiated during this time, depending upon further consideration of their value to the overall effort, their feasibility, the availability of resources, and other factors. Additional research could include identifying potential biomarkers of exposure, collecting preliminary biomonitoring data, analyzing samples of recycled tire crumb used on playground surfaces, and evaluating the feasibility of conducting an epidemiologic study. CPSC is exploring conducting a survey of parents to get first-hand perspectives on potential exposures from playground surface materials. As part of this coordinated effort, CPSC plans to conduct additional work on the safety of playgrounds.

Timeline and Deliverables

By the end of 2016, the agencies anticipate releasing a draft status report that describes the preliminary findings and conclusions of the research through that point in time. The draft status report will summarize the agencies' progress in: (1) Identifying key constituents of concern in recycled tire crumb used in artificial turf fields; (2) Assessing potential exposures to potentially harmful constituents; (3) Conducting an initial evaluation of potential cancer and non-cancer toxicity of key chemical constituents; and (4) Identifying follow-up activities that could be conducted to provide additional insights about potential risks. The results of the preliminary work on recycled tire-derived playground surface materials will also be described. The report will also outline any additional research needs and next steps.

More Information

Information and updates about this research will be posted to EPA's website – http://www.epa.gov/TireCrumb

EPA REFERENCE GUIDE

FRAP Status Report

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Executive Summary

See Link below to view 169 page FRAP Status Report

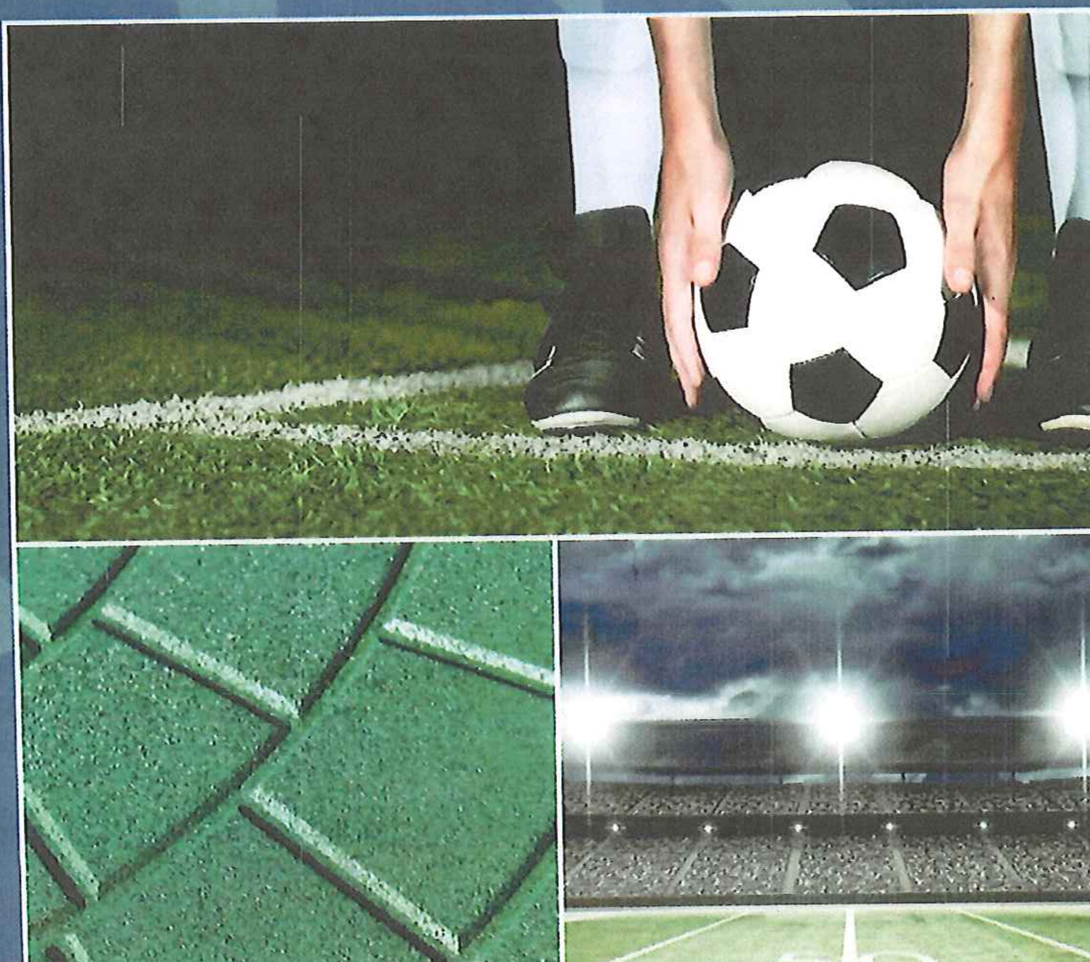
https://www.epa.gov/sites/production/files/201612/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf

EPA/600/R-16/364 | December 2016 | www.epa.gov

United States
Environmental Protection
Agency

Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds

STATUS REPORT



National Exposure Research Laboratory
Office of Research and Development

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I. Executive Summary

Over the past several years, parents, athletes, schools, and communities have raised concerns about the safety of recycled tire crumb rubber used as infill for playing fields and playgrounds in the United States. The public has expressed concerns that the use of these fields could potentially be related to certain health effects. Studies to date have not shown an elevated health risk from playing on fields with tire crumb rubber, but these studies have limitations and do not comprehensively evaluate the concerns about health risks from exposure to tire crumb rubber.

Synthetic turf field systems were initially introduced in the 1960s. Currently, there are between 12,000 and 13,000 synthetic turf recreational fields in the United States, with 1,200 – 1,500 new installations each year (STC et al., 2016). Synthetic turf fields are installed at municipal and county parks; schools, colleges and universities; professional team stadiums and practice fields; and military installations. Potentially millions of people are estimated to use these fields, including professional and college athletes, youth athletes in school or other athletic organizations, coaches, team and facility staff, referees, fans, bystanders and local communities.

On February 12, 2016, the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (CDC/ATSDR) and the U.S. Environmental Protection Agency (EPA)[4], in collaboration with the Consumer Product Safety Commission (CPSC)[5], released a *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds* (FRAP)[6]. The purpose of the FRAP is to study key questions concerning the potential for human exposure resulting from the use of tire crumb rubber in playing fields and playgrounds. This kind of information is important for any follow up evaluation of risk that might be performed.

The FRAP includes outreach to key stakeholders to obtain information to fill important data gaps, research to characterize constituents of tire crumb made from recycled tire rubber, studies to identify ways in which people may be exposed to tire crumb rubber based on their activities on the fields, and an analysis of existing scientific literature on the topic.

Prior to initiating the study, federal researchers developed a research protocol, *Collections Related to Synthetic Turf Fields with Crumb Rubber Infill*[7], which describes the study's objectives, research design, methods, data analysis techniques, and quality assurance/quality control measures in place to ensure the integrity of the following components of the research:

- literature review and data gaps analysis;
- tire crumb rubber characterization research;
- human exposure characterization research.

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[4] The specific roles of EPA and CDC/ATSDR are provided in the FRAP

[5] This report includes contributions written by the CPSC staff and has not been reviewed and/or approved by, and may not necessarily reflect the views of, the Commission.

[6] The FRAP is available through the Tire Crumb website: www.epa.gov/tirecrumb

[7] The research protocol is available through the Tire Crumb website: www.epa.gov/tirecrumb

The study protocol was reviewed by independent external peer reviewers, CDC's Institutional Review Board (IRB) and EPA's Human Subjects Research Review Official. The data collection components of the study went through the Office of Management and Budget's (OMB) Information Collection Request (ICR) review process. The OMB ICR process included a public comment period[8]. On August 5, 2016, EPA, CDC/ATSDR and CPSC received final approval from OMB to begin the research.

This status report provides a summary of the agencies' activities to-date, including:

- stakeholder outreach;
- tire and tire crumb rubber manufacturing process;
- final peer-reviewed Literature Review/Gaps Analysis;
- Tire Crumb Rubber Characterization and Exposure Characterization research;
- use of recycled rubber tires on playgrounds;
- next steps and a timeline.

Since research is currently ongoing, the status report does not include any preliminary findings of the research. The results of the research on synthetic turf fields will be available later in 2017.

> The purpose of the FRAP is to study key questions concerning the potential for human exposure resulting from the use of tire crumb rubber in playing fields and playgrounds.

Summary of Stakeholder Outreach

EPA, CDC/ATSDR, and CPSC teams have engaged in a number of outreach activities, listed below, to inform the public, research organizations, industry, government organizations and non-profit organizations about the FRAP and to gather and share information that may be used to inform the research. Section III and Appendix A provide additional information on stakeholder outreach covering the following areas:

- Solicited public comment on components of the study, including collection of tire crumb rubber samples and information from field users;
- Regularly updated the Tire Crumb Study website (www.epa.gov/tirecrumb), with links to the FRAP and the research protocol, Tire Crumb Questions and Answers, government websites that provide recommendations for recreation on fields with tire crumb, and other information;
- Hosted a public webinar to provide an overview of the FRAP;
- Distributed study updates to an e-mail list of about 800 stakeholders.

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[8] Public and peer review comments and the agencies' responses are available on the OMB's website – http://www.reginfo.gov/public/do/PRAViewDocument?ref_nbr=201607-0923-001.

EPA REFERENCE GUIDE

FRAP Literature Review

Appendix E – List of Literature Reviewed & EPA Literature Review Summary of Tire Crumb Rubber Studies

Summary Spreadsheet of Literature Review/Gaps Analysis

Appendix E - List of Literature Reviewed

Ref #	Title	Author
01	A Case Study of Tire Crumb Use on Playgrounds: Risk Analysis and Communication When Major Clinical Knowledge Gaps Exist	Anderson et al.
02	A preliminary chemical examination of hydrophobic tire leachate components Note: This reference is part III of III. Parts I and II were not relevant and therefore, not reviewed	Anthony, D.H.J. and Latawiec
03	Determination of Microbial Populations in a Synthetic Turf System	Bass JJ, Hintze DW
04	Chemicals in outdoor artificial turf: a health risk for users?	Beausoleil M, Price K, Muller C
05	Toxicological Evaluation of Hazard Assessment of Tire Crumb for Use on Public Playgrounds	Birkholz et al.
06	Metals contained and leached from rubber granulates used in synthetic turf areas	Bocca B, Forte G., Petrucci F., Costantini S., Izzo P.
07	Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products	California Office of Environmental Health Hazard Assessment
08	Safety Study of Artificial Turf Containing Crumb Rubber Infill Made from Recycled Tires: Measurements of Chemicals and Particulates in the Air, Bacteria in the Turf, and Skin Abrasions Caused by Contact with the Surface	California Office of Environmental Health Hazard Assessment
09	Review of the Human Health & Ecological Safety of Exposure to Recycled Tire Rubber found at Playgrounds and Synthetic Turf Fields	Cardno Chem Risk
10	Assessment of exposure to chemical agents in infill material for artificial turf soccer pitches: development and implementation of a survey protocol	Castellano P, Proietto AR, Gordiani A, Ferrante R, Tranfo G, Paci E,
11	Emission characteristics of VOCs from athletic tracks	Chang, F; Lin, T.; Huang, C.; Chao, H.; Chang, T.; Lu, C.
12	Environmental and Health Impacts of Artificial Turf: A Review	Cheng H., Hu Y., Reinhard M.
13	Assessment of occupational health hazards in scrap-tire shredding facilities	Chien YC, Ton S, Lee MH et al.
14	Synthetic Turf: Health Debate Takes Root	Claudio L.
15	Human Health Risk Assessment of Artificial Turf Fields Based Upon Results from Five Fields in Connecticut	Connecticut Department of Public Health. (CDPH)
16	Artificial Turf Field Investigation in Connecticut Final Report	Connecticut: University of Connecticut Health Center (UCHC)
17	2009 Study of Crumb Rubber Derived from Recycled Tires, final report	Connecticut Agricultural Experiment Station (CAES)
18	Artificial Turf Study: leachate and stormwater characteristics	Connecticut Department of Environmental Protection (CDEP)
19	Peer Review of an Evaluation of the Health and Environmental Impacts Associated with Synthetic Turf Playing Fields	Connecticut Academy of Science and Engineering. (CASE)
20	CPSC Staff Analysis and Assessment of Synthetic Turf Grass Blades	CPSC
21	Effects of leachate from crumb rubber and zinc in green roofs on the survival, growth, and resistance characteristics of Salmonella enterica subsp. enterica serovar typhimurium	Crampton M, et al.
22	A Review of the Potential Health and Safety Risks from Synthetic Turf Fields Containing Crumb Rubber Infill Note: See reference #59	Denly E., Rutkowski K., Vetrano K.M.
23	Measurement of Air Pollution in Indoor Artificial Turf Halls	Dye C., Bjerke A, Schmidbauer N., Mano S.
24	Artificial Turf – Exposures to Ground-Up Rubber Tires – Athletic Fields – Playgrounds – Gardening Mulch	Environment & Human Health Inc. (EHHI)
25	Study of the suitability of ground rubber tire as a parking lot surface	Florida Department of Environmental Protection (FDEP)
26	Human Health Risk Assessment of Synthetic Turf Fields Based Upon Investigation of Five Fields in Connecticut	Ginsberg et al.
27	Benzothiazole Toxicity Assessment in Support of Synthetic Turf Field Human Health Risk Assessment	Ginsberg, G; Toal, B; Kurland, T.
28	Toxicological Assessment of Coated Versus Uncoated Rubber Granulates Obtained from Used Tires for Use in Sports Facilities	Gomes et al.

29	Design of a New Test Chamber for Evaluation of the Toxicity of Rubber Infill	Gomes JF, Mota HI, Bordado JC, Balão M, Sarmento GM, Fernandes J, Pampulim VM, Custódio ML, Veloso I.
30	Impact of tire debris on in vitro and in vivo systems	Gualteri, M.; Andrioletti, M.; Mantecca, P.; Vismara, C.; Camatini; M.
31	Identification of Benzothiazole Derivatives and Polycyclic Aromatic Hydrocarbons as Aryl Hydrocarbon Receptor Agonists Present in Tire Extracts	He, G., Zhao, B., Denison, M.S.
32	A Scoping-Level Field Monitoring Study of Synthetic Turf and Playgrounds	U.S. Environmental Protection Agency (U.S. EPA)
33	Environmental and Health Risks of Rubber Infill: Rubber crumb from car tyres as infill on artificial turf	Hofstra, U
34	Examination of Crumb Rubber Produced from Recycled Tires. Department of Analytical Chemistry	Incorvia Mattina, MJ; Isleyen, M; Berger, W; Ozdemir, S.
35	Initial evaluation of potential human health risks associated with playing on synthetic turf fields on Bainbridge Island	Johns, DM
36	Characterization and potential environmental risks of leachate from shredded rubber mulches	Kanematsu, M; Hayashi, A; Denison, MS; Young, TM.
37	The fate of methicillin-resistant staphylococcus aureus in a synthetic field turf system	Keller, M.
38	Synthetic turf from a chemical perspective--a status report	Kemi (Swedish Chemicals Inspectorate)
39	Health Risk Assessment of Lead Ingestion Exposure by Particle Sizes in Crumb Rubber on Artificial Turf Considering Bioavailability	Kim, S; Yan, JY; Kim, HH; Yeo, IY; Shin, DC; Lim, YW.
40	New approach to the ecotoxicological risk assessment of artificial outdoor sporting grounds	Krüger, O; Kalbe, U; Richter, E; Egeler, P; Rombke, J; Berger, W.
41	Comparison of Batch and Column Tests for the Elution of Artificial Turf System Components	Krüger, O; Kalbe, U; Berger, W; Nordhauβ, K; Christoph, G; Walzel, HP.
42	Preliminary Assessment of the Toxicity from Exposure to Crumb Rubber: Its Use in Playgrounds and Artificial Turf Playing Fields	LeDoux, T.
43	Characterization of Substances Released from Crumb Rubber Material Used on Artificial Turf Fields	Li, X; Berger, W; Musante, C; Incorvia Mattina, MJ.
44	Artificial Turf: Safe or Out on Ball Fields Around the World	Lioy, P; Weisel, C.
45	Crumb Infill and Turf Characterization for Trace Elements and Organic Materials	Lioy, P; Weisel, C.
46	Hazardous organic chemicals in rubber recycled tire playgrounds and pavers	Llompart, M; Sanchez-Pardo, L; Lamas, J; Garcia-Jares, C; Roca, E.
47	Release of Polycyclic Aromatic Hydrocarbons and Heavy Metals from Rubber Crumb in Synthetic Turf Fields: Preliminary Hazard Assessment for Athletes	Marsili, L; Coppola, D; Bianchi, N; Maltese, S; Bianchi, M; Fossi, MC.
48	A Survey of Microbial Populations in Infilled Synthetic Turf Fields	McNitt, AS; Petrunak, D; Serensits, T.
49	Artificial-turf Playing Fields: Contents of Metals, PAHs, PCBs, PCDDs and PCDFs, Inhalation Exposure to PAHs and Related Preliminary Risk Assessment	Menichini, E; Abate, V; Attias, L; DeLuca, S; DiDomenico, A; Fochi, I; Forte, G; Iacovella, N; Iamiceli, AL, Izzo, P; Merli, F; Bocca, B.
50	~~Culture-based and non-growth-dependent detection of the Burkholderia cepacia complex in soil environments~~ Note: This reference is not relevant, therefore not reviewed.	~~Miller et al~~
51	Evaluation of the Environmental Effects of Synthetic Turf Athletic	Milone and MacBroom, Inc.
52	Environmental and Health Evaluation of the Use of Elastomer Granulates (Virgin and From Used Tyres) as Filling in Third-generation Artificial Turf	Moretto, R.
53	~~Emission and evaluation of health effects of PAHs and aromatic amines from tyres~~ Note: This study does not meet our search criteria (focuses on problematic substances in whole tires).	~~Nilsson, NH; Feilberg, A; Pommer, K. (2005).~~
54	Mapping Emissions and Environmental and Health Assessment of Chemical Substances in Artificial Turf	Nilsson, NH; Malmgren-Hansen, B; Thomsen, US.
55	Artificial Turf Pitches: An Assessment of the Health Risks for Football Players	Norwegian Institute of Public Health and the Radium Hospital
56	A study to assess potential environmental impacts from the use of crumb runner as infill material in synthetic turf fields	New York Department of Environmental Conservation (NYDEC)
57	An assessment of chemical leaching, releases to air and temperature at crumb-rubber infilled synthetic turf fields	New York Department of Environmental Conservation (NYDEC)

58	New York City Department of Parks and Recreation: Synthetic Turf Lead Results (online)	New York City Department of Parks and Recreation
59	~~A Review of the Potential Health and Safety Risks From Synthetic Turf Fields Containing Crumb Rubber Infill~~ Note: Same as Denly et al. 2008. See reference # 22.	~~New York City Department of Health and Mental Hygiene (DOHMH)~~
60	Bioaccessibility and Risk of Exposure to Metals and SVOCs in Artificial Turf Field Fill Materials and Fibers	Pavilonis, BT; Weisel, CP; Buckley, B; Lioy, PJ.
61	Potential health and environmental effects linked to artificial turf systems-final report	Plesser, T; Lund, O.
62	Zinc Leaching From Tire Crumb Rubber	Rhodes, EP; Ren, Z; Mays, DC.
63	Environmental Sanitary Risk Analysis Procedure Applied to Artificial Turf Sports Fields	Ruffino, B; Fiore, S; Zanetti, MC.
64	Used Tire Recycling to Produce Granulates: Evaluation of Occupational Exposure to Chemical Agents	Savary, B; Vinvent, R.
65	Artificial Turf Football Fields: Environmental and Mutagenicity Assessment	Schilirò, T; Traversi, D; Degan, R; Pignata, C; Alessandria, L; Scozia, D; Bono R; Gilli, G.
66	Leaching of DOC, DN and inorganic Constituents from Scrap Tires	Selbes, M; Yilmaz, O;, Khan, AA; Karanfil, T.
67	Human health issues on synthetic turf in the USA	Serentis,T J; McNitt, AS; Petrunak, DM.
68	An Evaluation of Potential Exposures to Lead and Other Metals as the Result of Aerosolized Particulate Matter from Artificial Turf Playing Fields	Shalat, SL.
69	Evaluating the Risk to Aquatic Ecosystems Posed by Leachate from Tire Shred Fill in Roads Using Toxicity Tests, Toxicity Identification Evaluations, and Groundwater Modeling	Sheehan, PJ; Warmerdam, JM; Ogle, S; Humphrey, D; Patenaude, S.
70	Synthetic Turf Field Investigation in Connecticut	Simcox, NJ; Bracker, A; Ginsberg, G; Toal, B; Golembiewski, B; Kurland, T; Hedman, C
71	An Assessment of Environmental Toxicity and Potential Contamination from Artificial Turf using Shredded or Crumb Rubber	Sullivan, JP.
72	Environmental risk assessment of artificial turf systems	Torsten Kallqvist
73	Hydroxypyrene in Urine of Football Players After Playing on Artificial Sports Fields with Tire Crumb Infill	Van Rooij, JGM; Jongeneelen, FJ.
74	Evaluating and Regulating Lead in Synthetic Turf	Van Ulirsch, G; Gleason, K; Gerstenberger, S; Moffett, DB; Pulliam, G; Ahmed, T; Fagliano, J.
75	Leaching of Zinc from rubber infill in artificial turf (football pitches)	Verschoor, AJ.
76	Air Quality Survey of Synthetic Turf Fields Containing Crumb Rubber Infill	Vetrano, KM; Ritter, G.
77	Memo to Gloria Addo-Ayensu, Fairfax County Health Dept., from Dwight Flammia, Virginia Department of Health	Virginia Department of Health (VDH)
78	The RMA TCLP assessment project: Leachate from tire samples	Zelibor, J L.
79	Hazardous Chemicals in Synthetic Turf Materials and Their Bioaccessibility in Digestive Fluids	Zhang, J; Han, IK; Zhang, L; Crain, W.
80	~~Technical and environmental properties of tyre shreds focusing on ground engineering applications~~ Note: Not reviewed-not applicable.	~~Edeskar, T.~~
81	~~Expert Witness: Evaluation of health risks caused by skin contact with rubber granulates used in synthetic turf pitches~~ Note: Not a scientific study, expert opinion only; Not reviewed.	~~Hametner, C.~~
82	Investigation of PAH and other hazardous contaminant occurrence in recycled tyre rubber surfaces: case study: restaurant playground in an indoor shopping centre	Celeiro, M. et al.
83	~~Current State and Perspective for Artificial Turf as Sport Environment: Focusing on Third-generation Artificial Turf as Football Playing Surface~~ Note: This document reviews many of the documents already on this list that have been reviewed. Also includes information from Aoki 2008, see reference 91.	~~Aoki, T.~~
84	Mutagenic Potential of Artificial Athletic Field Crumb Rubber at Increased Temperatures	Dorsey et al.
85	~~Synthetic playing surfaces and athlete health~~ Note: Not suitable; it addresses injuries to athletes.	~~Drakos, M. C., et al.~~

86	Utilisation of crumb rubber as a soil amendment for sports turf	Groenevelt, P. H. and P. E. Grunthal
87	Evaluation of Potential Environmental Risks Associated with Installing Synthetic Turf Fields on Bainbridge Island.	Johns, DM; Goodlin, T.
88	Health Risk Assessment for Artificial Turf Playgrounds in School Athletic Facilities: Multi-route Exposure Estimation for Use Patterns	Kim, HH et al.
89	Coated rubber granulates obtained from used tyres for use in sport facilities: A toxicological assessment	Mota, H., et al.
90	Review of the impacts of crumb rubber in artificial turf applications	Simon, R.
91	Leaching of heavy metals from infills on artificial turf by using acid solutions	Aoki, T.
92	~~Environmental and Health Evaluation of the use of Elastomer Granulates (Virgin and From Used Tyres) as Filling in Third-Generation Artificial Turf~~ Note: Same as Moretto et al 2007. See Study 52.	~~French National Institute for Industrial Environment and Risks~~
93	~~ACT Global Crumb Rubber Safety Study~~ Note: Summary only; no information on the types and source of materials studied	~~Tilford, RW~~
94	State of Knowledge Report for Tire Materials and Tire Wear Particles	ChemRisk, Inc.
95	Health Impact Assessment of the Use of Artificial Turf in Toronto	Toronto Public Health
96	Nitrosamines released from rubber crumb	van Bruggen et al.
97	FOLLOW-UP STUDY OF THE ENVIRONMENTAL ASPECTS OF RUBBER INFILL A lab study (performing weathering tests) and a field study rubber crumb from car tyres as infill on artificial turf	Hofstra et al.

EPA Literature Review Summary of Tire Crumb Rubber Studies *

*LRGA Literature Review Summary: Scientific literature references and brief study descriptions of tire crumb rubber studies reviewed by the EPA. The complete *Summary Spreadsheet of Literature Review/Gaps Analysis* including the categorization of each of the studies can be found at: https://www.epa.gov/sites/production/files/2016-12/summary_spreadsheet_of_literature_review_and_gaps_analysis.xlsx

	References - Scientific Literature	Brief Description/Results	Additional Information or Comments
1	Anderson, ME; Kirkland, KH; Guidotti, TL, Rose, C. (2006). A Case Study of Tire Crumb Use on Playgrounds: Risk Analysis and Communication When Major Clinical Knowledge Gaps Exist. Environ Health Perspect. 114(1):1-3.	This paper describes EPA Region 8's response to questions from parents about risks of exposure to tire crumbs in playgrounds. It described parents observations and EPA's effort to obtain information from the literature to formulate a response. The conclusion was that while there was no evidence of risk based on the existing literature, data gaps exist.	
2	Anthony, D.H.J. and Latawiec, A. (1993). A Preliminary Chemical Examination of Hydrophobic Tire Leachate Components. National Water Research Institute, Burlington, Ontario, Canada, Report No. 93-78. Part III. Parts I and II not reviewed: not relevant (see comments).	"This report describes preliminary results of the application of molecular spectrometric techniques and separational methods to an examination of major organic components in large sample preconcentrates of tire leachate in order to identify or chemically characterize those demonstrating toxicity in biological tests."	This is part III of the study. Part I discusses the comprehensive approach to ID/characterization of unknown contaminants and Part II discusses preconcentration technique used to isolate hydrophobic tire leachate components.
3	Bass, JJ; Hintze, DW. (2013). Determination of Microbial Populations in a Synthetic Turf System. Skyline-The Big Sky Undergraduate Journal. 1(1):1.	"This study compares the occurrence of microbial populations on two infilled synthetic turf fields (year old turf vs. 6 year old turf) in three locations...Much higher microbial populations were found on the older turf field with as much as a 10^4 increase over similar locations on the newer turf... the sideline had the highest counts with an average of $1.12x10^8$ CFUs (colony forming units) per gram of rubber infill on the older field...[and] $2.5x10^5$ CFUs per gram of infill" on the new sythetic field. "Counts from the MSA plates revealed a relatively high number of mannitol-fermenting salt-tolerant bacteria, a possible indication of staphylococci."	
4	Beausoleil, M; Price, K; Muller, C. (2009). Chemicals in Outdoor Artificial Turf: A Health Risk for Users? Public Health Branch, Montreal Health and Social Services Agency. http://www.ncceh.ca/sites/default/files/Outdoor_Artificial_Turf.pdf.	..."it appears that the health risks for players who use artificial turf are not significant and that it is completely safe to engage in sports activities on this type of outdoor field."	This study was a literature review and conclusions are based on qualitative analysis of the data.
5	Birkholz, DA: Belton, KL, Guidotti, TL. (2003). Toxicological Evaluation of Hazard Assessment of Tire Crumb for Use on Public Playgrounds. J Air Waste Manag. 53:903-07.	Birkholz et al. (2003) "designed a comprehensive hazard assessment to evaluate and address potential human health and environmental concerns associated with the use of tire crumb in playgrounds. Human health concerns were addressed using conventional hazard analyses, mutagenicity assays, and aquatic toxicity tests of extracted tire crumb. Hazard to children appears to be minimal. Toxicity to all aquatic organisms (bacteria, invertebrates, fish, and green algae) was observed; however, this activity disappeared with aging of the tire crumb for three months in place in the playground. We conclude that the use of tire crumb in playgrounds results in minimal hazard to children and the receiving environment."	
6	Bocca, B; Forte, G; Petrucci, F; Costantini, S; Izzo, P. (2009). Metals Contained and Leached from Rubber Granulates Used in Synthetic Turf Areas. Science of the Total Environment. 407(7):2183-90.	"The total amount and the amount leached during the acidic test varied from metal to metal and from granulate to granulate. The highest median values were found for Zn (10,229 mg/kg), Al (755 mg/kg), Mg (456 mg/kg), Fe (305 mg/kg), followed by Pb, Ba, Co, Cu and Sr... The highest leaching was observed for Zn (2300 µg/l) and Mg (2500 µg/l), followed by Fe, Sr, Al, Mn and Ba. Little As, Cd, Co, Cr, Cu, Li, Mo, Ni, Pb, Rb, Sb and V leached, and Be, Hg, Se, Sn, Tl and W were below quantification limits. Data obtained were compared with the maximum tolerable amounts reported for similar materials, and only the concentration of Zn (total and leached) exceeded the expected values."	
7	California Office of Environmental Health Hazard Assessment. (2007). Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Prepared for the California Integrated Waste Management Board. http://www.calrecycle.ca.gov/publications/Detail.aspx?PublicationID=1206.	"Overall, we consider it unlikely that a onetime ingestion of tire shreds would produce adverse health effects."" Only exposure to zinc exceeded its health-based screening value." "...ecological effects from contaminated soil cannot be ruled out based on these Preliminary Remediation Goals, although the selenium level in the soil was only marginally higher than the PRG and the zinc levels were close to the normal background levels."	Children 3 years old evaluated; study also evaluated potential injuries from falls.
8	California Office of Environmental Health Hazard Assessment. (2010). Safety Study of Artificial Turf Containing Crumb Rubber Infill Made from Recycled Tires: Measurements of Chemicals and Particulates in the Air, Bacteria in the Turf, and Skin Abrasions Caused by Contact with the Surface. Prepared for the California Department of Resources Recycling and Recovery. http://www.calrecycle.ca.gov/publications/Documents/Tires/2010009.pdf.	"PM2.5 and associated elements (including lead and other heavy metals) were either below the level of detection or at similar concentrations above artificial turf athletic fields and upwind of the fields.""The large majority of air samples collected from above artificial turf had VOC concentrations that were below the limit of detection. "Fewer bacteria were detected on artificial turf compared to natural turf."	Air measurements were taken in 4 artificial fields and 4 natural fields. The study also included a survey of soccer coaches to gather information about hours in games and practices. Ths report also included a literature review.
9	Cardno Chem Risk. (2013). Review of the Human Health & Ecological Safety of Exposure to Recycled Tire Rubber found at Playgrounds and Synthetic Turf Fields. Prepared for: Rubber Manufacturers Association, Washington, DC. http://www.rma.org/download/scrap-tires/Environmental%20Issues/literature_review_0813.pdf.	"A review of available studies concludes that adverse health effects are not likely for children or athletes exposed to recycled tire materials found at playgrounds or athletic fields (Table 1). Similarly, no adverse ecological or environmental outcomes from field leachate are likely."	The study presented cancer calculations for arsenic and non-cancer calculations for antimony. Population evaluated were 3 to 70 yrs old. This literature includes information from several of the studies listed in this spreadsheet. No original experiments were conducted.
10	Castellano, P; Proietto, AR; Gordiani, A; Ferrante, R; Tranfo, G; Paci, E; Pigini, D. (2008). Assessment of Exposure to Chemical Agents in Infill Material for Artificial Turf Soccer Pitches: Development and Implementation of a Survey Protocol. Prev Today. 4(3):25–42.	"The results of the monitoring carried out during the research presented in this paper showed that under the conditions considered - given the peculiar characteristics both of the infill used and of the geographic location of the pitch - there was no occupational exposure nor any additional exposure to the substances of interest other than an environmental exposure in urban areas. This research represents the preliminary stage of a larger project to further investigate aspects of exposure assessment of pollutants potentially emitted by the infill material used in artificial turf soccer pitches."	
11	Chang, F; Lin, T; Huang, C; Chao, H; Chang, T; Lu, C. (1999). Emission Characteristics of VOCs from Athletic Tracks. J Haz Materials A70: 1-20.	"The type II polyurethane track had the highest decay rate, while the synthetic rubber track had the lowest decay rate. Two years after the track installation, the VOC concentrations measured at 1.5 m above the track, the breathing height of school children, were not significantly higher than the background levels."	This study noted that all of the synthetic fields were all installed with adhesive and backings which might also contribute to VOC offgassing.
12	Cheng, H; Hu, Y; Reinhard, M. (2014). Environmental and Health Impacts of Artificial Turf: A Review. Environ Sci Technol. 48(4):2114-29.	This literature review covers topics such as: disposal of scrap tires, composition and production of tire rubber, ZnO and PAHs in tire rubber, and life cycle assessment studies. Review of studies where the toxicity characteristic leaching procedure (TCLP) was used indicated constituent concentrations well below MCLs or TCLP regulatory limits	"There remains a significant knowledge gap that must be urgently addressed with the fast expansion of the artificial turf market. Given the wide range of designs, ages, and conditions of artificial turf fields, it is likely that the contaminant release and the environmental impacts are variable from site to site. It is also important to assess more systematically the risk posed by the tire rubber crumb on the environment and human health".

13	Chien, YC; Ton, S; Lee, MH; Chia, T; Shu, HY; Wu, YS. (2003) Assessment of Occupational Health Hazards in Scrap-tire Shredding Facilities. Sci Total Environ. 309: 35–46.	"Levels of volatile organics were not significant, but a few mutagens/carcinogens, such as styrene, benzothiazole, phthalate ester and naphthalene were identified. Total particulate levels ranged from 0.43 to 6.54 mg/m^3, while respirable particulates were in the range 0.23–1.25 mg/m^3. Ames testing revealed indirect mutagenicity on strain TA98, indicating possible effects of frame-shift type mutagens. Chemical analysis of airborne particulates confirmed the presence of amines, aniline, quinoline, amides and benzothiazole, which are potentially convertible to frame-shift type mutagenic nitrosoamines."	"Total and respirable particulate levels were mostly under half the current TLVs of 10 and 3 mg/m^3, respectively, for ACGIH 'non-classified nuisance particulate'. Nevertheless, the results from the Salmonella/Ames test indicate that the airborne particulates of the working environment included mutagenic and thus potentially carcinogenic ingredients. Consequently, particulate generated from scrap-tire shredding may pose a health threat to workers, and should not be regulated as 'nuisance'."
14	Claudio, L. (2008). Synthetic Turf: Health Debate Takes Root. Environ Health Perspect. 116(3): A116–A122.	Review article; discusses risks vs benefits.	
15	Connecticut Department of Public Health (CDPH). (2010). Human Health Risk Assessment of Artificial Turf Fields Based Upon Results from Five Fields in Connecticut. http://www.ct.gov/deep/lib/deep/artificialturf/dph_artificial_turf_report.pdf.	"In spite of the conservative nature of the assessment, cancer risks were only slightly above de minimis levels for all scenarios evaluated including children playing at the indoor facility, the scenario with the highest exposure. The calculated risks are well within typical risk levels in the community from ambient pollution sources and are below target risks associated with many air toxics regulatory programs. Further, the main risk driver, benzene, was only above background in personal monitoring samples and so may be more related to the sampling equipment or host than being field-related. Chronic non-cancer risks were not elevated above a Hazard Index of 1." "Cancer risks are slightly above de minimis in all scenarios, being nearly two fold higher at the indoor field compared to outdoors and being higher for children than adults."	Samples collected via personal monitoring and area sampling (6 inches and 3 feet above the field), and off-field upwind and in the community.
16	Connecticut: University of Connecticut Health Center (UCHC). (2010) Artificial Turf Field Investigation in Connecticut Final Report. http://www.ct.gov/deep/lib/deep/artificialturf/uchc_artificial_turf_report.pdf.	"Of the 60 VOCs tested in air, 4 VOCs appear to be associated with turf. Of 22 PAHs, 6 were found in the air on the turf at 2 fold greater concentrations than in background locations on at least two fields. Of the five targeted SVOCs, benzothiazole and butylated hydroxytoluene were the only chemicals detected in the personal and area air samples from outdoor turf fields ranging from <80-1200 ng/m3 and <80-130 ng/m3, respectively. Nitrosamine air levels were below reporting levels. PM10 air concentrations were greater in background locations than on the turf at all fields with the exception of Field B. However, the PM10 air concentration on turf at Field B, 5.89 ug/m3, was within the range of other PM10 background concentrations. All of the composite samples of turf fibers and crumb rubber were below the level EPA considers as presenting a "soil-lead hazard" in play areas (400ppm)."	"The airborne concentrations of VOCs, targeted SVOCs (e.g. benzothiazole) and miscellaneous SVOCs were highest at the indoor field.These data were collected from only one indoor facility. Higher concentrations of these chemicals at the indoor field likely reflects the lack of air movement relative to outdoor fields...potential point sources were identified in the facility, (electric carts, portable chargers, and maintenance supplies) and the indoor facility did not have its exhaust system operating on the day samples were collected. More research is needed to better understand chemical exposures in indoor facilities."
17	Connecticut Agricultural Experiment Station (CAES). (2010) 2009 Study of Crumb Rubber Derived from Recycled Tires, final report. http://www.ct.gov/deep/lib/deep/artificialturf/caes_artificial_turf_report.pdf.		"...although there is a decrease in the amounts of all six compounds which outgas over the ten weeks of this experiment, the decrease is the least for 4-t-octylphenol. Second, at approximately 20 days of weathering under the conditions in this experiment, the five compounds appear to reach a consistent level of outgassing."
18	Connecticut Department of Environmental Protection (CDEP). (2010) Artificial Turf Study: Leachate and Stormwater Characteristics. http://www.ct.gov/deep/lib/deep/artificialturf/dep_artificial_turf_report.pdf.	"Zinc is the most prevalent contaminant in the leachate and stormwater studies." "The DEP concludes that there is a potential risk to surface waters and aquatic organisms associated with whole effluent and zinc toxicity of stormwater runoff from artificial turf fields...This study did not identify any significant risks to groundwater protection criteria in the stormwater runoff from artificial turf fields."	
19	Connecticut Academy of Science and Engineering (CASE). (2010). Peer Review of an Evaluation of the Health and Environmental Impacts Associated with Synthetic Turf Playing Fields. http://www.ct.gov/deep/lib/deep/artificialturf/case_artificial_turf_review_report.pdf.	"The CASE Peer Review Committee concluded based on a review of the state's reports that there is a limited human health risk, and an environmental risk as shown by the high zinc levels detected. Furthermore, it is believed that some of the results can be easily misinterpreted by the public."	
20	Consumer Product Safetyt Commission (CPSC). 2008. CPSC Staff Analysis and Assessment of Synthetic Turf Grass Blades. Available at: http://www.cpsc.gov/PageFiles/104716/turfassessment.pdf.	"The results (Table 1) for this set of tested synthetic turf fields show no case in which the estimated exposure for children playing on the field would exceed 15 ug lead/day."	
21	Crampton, M; Ryan, A; Eckert, C; Baker, KH; Herson, DS. (2014). Effects of Leachate from Crumb Rubber and Zinc in Green Roofs on the Survival, Growth, and Resistance Characteristics of Salmonella enterica subsp. enterica serovar typhimurium. Appl Environ Micro. 80.9:2804-2810.	"Extracts from crumb rubber were collected and Salmonella was exposed to this material for either 24 or 48 h and subsequently enumerated. The 1-h extract was more inhibitory to organisms than the synthetic rainwater (SRW) alone. Additionally, the 24-h and 48-h extracts were more inhibitory than the 1-h extract when in contact with Salmonella for 24 h."	"The median concentration of zinc in the crumb rubber-amended roof was 0.2 mg/liter ..., while the median concentration of zinc in the commercial medium was 0.15 mg/liter."
22	Denly, E; Rutkowski, K; Vetrano, KM. (2008). A Review of the Potential Health and Safety Risks from Synthetic Turf Fields Containing Crumb Rubber Infill. Prepared by TRC for the New York City Department of Mental Health and Hygiene, New York, NY. http://www.nyc.gov/html/doh/downloads/pdf/eode/turf_report_05-08.pdf	"Based on the information reviewed none of the risk assessments showed concentrations of contaminants that would be at a level of concern, even under conservative assumptions and thus it does not appear that the ingestion of tire crumb would pose a significant health risk for children or adults."	This study is a literature review of several studies on tire crumbs. They mainly focused on the results from the CalEPA 2007 study.
23	Dye, C; Bjerke, A; Schmidbauer, N; Mano, S. (2006). Measurement of Air Pollution in Indoor Artificial Turf Halls. Norwegian Pollution Control Authority/Norwegian Institute for Air Research, State Programme for Pollution Monitoring. http://www.isss-sportsurfacescience.org/downloads/documents/SI1HPZNZPS_NILUEngelsk.pdf.	"...airborne dust concentrations that one would expect in an indoor environment for both PM10 and PM2.5 fractions." "In all three halls, the proportion of organic material is considerable. The airborne dust contains polycyclic aromatic hydrocarbons (PAH), phthalates, semi-volatile organic compounds, benzothiazoles and aromatic amines. It also contains organic and inorganic pollutants which are not specified in this study. Possible problem areas linked to latex exposure via the skin and air passages should be assessed by specialists."	The study was conducted to obtain measurements of air quality for three indoor artificial turf pitches. The measurements were taken in a hall with recently laid rubber granulate (SBR rubber or Styrene Butadiene Rubber) and a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall which used granulate made from thermoplastic elastomer.
24	Environment & Human Health Inc. (EHHI). (2007). Artificial Turf – Exposures to Ground-Up Rubber Tires – Athletic Fields – Playgrounds – Gardening Mulch. http://www.ehhi.org/reports/turf/turf_report07.pdf.	"It is clear that the recycled rubber crumbs are not inert, nor is a high-temperature or severe solvent extraction needed to release metals, volatile organic compounds, or semi-volatile organi compounds. The release of airborne chemicals and dust is well established by the current information...There are still data gaps that need to be filled in and additional studies are warranted."	
25	Florida Department of Environmental Protection (FDEP). (1999). Study of the suitability of ground rubber tire as a parking lot surface. http://www.dep.state.fl.us/waste/quick_topics/publications/shw/tires/FCCIstudy.pdf.	"Except for the iron concentrations detected in groundwater samples collected from MW-1, MW-3, and MW-4, all remaining soil, groundwater, rain water, and surface water runoff concentrations were below State guidance concentrations."	For each study, several concentrations (Fe, Na, Cr, etc.) were above laboratory detection limits, but below State target levels.
26	Ginsberg, G; Toal, B; Simcox, N; Bracker, A; Golembiewski, B; Kurland, T; Hedman, C. (2011a). Human Health Risk Assessment of Synthetic Turf Fields Based Upon Investigation of Five Fields in Connecticut. J Toxicol Environ Health. A74(17):1150-74.	"Cancer and noncancer risk levels were at or below de minimis levels of concern. The scenario with the highest exposure was children playing on the indoor field. The acute hazard index (HI) for this scenario approached unity, suggesting a potential concern, although there was great uncertainty with this estimate. The main contributor was benzothiazole, a rubber-related semivolatile organic chemical (SVOC) that was 14-fold higher indoors than outdoors. Based upon these findings, outdoor and indoor synthetic turf fields are not associated with elevated adverse health risks."	See data in constituents tab for CDPH 2010
27	Ginsberg, G; Toal, B; Kurland, T. (2011b). Benzothiazole Toxicity Assessment in Support of Synthetic Turf Field Human Health Risk Assessment. Journal of Toxicology and Environmental Health, Part A: Current Issues. 74:17, 1175-1183, DOI: 10.1080/15287394.2011.586943; http://dx.doi.org/10.1080/15287394.2011.586943.	Based on a review of the literature, "The following BZT toxicity values were derived: (1) acute air target of 110 μg/m3 based upon a BZT RD50 study in mice relative to results for formaldehyde; (2) a chronic noncancer target of 18 μg/m3 based upon the no-observed-adverse-effect level (NOAEL) in a subchronic dietary study in rats, dose route extrapolation, and uncertainty factors that combine to 1000; (3) a cancer unit risk of 1.8E-07/μg-m3 based upon a published oral slope factor for 2-MBZT and dose-route extrapolation."	

28	Gomes, J; Mota, H; Bordado, J; Cadete, M; Sarmento, G; Ribeiro, A; Balao, M; Fernandes, J; Pampulin, V; Custodio, M; Veloso, I. (2010). Toxicological Assessment of Coated Versus Uncoated Rubber Granulates Obtained from Used Tires for Use in Sports Facilities. J Air Waste Manag Assoc. 60(6):741-6.	"The experimental study presented in this paper indicates that the R1 coating fulfils the requirements of adherence and color stability requested for this particular application and is effective in reducing environmental emissions from the rubber granulate materials; namely, in terms of leaching of pollutants such as PAHs and heavy metals. The other coating tested, R2, also shows good performance characteristics but has a leaching value for Sn exceeding the regulated limit."	Two coatings examined: (1) Based on emulsified PVC (OC-0814/R1) (2) Based on a cross-linked alquidic polymer (OC-0814/R2. Both coatings included color addivites and a flame-retarding agent.
29	Gomes, JF; Mota, HI; Bordado, JC; Balão, M; Sarmento, GM; Fernandes, J; Pampulim, VM; Custódio, ML; Veloso, I. (2011). Design of a New Test Chamber for Evaluation of the Toxicity of Rubber Infill. Toxicol Mech Methods. 21(8):622-7.	"The study presented in this article illustrates the use of the described test chamber as effective for simulating atmospheric conditions experienced by rubber infill (when applied in synthetic turf pitches) and measuring accurately the different leachates as well as emission parameters. Therefore, this procedure is to be considered as a technical option to the lysimeter "global turf system evaluation" when the rubber infill alone is to be evaluated."	This study examined the effectiveness of using a simulation chamber, but still examined tire crumb samples. Sample types were cryogenic and semi-cryogenic.
30	Gualteri, M; Andrioletti, M; Mantecca, P; Vismara, C; Camatini, M. (2005). Impact of Tire Debris on in vitro and in vivo Systems. Particle and Fibre Toxicology. doi:10.1186/1743-8977-2-1.	"Previous work and these results confirm the significant role of zinc in leached TD and the presence of additional organic toxicants. The studies performed have focused their attention on the potential toxic risk to living aquatic organisms from whole rubber tires or scrap. In this study TD has been investigated for its impact on human cell lines and on X. laevis embryos."	
31	He, G; Zhao, B; Denison, MS. (2011). Identification of Benzothiazole Derivatives and Polycyclic Aromatic Hydrocarbons as Aryl Hydrocarbon Receptor Agonists Present in Tire Extracts. Env Tox Chem. 30(8):1915-1925.	"The application of CALUX (Chemical-Activated LUciferase gene eXpression) cell bioassay-driven toxicant identification evaluation not only revealed that tire extract contained a variety of known AhR-active polycyclic aromatic hydrocarbons, but also identified 2- methylthiobenzothiazole and 2-mercaptobenzothiazole as AhR agonists. Analysis of a structurally diverse series of benzothiazoles identified many that could directly stimulate AhR DNA binding and transiently activate the AhR signaling pathway and identified benzothiazoles as a new class of AhR agonists. In addition to these compounds, the relatively high AhR agonist activity of a large number of fractions strongly suggests that tire extract contains a large number of physiochemically diverse AhR agonists whose identities and toxicological/biological significances are unknown."	
32	U.S. Environmental Protection Agency (Highsmith, R; Thomas, KW; Williams, RW.) (2009). A scoping-level field monitoring study of synthetic turf fields and playgrounds. Washington, DC: Office of Research and Development, National Exposure Research Laboratory; Report No. EPA/600/R-09/135 http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=215113&simpleSearch=1&searchAll=EPA%2F600%2FR-09%2F135)	"(5) On average, concentrations of components monitored in this study were below levels of concern; however, given the very limited nature of this study (i.e., limited number of components monitored, samples sites, and samples taken at each site) and the wide diversity of tire crumb material, it is not possible to reach any more comprehensive conclusions without the consideration of additional data"	
33	Hofstra, U. (2007a). Environmental and Health Risks of Rubber Infill: Rubber crumb from car tyres as infill on artificial turf. INTRON A833860/R20060318.	"Based on the available literature on exposure to rubber crumb by swallowing, inhalation and skin contact and our experimental investigations on skin contact we conclude, that there is not a significant health risk due to the presence of rubber infill for football players an artificial turf pitch with rubber infill from used car tyres."	
34	Incorvia Mattina, MJ; Isleyen, M; Berger, W; Ozdemir, S. (2007). Examination of Crumb Rubber Produced from Recycled Tires. Department of Analytical Chemistry. The Connecticut Agricultural Research Station, New Haven, CT. http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/examinationofcrumbrubberac005.pdf.	"The laboratory data presented here support the conclusion that under relatively mild conditions of temperature and leaching solvent, components of crumb rubber produced from tires (i) volatilize into the vapor phase and (ii) are leached into water in contact with the crumbs."	
35	Johns, DM. (2008). Initial Evaluation of Potential Human Health Risks Associated with Playing on Synthetic Turf Fields on Bainbridge Island. Seattle, WA: Windward Environmental LLC.	This study evaluates health risks for children (8-10 yrs old) and teenagers (11-18 years old) participating in team sports. It used the highest concentrations obtained from Norwegian Institute of Public Health and Radium Hospital 2006, Plesser and Lund 2004, and OHHEA 2007.	"Overall, the balance of the studies reviewed indicate that human health risks from playing on synthetic turf fields is minimal, even though low concentrations of some chemicals have been demonstrated to leach from the tire crumb, or volatilize as vapor. A conservative sport play scenario developed to better describe turf filed use on Bainbridge Island is consistent with the findings reported in the other published studies."
36	Kanematsu, M; Hayashi, A; Denison, MS; Young, TM. (2009). Characterization and Potential Environmental Risks of Leachate from Shredded Rubber Mulches. Chemosphere 76:952–958.	"The results indicate that aqueous extracts of rubber mulches (RM) contain high concentrations of zinc (Zn) compared with wood mulches (WM), and its concentration increased at lower pH and higher temperature...Our results suggest that organic constituents in water extracts of RM which have AhR activity may not be of significant concern while leaching of Zn from RM appears to be a potentially larger water quality issue for RM."	
37	Keller, M. (2013). The Fate of Methicillin-resistant Staphylococcus aureus in a Synthetic Field Turf System. The University of Toledo Digital Repository: theses and dissertations.	"..largest proportion of available MRSA was 116% of the applied MRSA was available from polymer coated sand, 113% from TPE, 110% from crumb rubber,108% from sand, 100% from organic, and 57% from EPDM rubber."	The study tested the MRSA availability on infill and turf fiber materials with aninoculation/recovery experiments.
38	Kemi (Swedish Chemicals Inspectorate). (2006). Synthetic Turf from a Chemical Perspective–a status report. Swedish Chemicals Inspecorate Order.No. 510 834.	"Measurement of indoor air and exposure calculations have shown that there is probably a small health risk associated with simply being on or playing on synthetic turf surfaces that use rubber from recycled tyres. The exposure levels and any allergic reactions, however, have been poorly studied. Exposure to these substances from other sources, such as car exhaust, must also be taken into consideration to achieve a total assessment of health risks. Current knowledge allows the conclusion to be drawn that synthetic turf that contains rubber from recycled tyres may give rise to local environmental risks. Investigations have shown that zinc and phenols can leach from the rubber granulate, and these substances can affect aquatic and sediment dwelling organisms, if they reach neighbouring water courses."	"Certain investigations and assessments have been carried out in order to illuminate the risks of using synthetic turf, but there remain major gaps in our knowledge. This is particularly true with respect to the extent to which the hazardous substances are released from the rubber, and the subsequent exposure to these substances of people and the environment."
39	Kim, S; Yan, JY; Kim, HH; Yeo, IY; Shin, DC; Lim, YW. (2012a). Health Risk Assessment of Lead Ingestion Exposure by Particle Sizes in Crumb Rubber on Artificial Turf Considering Bioavailability. Environ Health Toxicol. 27:e2012005.	"Results of this study confirm that the exposure of lead ingestion and risk level increases as the particle size of crumb rubber. Average lead exposure ranged from 1.7 x 10-5 mg/kg-day to 4.1x 10-4 mg/kg-day with the highest exposure value for children 7-9 yrs old with the acid extraction method and the lowest exposure to children 13-18 yrs in both the acid and digestion extraction. Mean hazard quotients were < 1.	This study calculated the risk of ingestion exposure of lead by particle sizes of crumb rubber in artificial turf filling material with consideration of bioavailability. The range of bioavailability depended on the particle size and the type of extraction used. The < 250 um and acid extraction had the highest bioavailability.
40	Krüger, O; Kalbe, U; Richter, E; Egeler, P; Rombke, J; Berger, W. (2013). New Approach to the Ecotoxicological Risk Assessment of Artificial Outdoor Sporting Grounds. Environmental Pollution. 175:69-74.	"The results show that freshwater algal growth inhibition tests (Pseudokirchnerlella subcapitata) and the acute toxicity test (Daphnia magna) are applicable to determine the ecotoxicity potential of artificial turf systems and their components."	
41	Krüger, O; Kalbe, U; Berger, W; Nordhauβ, K; Christoph, G; Walzel, HP. (2012). Comparison of Batch and Column Tests for the Elution of Artificial Turf System Components. Environ Sci Technol. 46(24):13085-92.	"Considering the risk assessment of artificial turf systems, emphasis should be placed not only on the plastic components but also on mineral aggregates used for basic layers, which might contribute to the release of contaminants, especially of zinc. For a thorough and realistic risk assessment, column tests of complete artificial turf systems, simulating the actual installation, may be more realistic."	
42	LeDoux, T. (2007). Preliminary Assessment of the Toxicity from Exposure to Crumb Rubber: its Use in Playgrounds and Artificial Turf Playing Fields. Division of Science, Research and Technology. New Jersey Department of Environmental Protection. http://www.state.nj.us/dep/dsr/research/whitepaper%20-%20rubber.pdf.	"Insufficient information was found to perform a complete formal exposure assessment/risk characterization on crumb rubber for the stated outdoor use at this time due to existing data gaps in the available information. After reviewing the information available, with the possible exception of allergic reactions among individuals sensitized to latex, rubber and related products, there was no obvious toxicological concern raised that crumb rubber in its intended outdoor use on playgrounds and playing fields would cause adverse health effects in the normal population."	
43	Li, X; Berger, W; Musante, C; Incorvia Mattina, MJ. (2010). Characterization of Substances Released from Crumb Rubber Material Used on Artificial Turf Fields. Chemosphere. 80(3):279-85.	"Ten volatile compounds were identified in the vapor phase over all commercial CRM samples and two aged field CRM samples by SPME coupled with GC–MS. Six volatile compounds were quantitated by direct vapor phase injection. In all 16 virgin commercial CRM samples, BT was the most abundant volatile compound. Zinc was the highest of all extractable metals in the acidified extraction fluid."	"There could be preferential usage of BHT, BHA and 4-t-OP as antioxidants in rubber manufacture for tire rubber and other rubber products. To the best of our knowledge this is the first report of detection these three antioxidants in the vapor phase released from any tire rubber materials."
44	Lioy, P; Weisel, C. (2008). Artificial Turf: Safe or Out on Ball Fields Around the World; Editorial. J of Expos Anal Environ Epidem. 18:533-534.	"At the present time, we believe that the million dollar expense to produce and install a synthetic field by communities and athletic facilities demands a much more thorough understanding of the environmental impacts, human exposure and health risk implications associated with all synthetic turf products available on the market. This calls for a comprehensive evaluation of artificial turf by exposure scientists, and others in environmental science and environmental health sciences."	

45	Lioy, P; Weisel, C. (2011). Crumb Infill and Turf Characterization for Trace Elements and Organic Materials. Report prepared for NJDEP, Bureau of Recycling and Planning.	"Overall the metals, PAHs and semi-volatile compounds found all classes of materials to be at very low concentrations. Thus, for the metals and compounds identified there would be de minimus exposures and risk among anyone using fields with the exception of lead in a single new turf material. It is therefore prudent to reemphasize the need to avoid lead-based pigments in these materials as coloring agents."	" As indicated our EOHSI study provides two new key sets of measurements, the bioavailability of metals and organics in crumb rubber, for which there are very limited data previously reported and the screening of the crumb rubber for metals and organics which has only previously been done extensively in Europe and should also be done on material produced in the US." ; This article also provides a summary of studies including analyte types (see Table 1)
46	Llompart, M; Sanchez-Pardo, L; Lamas, J; Garcia-Jares, C; Roca, E. (2013). Hazardous Organic Chemicals in Rubber Recycled Tire Playgrounds and Pavers. Chemosphere. 90(2):423-31.	"The analysis confirmed the presence of a large number of hazardous substances including PAHs, phthalates, antioxidants (e.g. BHT, phenols), benzothiazole and derivatives, among other chemicals. The study evidences the high content of toxic chemicals in these recycled materials. The concentration of PAHs in the commercial pavers was extremely high, reaching values up to 1%."	
47	Marsili, L; Coppola, D; Bianchi, N; Maltese, S; Bianchi, M; Fossi, MC. (2014). Release of Polycyclic Aromatic Hydrocarbons and Heavy Metals from Rubber Crumb in Synthetic Turf Fields: Preliminary Hazard Assessment for Athletes. Journal of Environmental and Analytical Toxicology. 5:(2).	"The results of the present study demonstrate that PAHs are continuously released from rubber crumb through evaporation. Athletes frequenting grounds with synthetic turf are therefore exposed to chronic toxicity from PAHs. The main conclusion we can draw from this preliminary study, which will be validated by further field and laboratory research, is that although synthetic turf offers various advantages over natural grass, the quantity of toxic substances it releases when heated does not make it safe for public health."	The study tested 9 different synthetic turfs from football fields. They calculated HQ. For cancer they calculated exposure making assumptions and the TEQ method for PAHs and compared exposures to those exposures from foods and found they were 1000 higher than exposures from food.
48	McNitt, AS; Petrunak, D; Serensits, T. (2006). A Survey of Microbial Populations in Infilled Synthetic Turf Fields. Penn State University, College of Agricultural Sciences, Department of Plant Science. http://plantscience.psu.edu/research/centers/ssrc/research/microbial.	"While microbes exist in the infill media the number was low compared to natural turfgrass field soils." The range of CFU was 0-80,000 in the infill material compared to 259,500 found in natural soil.	The study collected crumb rubber samples from both "high use" areas and "low used" areas. The fields were used by elementary to professional athletes.
49	Menichini, E; Abate, V; Attias, L; DeLuca, S; DiDomenico, A; Fochi, I; Forte, G; Iacovella, N; Iamiceli, AL, Izzo, P; Merli, F; Bocca, B. (2011). Artificial-turf Playing Fields: Contents of Metals, PAHs, PCBs, PCDDs and PCDFs, Inhalation Exposure to PAHs and Related Preliminary Risk Assessment. Sci Total Environ. 409(23):4950-7.	"Compared with the Italian limits for "green area" soils, high contents of Zn and PAHs were found in the granulates present in playing fields, whatever the origin of the rubber. Zn and BaP concentrations largely exceeded such limits by up to two orders of magnitude...PCBs and PCDDs+PCDFs were found in a recycled tyre granulate, at levels in the order of magnitude of the mentioned limits...Based on the 0.4 ng/m3 concentration and using a conservative approach, we calculated an excess lifetime cancer risk of 1×10−6 for an athlete with an intense 30-year activity."	"Further work is needed to assess the actual scenarios of exposure to PAHs by inhalation and the corresponding risks, and to reach more comprehensive conclusions."
50	~~Miller S, John CM, LiPuma J, Parke JL (2003). Culture-based and non-growth-dependent detection of the Burkholderia cepacia complex in soil environments. Applied and environmental microbiology 68.8:3750-3753.~~ Not relevant.	This paper does not specify that the 'turf' fields that were sampled were artifical turf fields with tire crumbs. Thus, this paper is not relevant. It is included on this list because it was listed on a previous literature review of microbial work done on tire crumb rubber artificial fields.	
51	Milone and MacBroom, Inc. Evaluation of the Environmental Effects of Synthetic Turf Athletic. (2008). http://www.actglobalsports.com/media/Milone_MacBroom.pdf.	"The rise in temperature of the synthetic fibers was significantly greater than the rise in temperature noted for the crumb rubber" "An analysis of the concentration of metals in the actual drainage water indicates that metals do not leach in amounts that would be considered a risk to aquatic life as compared to existing water quality standards."	"The field where benzothiazole was detected had recently been groomed, thereby bringing significant quantities of crumb rubber nearer to the surface of the field resulting in greater exposure to both the sunlight and air."
52	Moretto, R. (2007). Environmental and Health Evaluation of the Use of Elastomer Granulates (Virgin and From Used Tyres) as Filling in Third-generation Artificial Turf, France, ALIAPUR in partnership with Fieldturf Tarkett and the ADEME (Environmental French Agency). http://www.aliapur.fr/media/files/RetD_new/Synthetic_turf_-_Environmental_Study_Report.pdf.	"From an ecotoxological point of view, the nature of the percolates having passed through a 3rdgeneration artificial pitch are proven to be without impact on the environment, irrespective of the type of filling granulates." "...for the 9 VOC and aldehydes concerned and on the basis of the results acquired during the characterisation of the emissions, the maximum concentrations in the gymnasium, modelled at D28, are of pproximately the same magnitude as the ubiquitous concentrations in the ambient air (exterior and interior), or even inferior in certain cases."	
53	~~Nilsson, NH; Feilberg, A; Pommer, K. (2005). Emission and evaluation of health effects of PAHs and aromatic amines from tyres. Danish Ministry of the Environment Survey of Chemical Substances in Consumer Products, No. 54 2005~~ This study does not meet our search criteria (focuses on problematic substances in whole tires).		
54	Nilsson, NH; Malmgren-Hansen, B; Thomsen, US. (2008). Mapping Emissions and Environmental and Health Assessment of Chemical Substances in Artificial Turf. Danish Ministry of the Environment, Environmental Protection Agency. http://www2.mst.dk/udgiv/publications/2008/978-87-7052-866-5/pdf/978-87-7052-867-2.pdf.	"Overall, it can be concluded that more or less all foreign studies conclude that there are no health problems for users of artificial turf pitches, neither indoors or outdoors." <u>Health Assessments:</u> "Four representative substances were selected for the health assessment: benzothiazole, dicyclohexylamine, cyclohexanamine and dibutyl phthalate. These substances are present in high concentrations in contact water from the leaching tests and are representative of the harmful substances emitted from the products." "The overall assessment is that there are no health effects associated with exposure to the four substances tested, with the exception of a potential risk for developing allergy in particularly sensitive individuals (benzothiazole and the two amines)." <u>Environmental Assessments:</u> "a number of environmentally harmful substances were found in the contact water from leaching tests on infills and artificial turf mats."	"It was decided to use worst case scenarios, which means that the maximum exposure levels for rubber particles were used for the calculation of substance exposure." Inhalation of gases not investigated due to other studies providing info that it does not pose a health problem.
55	Norwegian Institute of Public Health and the Radium Hospital. (2006). Artificial Turf Pitches: An Assessment of the Health Risks for Football Players. Norwegian Institute of Public Health and the Radium Hospital, Oslo, Norway.	"On the basis of estimated exposure values and the doses/concentrations which can cause harmful effects in humans or in animal experiments, it is concluded that the use of artificial turf halls does not cause any elevated health risk. This applies to children, older children, juniors and adults. The estimated Margins of Safety (MOS) also give no cause for concern."	
56	New York Department of Environmental Conservation (NYDEC). (2008). A Study to Assess Potential Environmental Impacts from the Use of Crumb Rubber as Infill Material in Synthetic Turf Fields. http://www.dec.ny.gov/docs/materials_minerals_pdf/tirestudy.pdf.	"Many governmental bodies including Norway, Sweden and California have recently reviewed the health issues associated with the use of crumb rubber as infill at playgrounds and synthetic turf fields. Their assessments did not find a public health threat. However, several recent preliminary studies... indicated the presence of organic compounds, such as polycyclic aromatic hydrocarbons (PAH) and heavy metals, such as zinc, and raised concerns that these substances could have potential adverse impacts on the environment and public health, especially for children playing on these synthetic turf fields for extended time periods....to address these concerns, the DEC has initiated a study to assess the potential environmental impacts from the use of crumb rubber as an infill material in synthetic turf fields and to collect data that would be relevant for a public health and environmental assessment."	
57	New York Department of Environmental Conservation (NYDEC). (2009). An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-rubber Infilled Synthetic Turf Fields. http://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf.	"...crumb rubber may be used as an infill without significant impact on groundwater quality...Analysis of crumb rubber samples digested in acid revealed that the lead concentration in the crumb rubber samples were well below the federal hazard standard for lead in soil...A risk assessment for aquatic life protection...found that crumb rubber derived entirely from truck tires may have an impact on aquatic life due to the release of zinc. For the three other types of crumb rubber, aquatic toxicity was found to be unlikely...A public health evaluation was conducted on the results from the ambient air sampling and concluded that the measured levels of chemicals in air at the Thomas Jefferson and John Mullaly Fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields...the findings do not indicate that these fields are a significant source of exposure to respirable particulate matter"	
58	New York City Department of Parks and Recreation: Synthetic Turf Lead Results (online). Available at http://www.nycgovparks.org/sub_things_to_do/facilities/synthetic_turf_test_results.html.	"Aside from Thomas Jefferson Park, the test results for the remaining 112 fields and play areas were below the acceptable EPA lead level for soil (400 parts per million), the best standard available, and no potential lead hazards were found. Lead levels for the 112 fields ranged from 'not detected' to 240 ppm and 96% of the results were less than 100 ppm. Thomas Jefferson Park was the only field with an elevated lead level above the EPA standard."	
59	~~New York City Department of Health and Mental Hygiene (DOHMH). 2008. A Review of the Potential Health and Safety Risks From Synthetic Turf Fields Containing Crumb Rubber Infill. Prepared by TRC for DOHMH. May.~~ Same as Denly et al 2008. See Study 22.		

60	Pavilonis, BT; Weisel, CP; Buckley, B; Lioy, PJ. (2014). Bioaccessibility and Risk of Exposure to Metals and SVOCs in Artificial Turf Field Fill Materials and Fibers. Risk Analysis, 34: 44–55	"Artificial biofluids were hypothesized to yield a more representative estimation of dose than the levels obtained from total extraction methods. PAHs were routinely below the limit of detection across all three biofluids precluding completion of a meaningful risk assessment. No SVOCs were identified at quantifiable levels in any extracts based on a match of their mass spectrum to compounds that are regulated in soil. The metals were measurable but at concentrations for which human health risk was estimated to be low. The study demonstrated that for the products and fields we tested, exposure to infill and artificial turf was generally considered de minimus, with the possible exception of lead for some fields and materials."	
61	Plesser, T; Lund, O. (2004). Potential Health and Environmental Effects Linked to Artificial Turf Systems; Final Report. Norwegian Building Research Institute, Trondheim, Norway, Project #O-10820.	"The leachate from the fibres contained zinc. The concentration is higher than the Norwegian Pollution Control Authority's limit for zinc in water with Environmental Quality Class V (very strongly polluted water), but lower than the permitted zinc concentration in Canadian drinking water...The total concentrations of zinc and PAH in the recycled rubber granulates exceed the Norwegian Pollution Control Authority's normative values for most sensitive land use. The concentrations of dibutylphthalate (DBP) and diisononylphthalate (DINP) exceed the PNEC values for terrestrial life taken from the EU's programme for risk assessment. The concentration of isononylphenol is above the limits specified for cultivated land in the Canadian Environmental Quality Guidelines...The concentration of zinc indicates that the leachate water is placed in the Norwegian Pollution Control Authority's Environmental Quality Class V (very strongly polluted water), but is lower than the permissible zinc concentration in Canadian drinking water. The concentration of anthracene, fluoranthene, pyrene and nonylphenols exceed the limits for freshwater specified in the Canadian Environmental Quality Guidelines.	"As the measured concentration of environmental toxins (with the exception of copper) in the artificial turf fibres is lower than in the rubber granulates, and the artificial turf fibres in any case constitute a much smaller proportion of the artificial turf system in terms of mass, it is suggested that further investigations concentrate on the rubber granulates...An expanded risk assessment with an analysis of possible spreading paths and changes in leaching properties over time is necessary to determine the degree to which the concentrations of zinc, anthracene, fluoranthene, pyrene, phthalates and nonylphenols in the leachate are actually harmful to people and the environment...The recycled rubber granulates give off a significant number of alkylated benzenes in gaseous form. Trichloromethane (sample 1) and cis-1,2-dichlorethene (sample 5) were also found. It is recommended that measurements be taken of air quality above pitches to determine whether the air quality is satisfactory."
62	Rhodes, EP; Ren, Z; Mays, DC. (2012). Zinc Leaching From Tire Crumb Rubber. Environ Sci Technol. 46(23):12856-63.	"Results indicate that zinc leaching from tire crumb rubber increases with smaller crumb rubber and longer exposure time."	
63	Ruffino, B; Fiore, S; Zanetti, MC. (2013). Environmental Sanitary Risk Analysis Procedure Applied to Artificial Turf Sports Fields. Environ Sci Pollut Res. 20:4980–4992. DOI 10.1007/s11356-012-1390-2	"For all the fields and for all the routes, the cumulative carcinogenic risk proved to be lower than 10-6 and the cumulative noncarcinogenic risk lower than 1. The outdoor inhalation of dusts and gases was the main route of exposure for both carcinogenic and non-carcinogenic substances....the inhalation of atmospheric dusts and gases from vehicular traffic gave risk values of one order of magnitude higher than those due to playing soccer on an artificial field."	Exposure pathways considered: "direct dermal contact (DDC)), dermal contact with the rainwater soaking the infill (rain water contact (RWC)) and inhalation of dusts and gases from the fields (dust and gas inhalation (DGI)."
64	Savary, B; Vincent, R. (2011). Used Tire Recycling to Produce Granulates: Evaluation of Occupational Exposure to Chemical Agents. Ann Occup Hygen. 55(8):931-936.	"Exposure was assessed in four facilities where used tires are turned into rubber granulates...The results of this study indicate significant exposure to complex mixtures of rubber dust." "exposure levels measured in these four facilities were between 0.31 and 41.00 mg/m^3; the ambient concentrations were between 0.17 and 6.23 mg/m^3." "VOC levels >1 ppm. were not detected."	
65	Schilirò, T; Traversi, D; Degan, R; Pignata, C; Alessandria, L; Scozia, D; Bono R; Gilli, G. (2013). Artificial Turf Football Fields: Environmental and Mutagenicity Assessment. Arch Environ Contam Toxicol. 64(1):1-11.	"On the basis of environmental monitoring, artificial turf football fields present no more exposure risks than the rest of the city."	
66	Selbes, M; Yilmaz, O;, Khan, AA; Karanfil, T. (2015). Leaching of DOC, DN and Inorganic Constituents from Scrap Tires. Chemosphere. 139:617-23.	"...a constant rate of leaching was observed for iron and manganese, which are attributed to the metal wires present inside the tires. Although the total amounts that leached varied, the observed leaching rates were similar for all tire chip sizes and leaching solutions."	
67	Serentis,T J; McNitt, AS; Petrunak, DM. (2011) Human Health Issues on Synthetic Turf in the USA. Proceedings of the Institute of Mechanical Engineers, Part P, Journal of Sports Engineering and Technology. 225(3): 139-146.	"S. aureus colonies were not found to be present on any field; however, S. aureus colonies were found on other tested surfaces, including blocking pads, used towels, and weight equipment."	"Indoor fields tended to have lower overall microbial populations (0–7267CFU/g of infill) than outdoor fields (0–80 000CFU/g) (Table 2). While it is clear that microbes exist on synthetic turf surfaces, the number was low compared with those on natural turf grass."
68	Shalat, SL. (2011). An Evaluation of Potential Exposures to Lead and Other Metals as the Result of Aerosolized Particulate Matter from Artificial Turf Playing Fields. Submitted to the New Jersey Department of Environmental Protection. http://www.nj.gov/dep/dsr/publications/artificial-turf-report.pdf.	"The highest observed air level was observed on the PIPER (robotic) sample collected on Field 1 - 71.9 ng/m3 on a field with PIPER wipes of 10.33 µg/ft2. This air level approaches approximately half of the U.S.E.P.A., NAAQS of 150 ng/m3." "...the results suggest that there is a potential for inhalable lead to be present on turf fields that have significant amounts of lead present as detectable by surface wipes. It also would appear likely from this sample that if the lead is present to any appreciable extent in the wipes it will likely be present in the breathing zone of players who are active on these fields, and that furthermore, these levels potentially exceed ambient EPA standards. Given that these are only occasional exposures this tends to reduce the risk of adverse health effects."	
69	Sheehan, PJ; Warmerdam, JM; Ogle, S; Humphrey, D; Patenaude, S. (2006). Evaluating the Risk to Aquatic Ecosystems Posed by Leachate from Tire Shred Fill in Roads Using Toxicity Tests, Toxicity Identification Evaluations, and Groundwater Modeling. Environmental Toxicology and Chemistry. 25(2): 400-411.	"Elevated levels of iron, manganese, and several other chemicals were found in tire shred leachates. However, chronic toxicity tests with Ceriodaphnia dubia and fathead minnows (Pimephales promelas) showed no adverse effects caused by leachates collected from tire shreds installed above the water table. Exposure to leachates collected from tire shreds installed below the water table resulted in significant reductions to both survival and reproduction in C. dubia. The TIE results indicated that exposure to soluble metals (likely ferrous iron primarily) and the formation of iron hydroxide precipitates on this invertebrate species likely were the causes of the observed effects."	
70	Simcox, NJ; Bracker, A; Ginsberg, G; Toal, B; Golembiewski, B; Kurland, T; Hedman, C. (2011). Synthetic Turf Field Investigation in Connecticut. J Toxicol Environ Health A. 74(17):1133-49.	"Results showed that personal concentrations were higher than stationary concentrations and were higher on turf than in background samples for certain VOC. In some cases, personal VOC concentrations from natural grass fields were as high as those on turf. Naphthalene, BZT, and butylated hydroxytoluene (BHT) were detected in greater concentration at the indoor field compared to the outdoor fields. Nitrosamine air levels were below reporting levels. PM10 air concentrations were not different between on-field and upwind locations. All bulk lead (Pb) samples were below the public health target of 400 ppm."	"More research is needed to better understan
71	Sullivan, JP. (2006). An Assessment of Environmental Toxicity and Potential Contamination from Artificial Turf using Shredded or Crumb Rubber. Ardea Consulting: Woodland, CA. p. 1-43.	"The impacts on human health of crumb rubber used in artificial turf are not known at this time. However, there is some evidence that tire rubber can be harmful either from direct contact or from associated dust. The most common detrimental health effect resulting from direct exposure to tire rubber is allergic or toxic dermatitis. Inhalation of components of tire rubber or dust particles from tire rubber can be irritating to the respiratory system and can exacerbate asthma. It is not clear whether dermal or inhalation exposure to tire rubber can lead to sufficient absorption of chemicals to cause mutagenic or carcinogenic effects. The degree of direct contact between the rubber used in artificial turf is not well enough known at this time to determine whether the level of the potential for harm to humans playing on artificial turf containing crumb rubber. The impacts on the environment of using crumb rubber in artificial turf also are not known at the present time...Zinc is the predominant toxicant to plants...The aquatic toxicity issue is not very clear cut."	Good background information on uses of scrap tires and regulations governing their disposal. "The actual amount of contamination leaching from artificial turf used on playgrounds or athletic fields needs further research to determine the potential harm to human health or the environment."
72	Torsten Kallqvist. (2005). Environmental Risk Assessment of Artificial Turf Systems. Report 5111-2005. Norwegian Institute for Water Research. Oslo. http://www.isss.de/conferences/Dresden%202006/Technical/NIVA%20Engelsk.pdf.	"The risk assessment shows that the concentration of zinc poses a significant local risk of environmental effects in surface water which receives run-off from artificial turf pitches. In addition, it is predicted that concentrations of alkylphenols and octylphenol in particular exceed the limits for environmental effects in the scenario which was used (dilution of run-off by a factor of ten in a recipient). The leaching of chemicals from the materials in the artificial turf system is expected to decrease only slowly, so that environmental effects could occur over many years. The total quantities of pollution components which are leached out into water from a normal artificial turf pitch are however relatively small, so that only local effects can be anticipated."	

73	Van Rooij, JGM; Jongeneelen, FJ. (2010). Hydroxypyrene in Urine of Football Players After Playing on Artificial Sports Fields with Tire Crumb Infill. Int Arch Occup Environ Health. 83(1):105-10.	Only 1 of the 7 participants showed an increase in post-exposure urine concentration over pre-exposure concentrations. "This study provides evidence that uptake of PAH by football players active on artificial grounds with rubber crumb infill is minimal. If there is any exposure, than the uptake is very limited and within the range of uptake of PAH from environmental sources and/or diet."	
74	Van Ulirsch, G; Gleason, K; Gerstenberger, S; Moffett, DB; Pulliam, G; Ahmed, T; Fagliano, J. (2010). Evaluating and Regulating Lead in Synthetic Turf. Environmental Health Perspectives. 118(10):1345-9.	"Data collected from recreational fields and child care centers indicate lead in synthetic turf fibers and dust at concentrations exceeding the Consumer Product Safety Improvement Act of 2008 statutory lead limit of 300 mg/kg for consumer products intended for use by children, and the U.S. Environmental Protection Agency's lead-dust hazard standard of 40 µg/ft2 for floors.....Synthetic turf can deteriorate to form dust containing lead at levels that may pose a risk to children."	
75	Verschoor, AJ. (2007). Leaching of Zinc from Rubber Infill in Artificial Turf (football pitches). RIVM Report 601774011 Bilthoven. http://www.parks.sfgov.org/wcm_recpark/SPTF/Verschoor.pdf.	"...zinc leaches to the soil, groundwater and surface water...Environmental quality standards for zinc in surface water and groundwater are exceeded...The study showed that the predicted concentrations of zinc in soil, under typical Dutch drainage conditions, also exceeds environmental quality standards.The risks of zinc to public health are of no concern: the human toxicity of zinc is low and WHO drinking water criteria are not exceeded...Laboratory experiments and measurements of field samples of the rubber infill show that the emission of zinc increases over time, due to chemical and physical changes of the rubber particle."	The authors make the following recommendations: "Mechanisms of behaviour and ageing of (different types of) rubber should be investigated to obtain a better understanding of the risks of zinc and other components leaching from rubber...It is recommended that measurements are first taken in drainage water from existing artificial turf with rubber infill of differing age and quality. Sampling at several time intervals in different seasons is preferred...Bioassay is recommended to assess the toxicity of the drainage water...A mini artificial turf field (1x1x1 m) can be built and exposed to outdoor weather conditions in a lysimeter...more advanced models can be used for a refined risk assessment."
76	Vetrano, KM; Ritter, G. (2009). Air Quality Survey of Synthetic Turf Fields Containing Crumb Rubber Infill. Prepared by TRC for the New York City Department of Mental Health and Hygiene, New York, NY. http://www.nyc.gov/html/doh/downloads/pdf/eode/turf_aqs_report0409.pdf	"Of the 18 SVOCs (17 PAHs and benzothiazole), 69 VOCs and 10 metals tested, a total of eight VOCs and two metals were detected in the air..." "Ranges of PM2.5 air concentrations from both turf fields were within background levels. Results from one of the bulk crumb rubber samples...identified an elevated lead level in the synthetic turf field at Thomas Jefferson Park." "Although VOCs were detected in the air, there was little evidence of harmful levels at the two sampled synthetic turf fields. Also, there was no consistent pattern to indicate that detected VOCs were associated with the synthetic turf. Similar concentrations were found in the background samples from the comparison grass field and upwind locations"	"An analysis of the air in the breathing zones of children above synthetic turf fields did not show appreciable levels from COPCs contained in the crumb rubber. Therefore, a risk assessment related to actual exposure to children was not warranted from the inhalation route of exposure." The focus of this study was air sampling, but they also did constituent characterization of bulk samples (not included in constituents tab); lead and zinc were above soil cleanup objectives for restricted residential land use.
77	Virginia Department of Health (VDH). (2015). Memo to Gloria Addo-Ayensu, Fairfax County Health Dept., from Dwight Flammia, Virginia Department of Health. September 28, 2015.	"Thank you for contacting the Virginia Department of Health (VDH) Division of Environmental Epidemiology with your request to review the appropriateness and rigor of methodologies used in artificial turf field related research reports your office submitted May 8, 2015. VDH has finished reviewing these documents and concludes that the methodologies were appropriate for assessing chemicals in crumb rubber and in the environment where crumb rubber is used."	"Reports that provide sampling methodology done exclusively in a controlled laboratory setting may not necessarily represent a "real world exposure" to chemicals in crumb rubber. However, laboratory analysis provides an alternative to identifying chemicals (by employing strong extraction techniques and concentrating chemicals to detectable concentration before analysis) in crumb rubber that might be present in low concentrations in the environment."
78	Zelibor, J L. (1991). The RMA TCLP Assessment Project: Leachate from Tire Samples. Scrap Tire Management Council. 1991.	"The results of the study indicated that none of the tire and other rubber products tested, cured and uncured, exceeded proposed TCLP Regulatory Levels or US EPA Drinking Water Standards. Most compounds detected were found at trace levels (near method detection limits) from ten to one hundred times less than proposed TCLP regulatory limits."	"...It is recommended that a field study be prepared in conjunction with key states (Ohio, Illinois, Pennsylvania, California, Texas, New York, New Jersey, North and South Carolina, Florida, Georgia, among others) and coordinated by the Scrap Tire Management Council." Its purpose would be to address questions "concerning the effect of leachate from scrap tire products in the environment...[specifically], 1) Which regulatory standards are appropriate to evaluate potential adverse effects on human health and environment from compounds leached from scrap tire or rubber products?; 2) Are there any realistic environmental conditions/applications where scrap tires leach compounds that exceed regulatory standards? 3) Are compounds leached from scrap tire products in the environment under specific applications? If so, what is the fate of those compounds in the environment?; (and) 4) Is there an adverse effect on groundwater, surface water or wetlands from the storage or application of scrap tires?"
79	Zhang, J; Han, IK; Zhang, L; Crain, W. (2008). Hazardous Chemicals in Synthetic Turf Materials and Their Bioaccessibility in Digestive Fluids. J Expo Sci Environ Epidemiol. 18(6):600-7.	The conclusions were: "(1) Rubber granules often, especially when the synthetic turf fields were newer, contained PAHs at levels above health-based soil standards. PAH levels generally appear to decline as the field ages...(2) PAHs contained in rubber granules had low bioaccessibility (i.e., hardly dissolved) in synthetic digestive fluids including salvia, gastric fluid, and intestinal fluid. (3) The zinc contents were found to far exceed the soil limit. (4) Lead contents were low...in all the samples in reference to soil standards. However, the lead in the rubber granules was highly bioaccessible in the synthetic gastric fluid. The analysis of one artificial grass fiber sample showed a slightly worrisome chromium content...and high bioaccessible fractions of lead in both the synthetic gastric and intestinal fluids."	
80	~~Edeskar, T. (2004) Technical and environmental properties of tyre shreds focusing on ground engineering applications. Lulea University of Technology Technical Report.~~ Not reviewed - not applicable.		
81	~~Hametner, C. (Certified Court Expert) (2007). Expert Witness: Evaluation of health risks caused by skin contact with rubber granulates used in synthetic turf pitches. CEN/TC 217/WG 10 - N024.~~ Not reviewed; not a scientific study; expert opinion only.		
82	Celeiro, M. et al. (2014). Investigation of PAH and Other Hazardous Contaminant Occurrence in Recycled Tyre Rubber Surfaces: Case Study: Restaurant Playground in an Indoor Shopping Centre. International Journal of Environmental Analytical Chemistry. 94(12): 1264-1271.	"In this case-study, fourteen out of the sixteen EPA priority PAHs were identified and quantified in the investigated recycled tyre rubber playground surfaces. The analytical measurements also confirmed the presence of other harmful compounds including phthalates, adipates, antioxidants and benzothiazole among others, in some cases at high concentration levels (DEHP> 3000 µg g-1)."	

83	~~Aoki, T. (2011). Current State and Perspective for Artificial Turf as Sport Environment: Focusing on Third-generation Artificial Turf as Football Playing Surface. Nature and its Environments 2-14.~~ Review of many of the papers that are already reviewed here. Also includes information from Aoki 2008; see reference 91.		
84	Dorsey, M J; Anderaon, A; Ardo, O; Chou, M; Farrow, E; Glassman, EL; Manley, M; Meisner, H; Meyers, C; Morley, N; Rominger, K; Sena, M; Stiefbold, M; Stites, B; Tash, M; Weber, E; Counts, P. (2015). Mutagenic Potential of Artificial Athletic Field Crumb Rubber at Increased Temperatures. The Ohio Journal of Science. 115(2).	"These results suggest that at the higher temperatures such as those on artificial athletic field surfaces, the crumb rubber infill on these artificial athletic fields can become the source of a water soluble agent with mutagenic potential in bacteria."	"Risk assessment studies are needed to consider the health impact of repeated exposure to crumb rubber at the conditions relevant to artificial athletic fields."
85	~~Drakos, M. C., et al. (2013). Synthetic playing surfaces and athlete health. Journal of the American Academy of Orthopaedic Surgeons 21(5): 293-302.~~ — Not suitable; it addresses injuries to athletes.		
86	Groenevelt, P. H. and P. E. Grunthal (1998). Utilisation of Crumb Rubber as a Soil Amendment for Sports Turf. Soil and Tillage Research. 47(1–2): 169-172.	"No elevated levels of VOC's or BNA's were detected in the leachate collected. Slightly elevated levels of boron, sodium and zinc, leached from acidic sandy loam soil amended with 30% rubber crumb. Concentrations of these elements from soil mixed with rubber crumb and lime, however, did not differ from those observed for control plots...Rubber also significantly increased the concentration of zinc in turfgrass clippings. However, elevated concentrations were not sufficient to produce zinc toxicity in turfgrass."	
87	Johns, DM; Goodlin, T. (2008). Evaluation of Potential Environmental Risks Associated with Installing Synthetic Turf Fields on Bainbridge Island. Seattle, Washington: Windward Environmental LLC.	"The available literature demonstrates that some chemicals can leach from tire crumb when it is exposed to water. While some studies report the presence of organic chemicals in leachate, the chemicals were detected at such low concentrations that authors considered them to be of little environmental relevance. The most consistent chemical to be detected in leachate tests is the metal zinc." "Toxicity tests on storm water collected from installed fields, or in laboratory tests using simulated precipitation events, indicate that water the percolates through turf fields with tire crumb is not toxic in tests that cover a wide range of aquatic plants and animals, including algae, bacteria, crustaceans, and fish."	This paper reviews many of the papers listed in this spreadsheet, focusing on leaching of chemicals in stormwater or rainwater and its potential environmental effects. It does not report on any additional original research. See related references.
88	Kim, HH; Lim, YW; Kim, SO; Yeo, IY; Shin, DC; Jang, JY. (2012b). Health Risk Assessment for Artificial Turf Playgrounds in School Athletic Facilities: Multi-route Exposure Estimation for Use Patterns. Asian Journal of Atmospheric Environment 6(3): 206-221.	"On the basis of the knowledge that is currently available concerning health effects and exposure linked to the use of artificial turf playgrounds, we did not find a direct health risk for users, except for children with pica."	
89	Mota, H; Gomes, J; Sarmento, G. (2009). Coated rubber granulates obtained from used tyres for use in sport facilities: A toxicological assessment. Ciência & Tecnologia dos Materiais. 21(3-4): 26-30.	"PAH leaching is negligendable...heavy metals content in the acidic water leachates considerably lower than the limit values imposed by DIN 18035-7 for all metals at 48 h leaching. For R2 coated rubber granulate the only exception is for tin, where the obtained value of 0,31 mg/L at 48 h leaching surpasses the limit value of 0.05 mg/L...both coatings, R1 and R2, show a lower toxicity when compared with the non-coated rubber granulates."	
90	Simon, R. (2010). Review of the Impacts of Crumb Rubber in Artificial Turf Applications. University of California, Berkeley, Laboratory for Manufacturing and Sustainability, prepared for The Corporation for Manufacturing Excellence (Manex).	"A review of existing literature points to the relative safety of crumb rubber fill playground and athletic field surfaces. Generally, these surfaces, though containing numerous elements potentially toxic to humans, do not provide the opportunity in ordinary circumstances for exposure at levels that are actually dangerous. Numerous studies have been carried out on this material and have addressed numerous different aspects of the issue. For the most part, the studies have vindicated defenders of crumb rubber, identifying it as a safe, cost-effective, and responsible use for tire rubber."	This paper was a review of various other papers included in this spreadsheet. See Related References. It did not provide any information on original experiments.
91	Aoki, T. (2008) Leaching of Heavy Metals from Infills on Artificial Turf by using Acid Solutions. Football Science. 5:51-53.	"The concentrations of leaching heavy metals increased with an increase in the acidity of the acid solutions." "The concentrations of Zn decreased with the aging of the SBR infills, and in the case of aging time greater than 1.25 years, the concentrations of Zn were less than the effluent standard in Japan..."	
92	~~French National Institute for Industrial Environment and Risks (2007). Environmental and Health Evaluation of the use of Elastomer Granulates (Virgin and From Used Tyres) as Filling in Third-Generation Artificial Turf.~~ Same as Moretto et al 2007. See Study 52.		
93	~~Tilford, RW. (2015) ACT Global Crumb Rubber Safety Study. http://recycledrubbercouncil.org/wp-content/uploads/2015/10/Act-Global-Crumb-Rubber-Safety-Study.pdf~~ Summary only; no information on the types and source of materials studied.		
94	ChemRisk, Inc. (2008). State of Knowledge Report for Tire Materials and Tire Wear Particles.	"The current state of knowledge indicates that there are data gaps which significantly limit a scientifically robust analysis of the potential environmental health risks associated with the selected tire materials and TWP. Thus additional data collection has been recommended."	"It was concluded that the most significant data gaps are: 1) lack of understanding of the chemical composition of TWP, 2) lack of understanding of the levels of TWP in the environment (air, soil, and sediments) and their potential associated health risks; and 3) lack of understanding of the potential for TWP to leach chemicals into the environment." "As such is it recommended that the following research be conducted to allow for environmental health risk assessment of TWP: chemical composition analysis of TWP generated under representative driving conditions; acute aquatic toxicity studies of TWP; characterization of TWP leachate under simulated environmental/biological conditions; development of chemical marker for TWP in environmental media; and, measurement of TWP in air, soil, water and sediment to determine representative exposure concentrations."
95	Toronto Public Health (2015). Health impact assessment of the use of artificial turf in Toronto. April 2015. City of Toronto. https://www1.toronto.ca/City%20Of%20Toronto/Toronto%20Public%20Health/Healthy%20Public%20Policy/Built%20Environment/Files/pdf/H/HIA_on_Artificial_Turf_Summary_Report_Final_2015-04-01.pdf	"Available evidence indicates that under ordinary circumstances, adverse health effects among adults and children are unlikely to occur as a result of exposure to artificial turf infilled with crumb rubber in both outdoor and indoor settings." "Based upon a review of the available evidence, third generation artificial turf is not expected to result in exposure to toxic substances at levels that pose a significant risk to human health provided it is properly installed and maintained and users follow good hygienic practices (for example washing hands, avoiding eating on artificial turf and supervision of young children to ensure they do not eat the infill material)"	There are "still some information gaps: the allergenic potential of latex in crumb rubber has not been thoroughly investigated; exposure to lead, other metals, carbon nanotubes, as well as other contaminants have not been fully evaluated in all types of turf systems"
96	van Bruggen, M. (2007). Nitrosamines Released from Rubber Crumb. RIVM report 609300002/2007.	"RIVM undertook a number of measurements above several pitches, at two different levels above the surface. None of these measurements showed the presence of nitrosamines in the atmosphere above the pitch. Supplementary laboratory tests on the materials showed that nitrosamines can only be released from rubber crumb to a very limited extent. Further to these findings, RIVM concluded that nitrosamines do not pose a health hazard to the users of these artificial pitches."	
97	Hofstra, U. (2007b). Follow-up Study of the Environmental Aspects of Rubber Infill: a Lab Study (performing weathering tests) and a Field Study Rubber Crumb from Car Tyres as Infill on Artificial Turf. Report prepared for the Tyre and Environment Association and Tyre and Wheel Trade Association.	"The impact of weathering of the rubber crumb for the technical lifetime of an artificial turf field (approx. 10 to 15 years) does not cause the leaching of zinc from the rubber crumb made from recycled car tyres to exceed the threshold values for dissolved zinc in surface water or the derived threshold value from the Decree on Soil Quality for the emission of zinc into the soil."	Study conducted by Hofstra for the Tyre and Environment Association and Tyre and Wheel Trade Association

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FRAP Status Report: State-of-the-Science Literature Review and Gap Analysis (LRGA)
Executive Summary

White Paper Summary of Results.
Appendix B (pp 39-91 FRAP Status Report)

See link below to view the 169 page FRAP Status Report

https://www.epa.gov/sites/production/files/201612/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf

Appendix B – State-of-the-Science Literature Review/Gaps Analysis

Tire Crumb Research Study

State-of-the-Science Literature Review/Gaps Analysis

White Paper Summary of Results

December, 2016

I. Executive Summary

Concerns have been raised by the public about the safety of recycled tire crumb rubber used in synthetic turf fields and playgrounds in the United States. Recycled tire materials used for synthetic turf infill and playground surface applications may lead to human exposures to chemical constituents in tire material. Human exposures to tire crumb rubber vary with time and activity associated with use of synthetic fields and playgrounds. Limited studies have not shown an elevated health risk from playing on fields with tire crumb, but the existing studies have not comprehensively evaluated the concerns about health risks from exposure to tire crumb rubber and important data gaps exist (U.S. EPA, 2016).

Because of the need for additional information, the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (ATSDR), and the U.S. Consumer Product Safety Commission (CPSC) launched a multi-agency action plan to study key environmental human health questions. The Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds (referred to hereafter as the Federal Research Action Plan) includes numerous activities, including research studies (U.S. EPA, 2016). The Federal Research Action Plan includes numerous activities related to the design and implementation of a tire crumb research study. An important component of the Action Plan is to identify key knowledge gaps to inform the conduct of other elements of the Federal Research Action Plan.

To comprehensively understand the current state-of-the science and data gaps associated with the toxicity of and human exposure to constituents in tire crumb rubber, CDC/ATSDR, EPA and CPSC undertook a collaborative effort to review the scientific literature and analyze data gaps (See Appendix B). The first objective of the Literature Review/Gaps Analysis (LRGA) collaboration was to identify the existing body of literature related specifically to human exposure to tire crumb rubber through the use of synthetic turf athletic fields and playgrounds. The second objective was to characterize and summarize the relevant data from the scientific literature. The final objective was to review the summary information and identify data gaps to build on the current understanding of the state-of-the-science and inform the development of specific research efforts that would be most impactful in the near-term.

Federal researchers examined a wide variety of information sources to build a list of relevant citations. The LRGA focused on scientific publications that addressed tire crumb rubber use, physical characteristics and chemical composition, potential pathways of exposures, bioavailability, and component toxicity and risk assessment. It included studies that examined occupational exposures at tire recycling plants, human exposures related to field and playground installations, and subsequent exposures involved with use of synthetic turf and playground facilities. It did not include studies on automotive tire manufacturing processes and related exposures and risks. In determining whether or not to include a publication found in the course of the literature search, a set of relevance criteria was developed. A Quality Assurance Project

Plan was also developed to guide data collection, organization and analysis. A number of other steps were taken to ensure quality in data entry and analysis.

The LRGA identified 88 relevant references. Each reference that was reviewed was categorized according to 20 general information categories (e.g., study topic, geographic location, sample type, conditions, populations studied) and more than 100 sub-categories (e.g., study topic sub-categories: site characterization, production process, leaching, off-gassing, microbial analysis, and human risk). As part of the effort, greater than 350 discrete chemical compounds also were identified in the literature collected for this effort and a list of potential chemical constituents was compiled to inform further research efforts.

The studies that were identified covered a wide range of topics and locations, but some topic areas received greater coverage than others. For example, information on chemical leaching and offgassing and volatilizing from tire crumb rubber was found in 36 and 25 studies, respectively, but less information was available on microbiological, bioavailability, and biomonitoring aspects of tire crumb rubber exposures (i.e., seven, five, and three studies, respectively). No epidemiological studies were identified in the literature search. Data gaps could be more pronounced for locations such as playgrounds and indoor fields, and for studies that examine environmental background levels of tire crumb rubber constituents. Studies on occupational exposures from turf and playground installations were also limited. Metal constituents of tire crumb rubber, such as lead and zinc, have been frequently identified in the literature as a constituents of concern, but research on exposures to these metals by field and playground users is limited. While a number of volatile and semivolatile organic chemicals (especially polycyclic aromatic hydrocarbons) have been measured in some studies, research on other organic chemical constituents identified by the LRGA is more limited.

Other important data gaps include the lack of more in-depth characterizing of dermal and ingestion exposure pathways, identifying constituents and scenarios resulting in the highest exposures, developing and applying biomonitoring for constituents of concern, and assessing the feasibility and approaches for epidemiological investigations. Several important data gaps for assessing exposures and risks of tire crumb rubber at synthetic fields and playgrounds are summarized in Table B-1.

The LRGA does not include critical reviews of the strengths and weaknesses of each study but does provide the author's conclusions regarding their research, where applicable. The LRGA does not make any conclusions or recommendations regarding the safety of the use of recycled tire crumb rubber in synthetic turf fields and playgrounds. The review provides information useful for guiding and designing future research efforts needed to further address questions regarding exposures and risks for tire crumb rubber used in synthetic turf fields and playgrounds.

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FRAP Data Gap Analysis
Table B-1. Data Gaps for Research on Tire Crumb Rubber in Synthetic Fields and Playgrounds.

Table B-1
Appendix B (pp 43-44 FRAP Status Report)

See link below to view the 169 page FRAP Status Report

https://www.epa.gov/sites/production/files/201612/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf

Table B-1. Data Gaps for Research on Tire Crumb Rubber in Synthetic Fields and Playgrounds

	Research Area	Data Gaps
Tire Crumb Rubber Characterization	Chemical Characterization	• Studies that have measured metal, volatile organic chemicals (VOCs), and semi-volatile organic chemicals (SVOCs) (e.g., polycyclic aromatic hydrocarbons [PAHs] and benzothiazole) were usually based on small numbers of tire crumb rubber samples. The wide range of organic chemicals potentially used in tire manufacture, or their degradates, have not been analyzed systematically across a large range of tire crumb rubber samples from synthetic fields and playgrounds in the United States. • Limited information is available on chemical constituents in molded rubber products made with tire crumb rubber used in some playground settings.
	Emissions Assessments	• Few laboratory-based studies have investigated VOC and SVOC emissions from synthetic fields and playgrounds under different temperature conditions. Measurements using dynamic emission chamber measurements have been reported, but the number and types of measured chemical emissions have been limited.
	Microbial Assessments	• Microbiological assessments for synthetic turf fields and playgrounds have been limited and have been based on traditional culture methods. The use of molecular methods has not been applied in studies of tire crumb rubber.
	Bioaccessibility	• Several studies have examined potential bioaccessibility of metals and PAHs. However, 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 are lacking.
	Variability	• 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. Also, information is limited on the range of chemical, microbiological, and physical characteristics and factors related to variability in tire crumb rubber and potential exposures.

Table B-1 (continued). Data Gaps for Research on Tire Crumb Rubber in Synthetic Fields and Playgrounds

	Research Area	Data Gaps
Exposure/Risk Characterization	Exposure Factors	• Exposure and risk assessments have typically relied on generic exposure factors. Information specific to the frequency and duration of synthetic field and playground uses, physical activities, contact rates, and hygiene are limited. • Exposure factor data are not available either across the wide variety of sports and recreational users of synthetic turf fields and playgrounds with tire crumb rubber, or for occupational exposures.
Exposure/Risk Characterization	Dermal/Ingestion Exposures	• While multiple studies have attempted to characterize potential inhalation exposures to tire crumb rubber chemical constituents, more limited information is available for understanding dermal and ingestion exposures.
Exposure/Risk Characterization	Broken Skin/Ocular Exposures	• Little information is available on the potential for increased exposures via broken skin (i.e., due to cuts and scrapes) and through ocular fluids.
Exposure/Risk Characterization	Particle Exposures	• There is limited information on exposure to tire crumb particles and their constituents through inhalation, dermal, and ingestion. Information on the exposure potential as synthetic fields and playgrounds age and weather, and for various uses and activities on synthetic fields and playgrounds is limited.
Exposure/Risk Characterization	Variability	• Few studies have evaluated the variability of exposures to tire crumb rubber constituents by activity type, exposure scenario, age, material type and condition, facility type and condition, and ambient conditions such as temperature and wind or ventilation. Limited information is available on the variability of exposures and related factors across a wide range of user groups and scenarios. • A few studies suggest that inhalation exposures at indoor facilities are higher compared to those at outdoor facilities, but the available information is limited.
Exposure/Risk Characterization	Biomonitoring	• Only a few biomonitoring studies have been performed. Only hydroxypyrene has been measured as a biomarker in athletes and workers. • Additional tire rubber-specific biomarker measurements have not been reported for synthetic field and playground users and biomarker analysis methods might be lacking for some chemicals. • Large scale biomonitoring studies of populations exposed and not-exposed to synthetic turf fields and playgrounds with tire crumb rubber have not been reported.
Exposure/Risk Characterization	Cumulative/Aggregate Assessments	• Exposures to multiple tire crumb constituents are likely to occur via multiple pathways (e.g., inhalation, ingestion, and dermal contact). However, studies that evaluated cumulative and aggregate exposure and risks are limited.
Exposure/Risk Characterization	Epidemiology Studies	• No epidemiological investigations for synthetic turf field or playground users were identified in the literature review. • Survey and biomonitoring tools for accurate assessment of relative exposures for synthetic field and playground users in an epidemiological study are lacking.
Alternative Assessments	Alternative Infills/Materials	• Most research to date has focused on characterizing tire crumb rubber infill. Similar research on other infill materials, including natural materials, ethylene propylene diene monomer (EPDM), thermoplastic elastomers (TPE), and recycled shoe rubber are either lacking or limited.
Alternative Assessments	Natural Grass Fields	• Few studies have been performed to assess potential chemical exposures from natural grass playing fields.
Alternative Assessments	Other Exposure Sources	• Only a few comparative assessments have been performed on relative exposures to chemicals associated with tire crumb rubber from other sources.

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FRAP Additional References

Appendix A – CDC Review of Published Literature and Select Federal Studies on Crumb Rubber and Synthetic Turf.

Appendix B (pp 92-104 FRAP Status Report)

See link below to view the 169 page FRAP Status Report

https://www.epa.gov/sites/production/files/201612/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_play grounds_status_report.pdf

IX. Appendices

Appendix A - CDC Review of Published Literature and Select Federal Studies on Crumb Rubber and Synthetic Turf

Review of Published Literature and Select Federal Studies on Crumb Rubber and Synthetic Turf

Product Sampling and Chemical Composition Studies

1. **Synthetic Turf Field Investigation in Connecticut**
   N. Simcox, A. Bracker, G. Ginsberg, B. Toal, B. Golembiewski, T. Kurland, C. Hedman; *Journal of Toxicology and Environmental Health, Part A*; **2011**.

   The purpose of the study is to characterize concentrations of VOCs, SVOCs, rubber-related chemicals, and PM10 in ambient air at selected fields with crumb rubber infill in Connecticut during summertime conditions and during active field use.

   Methods:
   - During July 2009, three types of fields were sampled:
     - Outdoor field with crumb rubber infill
     - Indoor facility with crumb rubber infill
     - Outdoor field with grass turf as background location
   - Air samples collected at older fields (>3 years) and at new fields (< 2 years).
   - Personal air sampling during simulated soccer game:
     - VOCs
     - SVOCs
     - Benzothiazole (BZT)
     - 2-mercaptobenzothiazole
     - 4-tert-octylphenol
     - Butylated hydroxyanisole
     - Butylated hydroxytoluene (BHT)
     - Nitrosamines
     - PM10

   Study results and/or conclusions:
   - For turf fiber and crumb rubber infill, lead levels were below the EPA "soil-lead hazard" limit and below the 300ppm target set by Consumer Product Safety Act for products to be used by children.
   - Of 60 VOCs, 31 were detected on field.
   - Personal air monitoring concentrations were higher on artificial turf than on grass for 21 VOCs.
   - Stationary samples on the outdoor fields were similar to background.
   - Total VOCs were higher indoors than outdoors, however, only a few VOCs were elevated indoors compared to background.
   - Benzo(a)pyrene was higher at the outdoor field than background (range ND-0.19 versus ND-0.05).
   - For the indoor field, 1-methylnapthalene, 2-methylnapthalene, fluorene, napthalene, and pyrene were 10-fold higher than background.
   - There were several other PAHs found only on the indoor turf, acenapthene, acenaphthylene, fluorene, napthalene, and 2,6-dimethylnapthalene.
   - BZT and BHT were higher on the indoor field than outdoor field (BZT range 11,000-14,000 ng/m^3 versus <80-1,200 ng/m^3; BHT range 1,240-3900 ng/m^3 versus <80-130 ng/m^3).

   Study limitations:
   - Potential selection bias as field location participation was voluntary.
   - Sample size was small.
   - Summer 2009 temperatures were lower than normal.
   - Personal sampling occurred at waist height, not in the breathing zone.
   - Some VOCs were found in the personal samples, but not the turf or background indicated non-turf related sources.

2. **Hazardous organic chemicals in rubber recycled tire playgrounds and pavers**
M. Llompart, L. Sanchez-Pardo, J. Lamas, C. Garcia-Jares, E. Roca; *Chemosphere*; 2013.

The purpose of the study was to investigate the presence of hazardous organic chemicals in recycled tire playground surfaces.

Methods:

- 21 samples from 9 urban playgrounds
- 2 types of ground covers - floor tiles compositions and carpet covers
- 7 samples from a local store; 2 puzzle pavers and 5 recycled rubber tire tiles of different colors
- Ultrasound-assisted extraction followed by pressurized solvent extraction
- GC-MS for PAHs, plasticizers and other phthalates (31 compounds total)
- Solid-phase microextraction (SPME) for vapour phase composition profiles

Study results and/or conclusions:

- For playground samples
  - Full GC-MS scan identified a large number of VOCs, SVOCs, and POPs.
  - All samples contained PAHs with a range of 1.25 μg g-1 to 70.4μg g-1 total PAH amount with one sample having a concentration of 178μg g-1
  - Pyrene was the most abundant congener found in all samples.
  - Napthalene, phenanthrene, fluoranthene, and chrysene were found in 20 or 21 samples.
  - B(a)P was found in 5 samples with values ranging from 0.4μg g-1 to 5.0μg g-1.
  - Benzothiazole (BTZ) was found in all playground samples with a mean concentration of 10μg g-1.
  - 2-mercaptobenzathiole (MBTZ) was found in playground samples, but there were methodological issues with the analysis.
  - 4-tert-butylphenol (TBP) was present in half the playground samples at low concentrations.
  - Butylated hydroxytoluene (BHT) was found in all samples but butylated hydroxyanisole (BHA) was not found in the samples.
  - Phthalates were found in all samples with the most abundant congener being di(2-thylhexyl)phthalate, concentrations ranging from 4 to 64 μg g-1.
  - Diisononyl phthalate (DINP) was found in 8 of 21 playground samples but was not detected in commercial pavers.
  - For the SPME analysis, all PAHs found in the samples were detected excluding the less volatile ones. BZT, DEP, DIBP, DBP, DEHP, and BHT were found in all cases.
- For commercial pavers:
  - Higher PAH concentrations compared to playground samples.
  - For 5 of 7 samples, concentrations were extremely high - 2000μg g-1 to 8000μg g-1.
  - All PAHs were found in all samples with a mean concentration of B(a)P = 500μg g-1.
  - BZT was found in all commercial pavers with concentrations ranging from ~20 to >150 μg g-1.
  - MBTZ was not detected in commercial pavers.
  - TBP was present in all pavers with concentrations ranging from 8.6 to 21μg g-1.
  - BHT was found in all pavers with a mean concentration 19μg g-1.
  - Phthalate concentrations were higher in pavers than playground samples. DEHP concentrations ranged from 22 to 1200μg g-1.
  - For the SPME analysis, volatile PAHs and some less volatile PAHs (including B(a)P) were found in some samples. BZT, DEP, DIBP, DBP, DEHP, and BHT were found in all cases.
  - TBP was also found in most samples.
- Research is ongoing as a high number of compounds (excluding the ones in this study) were found in the samples.

Study Limitations:

- The study did not determine bioavailability of the chemicals after ingestion or upon dermal exposure.
- For the SPME analysis, inhalation exposure is indicated as possible by the authors; however, laboratory vapor phase composition does not mimic field conditions and thus potential exposure conditions.

3. **Metals contained and leached from rubber granulates used in synthetic turf areas**
B. Bocca, G. Forte, F. Petrucci, S. Costantini, P. Izzo; *Science of the Total Environment*; 2009.

The purpose of the study was to quantify metals contained in and leached from different types of rubber granulates used in synthetic turf.

Methods:

- 32 samples from 32 different playgrounds in Italy were collected with samplings performed at different positions in the playground to obtain a representative sample for each area with 250g granulate obtained from 12 sectors.
- 50g granulate from each of the 12 samples pooled to obtain 1 sample per playground.
- Each sample was analyzed for metal content.
    - Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Li, Mg, Mn, Mo, Ni, Pb, Rb, Sb, Se, Sn, Sr, Tl, V, W, Zn
- The levels were compared to the maximum concentrations allowable for soils.

<u>Study results and/or conclusions</u>:

- The rubber granulates contained all the metals included in the analysis, but the concentration range was wide in the different samples.
- Relatively high levels of Al, Fe, Mg, and Zn were found.
- All samples had metal concentrations significantly lower than the allowable limit, except Co, Sn, and Zn.
- 50% of samples exceeded the Co and Sn limit, while 97% of samples exceeded the limit for Zn with values around 100x higher than the standard.
- The highest leaching was observed for Zn (2,300 µg/L).
- Very low concentrations of As, Cd, CO, Cr, Cu, Li, Mo, Ni, Pb, Rb, Sb, and V were leached and Be, Hg, Se, Sn, Tl, and W were under the LOQ.

<u>Study Limitations</u>:

- Assessments of risk should be conducted for each individual case at a local level due to differences in local ground conditions, type of drainage, and the composition of the filler material.
- The results were compared to the allowable limit for metals in soil which may not be an appropriate comparison.

4. **Health Risk Assessment for Artificial Turf Playgrounds in School Athletic Facilities: Multi-route Exposure Estimation for Use Patterns**

H. Kim, Y. Lim, S. Kim, I. Yeo, D. Shin, J. Yang; *Environmental Health and Toxicology*; **2012.**

The purpose of the study was to identify major exposure routes and calculate total risk through a health risk assessment for chemicals released from artificial turf playgrounds and urethane flooring tracks.

<u>Methods</u>:

- 50 schools with artificial turf and urethane flooring at the playgrounds; 27 elementary schools and 23 middle and high schools
- Inhalation of VOCs and formaldehydes due to volatile outdoor air from surfaces of artificial turf and urethane flooring
- Dermal uptake from surfaces of artificial turf and urethane flooring
- Ingestion exposure to fine particles
- Trace metals (Pb, Cr, Ni, Cd, Zn, Hg)
    - Dust collected at 5L/min for 8 hours.
    - Urethane layer collected from flooring materials in schools.
    - Infill chip layer collected from chip flooring material in parks.
    - Product surface sampling was conducted using texwipe.
    - Hand surface sampling was performed using texwipe after children played on the facility.
- VOCs
    - Air samples collected at 0.2L/min at 1.5m for 2 hours
    - Infill chips (see Metals #2 and #3).
    - Air samples collected
    - Infill materials (see Metals #2 and #3; surface sampling and hand sampling not performed)
- Phthalates
    - Infill materials (see Metals #2 and #3)
    - Surface sampling (see Metals #4)
    - Hand sampling (see Metals #5)
- Sampling was conducted at the top of the central playground so as to eliminate other potential emission sources.

<u>Study results and/or conclusions</u>:

- Infill content for heavy metals had highest concentration of Zn > Pb > Cr.
- Pb exceeded standard in infill from 8 of the schools and exceeded the domestic standard (10mg/kg) in 2 of the schools.
- For the air monitoring, Zn had the highest concentration; Pb was detected but levels were 10% of Korean ambient air standards.
- Bioavailability values were estimated and for infill chips were shown to be 10-10,000 times lower than the measured content level; for the urethane flooring, the bioavailability was estimated to be approximately 10x lower than the infill chips.
- The excess cancer risk (ECR) for individual chemicals was estimated to be a level of one person out of one million (1×10-6) or less.

- The ECR for carcinogens in children with pica, who represent the most extreme exposure type among the facility users, was shown to be 1.14×10-7 for benzene and 8.47×10-7 for PAHs.
- The hazard index (HI) of the facility users for each individual chemical according to the mean exposure scenario was shown to be less than 0.1, which was low, except for children with pica.
- The HI of children with pica for non-carcinogenic materials was shown to be less than 0.001for Pb, 0.067 for Cr, Cd and Hg, 0.005 for Zn, 0.001 for VOCs; and 0.273 for phthalates, all of which were low, except for phthalates.

Study Limitations:

- The study did not consider asthma or allergic reactions in the health assessment.
- The authors assumed that all chemicals in the air sampling were from artificial turf or urethane flooring, and that there were no other air emission sources.

5. **Comparison of Batch and Column Test for the Elution of Artificial Turf System Components**
O. Kruger, U. Kalbe, W. Berger, K. Nordhaub, G. Christoph, H.P. Walzel; *Environmental Science and Technology*; **2012**

The purpose of the study was to compare the behavior of synthetic sports flooring components at different elution methods.

Methods:

- Artificial turf components from 6 German producers.
- Batch tests were performed with a liquid to solid ratio of 2L/kg.
- Column tests were performed with a liquid to solid ratio of 26.5 L/kg.
- pH, electric conductivity, turbidity of the eluates, and contaminant release were measured.
- Specific emphasis placed on zinc (ICP-OES) and PAHs (15 measured with HPLC).

Study results and/or conclusions:

- Lead and cadmium were under the LOQ while zinc concentrations varied from below LOQ - 129 mg/L.
- The PAH concentrations varied from 0.07-3.41 µg/L.
- The batch testing produced higher concentrations of zinc; however, column testing provides conditions closer to actual field conditions.

Study Limitations:

- Batch test conditions did not mimic actual field conditions.

6. **Release of Polycyclic Aromatic Hydrocarbons and Heavy Metals from Rubber Crumb in Synthetic Turf Fields: Preliminary Hazard Assessment for Athletes**
L. Marsili, D. Coppola, N. Bianchi, S. Maltese, M. Bianchi, M.C. Fossi; *Journal of Environmental and Analytical Toxicology*; **2014.**

The purpose of the study was to quantify the PAHs and heavy metals contained in the crumb rubber (tires produced before 2010), to determine whether PAHs are released and at what concentrations, and to estimate respiratory uptake by athletes training on these fields.

Methods:

- Samples were taken from nine different synthetic turfs from football fields in Italy
- 4 samples were new tire crumb rubber that was not yet on a fields.
- 4 samples of tire crumb rubber from fields 1-8 years old, and 1 sample from virgin rubber (i.e. not recycled tires)
- Heavy metals: Pb, Cu, Ni, Zn, Cr, Cd, Fe
    - Concentrations determined via spectrophotometer and spectrometer
- PAHs: 14 analytes determine via HPLC

Study results and/or conclusions:

- The majority of samples had concentrations of heavy metals that were below the maximum limits set by the Italian National Amateur League.
- Cd exceed the limit in 3 samples, 2 new and 1 installed.
- Zn was very high in all samples, exceeding the limit by a minimum factor of 20.
- PAH concentrations varied by sample. For all crumb rubber samples, highest concentrations were benzo(b)fluoranthene or pyrene.
- The data indicate that PAHs are released continually from the crumb rubber via evaporation and athletes frequenting fields could be exposed to chronic toxicity from PAHs.

Study Limitations:

- The preliminary hazard assessment overestimates the PAH contribution.
- Theoretical approach which must be considered as an extreme worst case scenario.

7. **A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds**
U.S. Environmental Protection Agency; **2009.**

The purpose of the study was to generate limited field monitoring data that will be used by EPA to help determine possible next steps to address concerns regarding the safety of tire crumb infill in recreational fields.

Methods:

- Scoping level study evaluating environmental concentrations of tire crumb constituents in recreational fields.
- Two synthetic turf fields and one playground were chosen as the sampling locations.
- Air sampling was conducted at 1m height:
    - PM10 analyzed for mass, metals, and particle morphology
    - VOCs for 56 analytes (2pm collection time at the fields and at an upwind background location).
- Wipe sampling was conducted at the fields and also with tire crumb infill and turf blade samples
    - Pb, Cr, Zn, As, Al, Ba, Cd, Cu, Fe, Mn, Ni (ICP/MS).
- Percent bioaccessible Pb was calculated.

Study results and/or conclusions:

- All VOCs, PM, and metals were similar to all background levels and were below the national ambient air quality standards.
- Methyl isobutyl ketone was detected at one synthetic turf field and was not detected in the background samples.
- The extractable lead concentrations from the infill, turf blades, and tire crumb materials were low and below the EPA standard for lead in soil.
- Lead concentrations in the wipe samples were low and below the EPA standard for lead in residential floor dust.

Study Limitations:

- Semi volatile organic compounds were not measured in this study.
- Sites where samples were taken could have many variabilities in the materials used and possible environmental differences.
- There were some difficulties obtaining permission to access the playgrounds and synthetic turf fields.

8. **CPSC Staff Analysis and Assessment of Synthetic Turf "Grass Blades"**
Consumer Product Safety Commission

The purpose of the study was to determine the total lead content and accessibility of the lead.

Methods:

- Samples of synthetic turf at the time of installation and samples from when 1 field was dismantled.
- Lead content of grass blades was determined using ICP.
- Samples with detectable lead were tested for accessibility of lead.
- For in-service fields, X-ray fluorescence was used to detect the presence of lead.

Study results and/or conclusions:

- Synthetic turf lead content ranged from 0.09% to 0.96% and varied between the turfs and also within a field depending on color.
- The results for this set of tested synthetic turf fields show no case in which the estimated exposure for children playing on the field would exceed 15 mg lead/day (according to the CPSC's recommendation for chronic lead ingestion not exceeding 15 mg lead/day, daily).

Study Limitations:

- Accuracy of wipe sampling method for estimating exposure to lead contact residue is unknown.
- Dermal contact to skin with lead residue during a typical play event on a field was assumed.
- Experimental wipe method overestimated transfer to a persons' bare skin by a factor of 5 to 13.
- Bioavailability of lead from synthetic turf may not be the same as it is for the food and drink exposures that were the basis of the dose-response.

- Staff did not make adjustments in the assessment to account for differences in lead content as fields can have areas with different lead content (i.e. painted areas, etc.).

9. **Environmental–sanitary risk analysis procedure applied to artificial turf sports fields**
B. Ruffino, S. Fiore, M. C. Zanetti; *Environmental Science and Pollution Research*; **2013.**

The purpose of the study was to characterize chemicals in crumb rubber and assess their capacity to release the chemicals on contact with water. The study also evaluated if the rubber granules may pose a risk to child and adult players via direct contact, contact with rainwater soaking the field, or inhalation of dusts and gases released.

Methods:

- Four sports turf fields with crumb rubber infill, 1 field with thermoplastic elastomer, and 1 natural turf field.
- Field age varied from 1-3 years old.
- Rubber and soil samples were analyzed for BTX (GC-MS), PAHs (8, GC-MS), and metals (18, ICO-OES).
- In-water extractable compounds (BTX, PAHs, and metals) were analyzed.
- Gases and dusts were collected immediately above the ground, close to the sports fields, and at a point in the center of the city.
    - Samples were analyzed for BTX (gases) and PAHs (dust).

Study results and/or conclusions:

- Concentration of benzene is similar to those in the natural turf field.
- Pyrene concentrations in synthetic turf are approximately 20 mg/kg and B(a)P concentrations were 10 mg/kg.
- Zinc concentrations were substantially higher in synthetic turf compared to the natural turf sample; 115 times higher at the synthetic turf field with the lowest percentage zinc.
- The leaching tests identified higher BTX and PAHs in leachates from new infill material was higher than the old infill materials.
- For all turf fields examined and for all routes considered, the cumulative CR proved to be lower than 10–6 and the non-carcinogenic risk (for the sum of COCs) lower than 1, in line with Italian guidelines.
- Additionally, for the inhalation route, the inhalation of dust and gases from activity on artificial turf fields gave risk values less than those due to inhalation of atmospheric dust and gases from vehicular traffic.

Study Limitations:

- Some of the artificial turf fields were in various stages of age (the samples that were from newer fields had higher chemical and metals concentrations than older fields).
- Sample comparison was limited to one city's atmospheric dusts and gases and may not be the best representation of typical vehicular dust and gases being emitted.

10. **Human Health Risk Assessment of Synthetic Turf Fields Based Upon Investigation of Five Fields in Connecticut**
G. Ginsberg, B. Toal, N. Simcox, A. Bracker, B. Golembiewski, T. Kurland, C. Hedman; *Journal of Toxicology and Environmental Health, Part A*; **2011.**

The purpose of the study was to develop a screening level risk assessment in which high-end assumptions for exposure were used for uncertain parameters and surrogate data were employed for chemicals with inadequate toxicity information so that chemicals did not fall out of the assessment on the basis of missing data.

Methods:

- Personal air samples were taken from volunteers during 2-h sampling event at 5 artificial grass fields (4 outdoor and 1 indoor) with crumb rubber infill.
- Stationary air samples were also taken near the field.
- Air samples were analyzed for VOCs (60), SVOCs (120, including 22 PAHs), lead, nitrosamines (7), and PM10.

Study results and/or conclusions:

- 10 VOCs were considered chemicals of potential concern (COPC) for the outdoor and fields and 13 VOCs for the indoor fields.
- Personal monitoring results were higher for VOCs than the stationary sampling results.
- The VOCs of potential concern were above background concentrations at only one of the outdoor fields (not the same field in every case), except for toluene and hexane which were above background at two fields.

- Personal monitoring samples showed VOCs were 1.5-to-3-fold greater than background at outdoor fields, except methylene chloride which was 12.8-fold higher.
- Indoor VOCs detections tended to have greater elevations relative to background.
- 2 SVOCs were selected as COPC, benzothiazole (BTZ) and butylated hydroxytoluene (BHT).
- BZT was above background at indoor and outdoor fields; max indoor result was 11.7-fold higher than max outdoor result.
- BHT was detected at all fields and results were higher for stationary monitoring.
- BHT is a COPC for the indoor field.
- A variety of PAHs were detected above background but the concentrations were generally low (well below 1µg/m3).
- Less volatile PAHs were detected in the outdoor field while the more volatile PAHs were found indoors but generally not outdoors
- Lead results were below the 300ppm target set by the CPSC for lead in products intended for children.
- Based upon the findings, outdoor and indoor synthetic turf fields are not associated with elevated adverse health risks.

<u>Study Limitations</u>:
- Small number of fields in the study.
- Only one indoor field was included in the study.
- Some limitations in weather variables when taking samples at outdoor fields.
- Small number of samples taken per field.
- The study did not attempt to measure latex antigen in the crumb rubber or in the PM10 collected from on field air samples.
- Some VOC detections in the personal monitoring may have originated in the device.

11. **Artificial Turf Football Fields: Environmental and Mutagenicity Assessment**
T. Schiliro, D. Traversi, R. Degan, C. Pignata, L. Alessandria, D. Scozia, R. Bono, G. Gilli; *Archives of Environmental Contamination and Toxicology*; **2013.**

The purpose of the study is to develop an environmental analysis drawing a comparison between artificial turf football fields and urban areas relative to concentrations of particles (PM10 and PM2.5) and PAHs, BTEX, and mutagenicity of organic extracts from PM10 and PM2.5.

<u>Methods</u>:
- 24 Air samples were taken from 6 football fields (5 were artificial turf) and 2 urban locations in 2 sampling events to study influence of meteorological and seasonal conditions and the presence of play.
- PM10, PM2.5, BTX (benzene, toluene and Xylene), and PAHs were measured in the air samples.
- The mutagenicity of the organic extracts of the PM and PM2.5 samples were studied using the Ames test.

<u>Study results and/or conclusions</u>:
- Air samples from the artificial turf field had no significant differences from the samples from the urban sites.
- BTX concentrations at the urban site were significantly greater than on the turf fields.
- Seasonal differences were also seen.
- In regards to environmental monitoring, artificial turf fields present no worse exposure risks than those found in the city.
- PAH concentrations, when detected, were low.
- PAH concentrations were greater in the winter than the summer.
- B(a)P was present on the football fields during the winter sampling.
- During the winter season sampling, PAHs, except anthracene, were often present on each football field and at the urban site.
- The mutagenicity showed a seasonal trend and was greater on fields characterized by traffic and/or industrial emissions in the surrounding area.

<u>Study Limitations</u>:
- Urban locations used to compare field results might not be a good overall representation of urban areas in general.
- Non-turf related environmental variables at both the fields and urban areas could be of influence.

12. **Artificial-turf playing fields: Contents of metals, PAHs, PCBs, PCDDs and PCDFs, inhalation exposure to PAHs and related preliminary risk assessment**

E. Menichini, V. Abate, L. Attias, S. De Luca, A. di Domenico, I. Fochi, G. Forte, N. Iacovella, A. L. Iamiceli, P. Izzo, F. Merli, B. Bocca; *Science of the Total Environment*; 2011

The purpose of this study was to identify some potential chemical risks and to roughly assess the risk associated with inhalation exposure to PAHs from materials used to make up artificial turf fields.

<u>Methods</u>:

- Rubber granulates were collected from 13 Italian fields. For the 13 fields, samplings were performed at different positions in the playground to obtain a representative sample for each area (see Bocca et al #4).
- Rubber samples varied and included virgin thermoplastic, coated and uncoated recycled tires, recycled vulcanized rubber, and recycled ground gaskets.
- Samples were analyzed for 25 metals and 9 PAHs.
- Air samples were collected on filter at two fields, using static and personal samplers, and at background locations outside the fields.

<u>Study results and/or conclusions</u>:

- High contents of Zn and benzo(a)pyrene were found in the granules present in playing fields (above the Italian standards for soils).
- Other chemicals such as PAHs, VOCs, PCBs, PCDDs and PCDFs were found in the recycled crumb rubber but were at levels within the mentioned limits.
- Based on the 0.4 ng/m3 concentration and using a worst-case conservative approach, an excess lifetime cancer risk of 1× 10−6 was calculated for an intense 30-year activity (5h/d, 5d/w, all year long).

<u>Study Limitations</u>:

- Only particle phase air samples were taken (TSP or PM10). So the inhalation exposure may be under-estimated for missing information on contaminants in the gaseous phase.
- Inhalation risk assessment was based on limited data and the risk assessment should be regarded as preliminary.
- Fields may vary in age and type of rubber used which could affect the samples and chemicals found in them. Environmental factors such as climate and weather could have an effect on study samples at the time of sampling.

13. **Characterization of substances released from crumb rubber material used on artificial turf fields**
X. Li, W. Berger, C. Musante, M. I. Mattina; *Chemosphere*; 2010.

The purpose of the study was to assess major volatilized and leached chemicals from crumb rubber material (CRM); assess the change of alteration of the pattern of volatile compounds with time after installation for both laboratory and field-aged samples under natural weathering conditions.

<u>Methods</u>:

- Vapor offgas and leachate samples from 15 crumb rubber material (CRM) samples were analyzed.
- The CRM samples were obtained from local schools and commercial suppliers.
- 10 organic chemicals (PAHs and VOCs) were measured in the vapor phase over CRM.

<u>Study results and/or conclusions</u>:

- During the vapor phase, CRM emitted volatile PAHs and other compounds.
- Benzothiazole (BTZ) was the most abundant volatile compound found in all the samples.
- Zinc was found to be the highest of all metals found in the samples' extraction fluid.
- There was a significant reduction in volatile compounds found in samples that were from artificial turf fields that were 2 years old compared to newer fields.
- It was also determined that there is some variability in the out-gassing profile of CRM from different manufacturers.

<u>Study Limitations</u>:

- This study provides mostly qualitative, not quantitative results, which makes the results difficult to compare to other studies.

14. **Toxicological Assessment of Coated Versus Uncoated Rubber Granulates Obtained from Used Tires for Use in Sports Facilities**
J. Gomes, H. Mota, J. Bordado, M. Cadete, G. Sarmento, A. Ribeiro, M. Balao, J. Fernandes, V. Pampulim, M. Custodio, I. Veloso; *Journal of the Air and Waste Management Association*; 2012.

The purpose of the study was to investigate whether coating rubber granulates decreased emissions of leachates and airborne substances.

<u>Methods</u>:

- Raw rubber granulates were obtained along with two coatings, a polyvinyl chloride and a cross-linked alquidic polymer, both which contained color additives and a flame-retarding agent.
- The coated rubber granulates were compared with the raw rubber granulates.
- Chemicals analyzed:
    - PM2.5 and PM10
    - PAHs (16; GC-MS)
    - Heavy metals (Cd, Cr, Hg, Pb, Sn, Zn; ICP-OES)

<u>Study results and/or conclusions</u>:

- Rubber granulates obtained cryogenically and semicryogenically have lower inhalable particles than those obtained mechanically
- For PAHs in raw and coated samples, one type of coating resulted in increased content of some PAHs.
- However, the leaching of PAHs from raw, R1 coated or R2 coated is negligible.
- For heavy metals, the concentrations in the leachate is very small and the coating does appear to prevent leaching of the metals.
- Both R1 and R2 coatings showed lower ecotoxicity than the non-coated rubber granulates.

<u>Study Limitations</u>:

- There are only two types of coating included in the analysis.
- It is noted that one of the coatings include polyvinyl chloride which has been excluded from certain textile products due to concerns over potential adverse health effects after human exposure.

15. Evaluating and Regulating Lead in Synthetic Turf

G. Van Ulirsch, K. Gleason, S. Gerstenberger, D. B. Moffett, G. Pulliam, T. Ahmed, and J. Fagliano; *Environmental Health Perspectives*; 2010

The purpose of the study was to present data showing elevated lead in fibers and turf-derived dust; identify risk assessment uncertainties; recommend that government agencies determine appropriate methodologies for assessing lead in synthetic turf; and recommend an interim standardized approach for sampling, interpreting results, and taking health-protective actions.

<u>Methods</u>:

- This is a commentary on lead in synthetic turf, using data collected from recreational fields and child care centers on lead levels in turf fibers and surface dusts.

<u>Study results and/or conclusions</u>:

- Synthetic turf can deteriorate to form dust containing lead at levels that may pose a risk to children.
- Given elevated lead levels in turf and dust on recreational fields and in child care settings, it is imperative that a consistent, nationwide approach for sampling, assessment, and action be developed.

<u>Study Limitations</u>:

- N/A. This is a commentary.
- Updated guidelines/standards for lead in synthetic turf blades were released after publication of the article.

Biomonitoring Study

1. Hydroxypyrene in urine of football players after playing on artificial sports field with tire crumb infill

J. G. M. Van Rooij, F. J. Jongeneelen; *International Archives of Occupational and Environmental Health*; 2010.

The purpose of the study was to assess the exposure of football players to PAHs from sporting on synthetic ground with rubber crumb infill (by measuring urinary 1-hydroxypyrene).

Methods:

- All urine samples were collected over 3 days (the days before, of, and after a 2.5-h football match) from 7 football players.
- 1-Hydroxypyrene (PAH biomarker) was measured in urine.

Study results and/or conclusions:

- The football players spent a total of 2.5 hours on the synthetic turf field.
- Three players likely had PAH exposure from pre-sporting activities and were omitted from the analysis.
- Uptake of PAH by football players playing on synthetic turf with rubber crumb infill is minimal.
- If there is any exposure, then the uptake is very limited and within the range of uptake of PAH from environmental sources and diet.

Study Limitations:

- Only 7 football players were in the study. The sample size is too small to represent the target population.
- Short exposure duration (2.5-h) and PAHs from other sources (such as diet) could have affected the player's results.
- Dietary and lifestyle questionnaires were not administered.

Bioavailability Studies

1. **Bio-accessibility and Risk of Exposure to Metals and SVOCs in Artificial Turf Field Fill Materials and Fibers**
   B. T. Pavilonis, C. P. Weisel, B. Buckley, P. J. Lioy; *Risk Analysis;* **2014**

   The purpose of the study was to determine whether the bio-accessible fraction of metals and SVOCs found in artificial turf fields exceeded non-cancerous risk-based guidance values for children and adult athletes.

   Methods:

   - New crumb infill (n=9), new turf fiber products (n=8), and field samples (n=7) were collected.
   - Using synthetic biofluid solutions, bio-accessibility analyses for metals and SVOCs were performed for the digestive system, respiratory system, and dermal absorption.

   Study results and/or conclusions:

   - PAHs were generally below the limit of detection in all three artificial biofluids.
   - SVOCs found were not present in toxicological databases evaluated and were in everyday consumer products.
   - Trace metals found were at minimal levels.

   Study Limitations:

   - Possible selection bias and the small number of fields used in this study.
   - The simulated digestive fluid may not reflect accurately true digestive capabilities in humans.
   - A large amount of variability was found among the field samples used in this study (some samples may have been from older fields or different versions/types of artificial turf).

2. **Health Risk Assessment of Lead Ingestion Exposure by Particle Sizes in Crumb Rubber on Artificial Turf Considering Bioavailability**
   S. Kim, J. Yang, H. Kim, I. Yeo, D. Shin, Y. Lim; *Environmental Health and Toxicology;* **2012.**

   The purpose of the study was to assess the risk of ingestion exposure of lead by particle sizes of crumb rubber in artificial turf filling material with consideration of bioavailability

   Methods:

   - Lead was measured using ICP-MS in the extracts of tire crumb particles of various size (larger or smaller than 250 um) extracted using artificial digestive and acid extraction methods.
   - Average lead exposure amounts were calculated for students.

   Study results and/or conclusions:

   - Lead was found in the digestion extracts of tire crumb material.
   - Acid extraction method resulted in lead concentrations 6.5 times higher than content concentration.
   - Digestive extraction resulted in lead concentration 10.3 times higher than content concentration.

- Results of this study confirm that the exposure of lead via ingestion and risk level increases as the particle size of crumb rubber gets smaller.

Study Limitations:

- It appears that only one type of crumb rubber was investigated.
- There is uncertainty as to whether or not the EDPM rubber powder prototype used in the study is representative of the entire artificial turf.

3. **Hazardous chemicals in synthetic turf materials and their bio-accessibility in digestive fluids**
J. Zhang, I. Han, L. Zhang, W. Crain; *Journal of Exposure Science and Environmental Epidemiology*; **2008.**

The purpose of the study was to obtain data that will help assess potential health risks associated with chemical exposure from artificial turf and to determine the bio-accessibility of PAHs and toxic metals in synthetic human saliva, gastric fluid and intestinal fluid.

Methods:

- Seven samples of rubber granules and one sample of artificial grass fiber from synthetic turf fields at different ages of the fields.
- PAHs (15) and metals (Cr, Zn, As, Cd, Pb; ICP-MS) were measured in the granule/grass fiber samples and synthetic digestive fluids (saliva, gastric fluid, intestinal fluid).

Study results and/or conclusions:

- Total PAHs ranged from 4.4ppm to 38.15ppm.
- PAHs in rubber granules had low bio-accessibility (i.e., hardly dissolved) in synthetic saliva, gastric fluid, and intestinal fluid.
- Rubber granules often contained PAHs at levels above health-based soil standards.
- PAH levels declined as the field ages.
- Decay trend may be complicated by adding new rubber granules to compensate for loss of the material.
- Zinc contents were found to far exceed the soil limit, range 5710-9988.
- Lead content was low in all the samples compared to soil standards.
- Lead in the rubber granules was highly bioaccessible in the synthetic gastric fluid.

Study Limitations:

- The digestive system is difficult to simulate, and the simulated digestive fluid may not accurately reflect true digestive capability in humans.

Toxicological Studies

1. **Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds**
D. A. Birkholz, K. L. Belton, T. L. Guidotti; *Journal of the Air and Waste Management Association*; **2012.**

The purpose of the study was to design a comprehensive hazard assessment to evaluate and address potential human health and environmental concerns associated with the use of tire crumb in playgrounds.

Methods:

- 200g tire crumbs were leached in water to produce the test leachate.
- Genotoxicity was assessed using *Salmonella typhimurium* mutagenicity fluctuation assay, SOS chromotest, and Mutatox.
- Human health concerns were addressed using conventional hazard analyses.

Study results and/or conclusions:

- All samples analyzed did not meet the criteria for genotoxicity and were considered negative.
- Genotoxicity testing of tire crumb samples following solvent extraction concluded that no DNA or chromosome-damaging chemicals were present.
- This suggests that ingestion of small amounts of tire crumb by small children will not result in an unacceptable hazard/risk for development of cancer.
- The use of tire crumb in playgrounds results in minimal hazard to children and the receiving environment.

Study Limitations:

- The authors of this study concentrated only on potential genotoxicity from the exposure to tire crumb material in playgrounds, other adverse health effects that may be caused by other elements/compounds in the tire crumbs may have been overlooked.

2. **Benzothiazole toxicity assessment in support of synthetic turf field human health risk assessment**
G. Ginsberg, B. Toal, T. Kurland; Journal *of Toxicology and Environmental Health, Part A*; 2011.

The purpose of the study was to assess benzothiazole (BZT) toxicity in support of a risk assessment of synthetic turf fields conducted by the Connecticut Department of Public Health.

Methods:

- The study reviewed the following information on BZT and its surrogate, 2-mercaptobenzothiazole (2MBZT), to derive BZT toxicity values for cancer and non-cancer effects:
    - properties and uses
    - BZT exposure
    - toxicokinetics of BZT and 2MBZT
    - toxicity of BZT and 2MBZT with regard to acute toxicity, mutagenicity, subchronic and chronic toxicity and cancer, developmental and reproductive effects

Study results and/or conclusions:

- The following BZT toxicity values were derived:
    - Acute air target of 110 µg/m3 based upon a BZT RD50 study in mice relative to results for formaldehyde.
    - A chronic, noncancer target of 18 µg/m3 based upon the no observed adverse effect level (NOAEL) in a subchronic dietary study in rats, dose route extrapolation, and uncertainty factors that combine to 1000.
    - A cancer unit risk of 1.8E-07/µg-m3 based upon a published oral slope factor for 2-MBZT and dose-route extrapolation.

Study Limitations:

- There were numerous uncertainties and limited information in the BZT toxicology database.
- BZT was not tested in sub-chronic/ chronic studies, cancer bioassay, or developmental and reproductive studies.
- Some endpoints were studied using 2-MBZT as a surrogate, which makes an imperfect comparison due to differences in structure and metabolic pathways.
- Only a screening-level assessment for BZT exposure.
- The proposed toxicity values are for BZT in general, not specifically for BZT in synthetic turf.

3. **Evaluating the Risk to Aquatic Ecosystems Posed by Leachate from Tire Shred Fill in Roads Using Toxicity Tests, Toxicity Identification Evaluations, and Groundwater Modeling**
P.J. Sheehan, J.M. Warmerdam, S. Ogle, D. Humphrey, S. Patenaude; *Environmental Toxicology and Chemistry;* 2006.

The purpose of the study was to evaluate the toxicity of leachates from tire shreds used as roadbed fill and to define the circumstances under which use of the tire shreds as roadbed fill, both above and below the water table, will pose a negligible hazard to adjacent surface-water ecosystems.

Methods:

- Shred infill obtained from two study sites, one above the water table and one at and below the water table. For this infill, tire shreds contain a mixture of steel and glass belted scrap tires and substantial amounts of steel belts are exposed at the cut edges.
- Site #1 constructed in 1993 with 3 sample collection areas with precipitation infiltrating the road embankment and into collection basins for sampling. There was one "control" basin without a tire shred layer.
- Site #2 was constructed in 1994 and tire shreds come into direct contact with groundwater. Water samples were collected from 3 wells: 1 upgradient, 1 within the trench with direct contact to tire shreds and 1 downgradient.
- Leachates analyzed for metals, VOCs, and sVOCs.
- Short-term chronic *C. dubia* test and short-term chronic fathead minnow test used to determine toxicity.

Study results and/or conclusions:

- Site #1:
    - No adverse effects on *P. promelas* survival or growth

- Substantial reduction in C. dubia survival in phase 2 of the reference water likely due to high conductivity of the leachate sample.
    - Metals, VOCs and sVOCs were detected in two samples but the concentrations were low and not indicative of leaching substantial amounts of chemicals.
- Site #2:
    - Slight reductions in P. promelas survival in both phase 1 and 2 of the reference sample.
    - No impairment in survival seen in the two samples (at and down gradient).
    - Significant reductions in growth seen for both the reference sample and the other two site samples.
    - For *C. dubia*, > 80% mortality was seen in the leachate samples (phase 1); significant reductions in reproduction also seen but reductions in reproduction were also seen in the reference samples.
    - Elevated levels of some VOCs and metals (especially iron and manganese) indicated chemicals leach from shred fill; however, the leaching of iron is likely from the steel belts exposed on the cut edge.

Study Limitations:

- The type of infill used in road beds is quite different from the crumb rubber infill used in synthetic turf.
- The modeling estimates used numerous different scenarios to determine amount of filtration needed which is not applicable to studies investigating human exposure to chemicals synthetic turf.

4. **Impact of tire debris on in vitro and in vivo systems**

M. Gualteri, M. Andrioletti, P. Mantecca, C. Vismara, M. Camatini; *Particle and Fibre Toxicology*; **2005.**

The purpose of the study was to investigate tire debris effects on the development of *X. laevis* and on human cell lines.

Methods:

- Tire debris samples were obtained from laboratory processing using tire scrap materials.
- Eluates were obtained after soaking in water (pH 3); organic extracts obtained and used for the cell line test (A549) and the tests using *X. laevis* embryos
- Cell viability assay and Comet assay were used to determine toxicity, doses 10, 50, 60, 75 µg/mL
- in vivo: *X. laevis* embryos were exposed to 50,80,100, 120 µg/mL organic extracts

Study results and/or conclusions:

- A time-dependent increase of Zn in the human liver cell line was seen after treatment with 50µg/ml zinc at 2, 4, and 24 hours.
- An increase in cell death was seen at the higher doses (50, 60, 75 µg/ml) compared to controls.
- Cell proliferation was decreased in a time and dose-dependent manner.
- DNA damage increased at 50 and 60µg/mL as shown by the comet assay.
- Cell morphology was impacted after 72 hours treatment. The highest dose showed visible vacuolization in the cytoplasm and apoptotic nuclear images; present in 50% of cells at 72 hours with 75µg/ml treatment.
- Zn concentration of 44.73µg/ml (50 g/l tire debris) resulted in 80% mortality of embryos and a concentration of 35.28µg/ml (100 g/L tire debris) resulted in 26.8% mortality. Malformation was similar between the two doses. Dilutions of the organic extracts showed significant increases at 1% for 44.73 and at 10% for 35.28.
- The eluates had teratogenic effects for both doses.
- For *X. laevis* development, 80µg/ml and above resulted in significant mortality with 15.9% mortality at 120µg/mL.
- Increase in malformed larvae found at 80 and 100µg/mL; at 120 µg/mL, 37.8% of larvae were malformed.
- Most frequent malformation was gut rolling.

Study Limitations:

- The type of sample used in the analysis (tire debris) is not the same type of tire material as seen in crumb rubber infill.
- The analysis only looked at zinc and did not include other known contaminants of tire crumb/tire debris.
- No indication if the doses used in the laboratory analysis are similar to doses/exposure levels in the environment.

EPA REFERENCE GUIDE

FRAP Additional References

Appendix C – EPA-NCEA Summary of Available Exposure and Health Risk Assessment Studies on Artificial Turf, Playgrounds and Tire Crumbs

Appendix B (pp 107-110 FRAP Status Report)

See link below to view the 169 page FRAP Status Report

https://www.epa.gov/sites/production/files/201612/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf

Appendix C - EPA-NCEA Summary of Available Exposure and Health Risk Assessment Studies on Artificial Turf, Playgrounds and Tire Crumbs

Summary of Available Exposure and Health Risk Assessment Studies on Artificial Turf, Playgrounds and Tire Crumbs

Bulleted Summary

- Artificial turf is made of plastic blades that simulate grass and a layer of "infill" material made of recycled tire crumb or crumb rubber.
- There are benefits to using these materials, but concerns have been raised by the public and others regarding health issues associated with their use.
- EPA formed a workgroup in 2008; performed a scoping study, and published a report in 2009.
- There are several studies found in the literature conducted by federal and state governments, academia, and industry.
- The studies varied in scope ranging from studies focused on environmental concentrations found in air; concentrations of the chemicals found in the bulk material; and health risk assessments. Some studies focused the inhalation pathway, while others considered other pathways including ingestion and dermal exposures. Chemicals studied included VOCs, sVOCs, PM_{10}, and metals. Other studies examine the potential for environmental impacts, including leaching of metal into waterways.
- Federal and state government studies include:
  - Norwegian Institute of Public Health (2006) "Artificial turf pitches – an assessment of the health risks for football players"
  - OEHHA 2007 "Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products"
  - CPSC 2008 "CPSC Staff Analysis and Assessment of Synthetic Turf Grass Blades"
  - New Jersey Department of Health and Senior Services (April 2008) "New Jersey Investigation of Artificial Turf and Human Health Concerns; Fact Sheet"
  - New York Department of Health (2008) "A Review of the Potential Health and Safety Risks From Synthetic Turf Fields Containing Crumb Rubber Infill"
  - New York City Department of Health and Mental Hygiene (March 2009) "Air Quality Survey of Synthetic Turf Fields Containing Crumb Rubber Infill"
  - New York State Department of Environmental Conservation (May 2009) "An Assessment of Chemical Leaching, Releases to Air, and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields
  - EPA (2009) "A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds"
  - Connecticut Department of Health (2010) "Human Health Risk Assessment of Artificial Turf Fields Based Upon Results from Five Fields in Connecticut"
  - New Jersey Department of Environmental Protection (July 2011) "An Evaluation of Potential Exposures to Lead and Other Metals as the Result of Aerosolized Particulate Matter from Artificial Turf Playing Fields"
- These studies concluded that there is no or limited health risk associated with the use of these materials. However, the studies were limited in scope and not all of them carried out a complete exposure/risk assessment. There are uncertainties associated with the assumptions used to derive these conclusions.
- Some potential future activities can be undertaken including: reviewing additional reports and scientific literature; examining the available data more closely; reviewing exposure assumptions; determine if an exposure/risk assessment can be conducted with the available data; studying other factors that may influence exposure; identify key data gaps; and assess the potential for microbiological exposures.

Background

Artificial turf is made of plastic blades that simulate grass and a layer of "infill" material to keep the blades upright. This "infill" is made of recycled "tire crumb" or "crumb rubber" material. This artificial or synthetic turf is often used to cover the surfaces of athletic field. Tire crumbs and crumb rubber are also used as groundcover under playground equipment, running track material, and as a soil additive on sports and playing fields. Although use of these materials has been recognized as beneficial (e.g., recyling, reduction of sports injuries), concerns have been raised by the public and others regarding health issues associated with these materials.

In 2005, EPA Region 8 Pediatric Environmental Health Specialty Unit (PEHSU) received telephone inquiries from parents concerned about health risks to children exposed to a recycled tire crumb product used in fields and school playgrounds. EPA Region 8 requested that the Agency consider this issue and a workgroup was formed and charged to consider the state of science and make recommendations for future research. A second science workgroup was formed to consider available methods to study the situation, and they recommended conducting a scoping study to assess approaches and methods, and to provide limited measurement data for consideration. The workgroup produced a report entitled "Scoping-level Field Monitoring Study of Synthetic Turf Fields and Playgrounds" published in 2009.

Over the years, there have been several published articles on the health concerns resulting from exposures to the materials used in artificial turf. In October of 2014, a soccer coach reportedly suggested an association between cancer cases found in soccer players and exposures to artificial turf. A list of 38 American soccer players (34 of them goalies) had been diagnosed with cancer (http://www.nbcnews.com/news/investigations/how-safe-artificial-turf-your-child-plays-n220166). In response to the news report, a representative from FieldTurf, an artificial field turf company, requested a meeting with EPA to present their views with regard to the safety of turf fields. A conference call was hosted by Michael Firestone of OCHP. FieldTurf stated that scientific research from academia, federal and state governments has failed to find any link between synthetic turf and cancer. More recently, in March 16, 2015, another news article in claimed that the federal government is promoting artificial turf despite health concerns (http://www.usatoday.com/story/news/2015/03/15/artificial-turf-health-safety-studies/24727111/).

Several studies have been conducted on artificial turf and the use of tire crumb materials. Some focused primarily on obtaining concentration data for various compounds that may off-gas from recycled tire materials, while others attempted to estimate health risks associated with their use. There are also several studies that focus on characterizing the compounds contained in bulk samples of artificial turf. Summarized below are the studies conducted by EPA, CPSC, and the states of New York, Connecticut, and California. Included also is a study conducted in Norway. It is important to note that this list is not comprehensive and focuses primarily on studies conducted by federal and state governments.

Norwegian Institute of Public Health (NIPH) and the Radium Hospital 2006

NIPH conducted a health risk assessment of football players that played in artificial turf fields. They examined 9 scenarios including: inhalation, dermal, and ingestion exposures (only for children) for adults, juniors, older children and children. The assessment included various constituents in the tire crumb: VOCs, PAHs, phthalates, PCBs, PM_{10}, and alkyl phenols. The study was limited because of the absence of toxicity data. The study concluded that the use of artificial turf does not cause any elevated health risk. The estimated Margins of Safety (MOS) were no cause for concern.
http://www.isss.de/conferences/Dresden%202006/Technical/FHI%20Engelsk.pdf

OEHHA California study 2007

Office of Environmental Health Hazard Assessment (OEHHA) conducted a risk assessment of the recycled waste tires in playgrounds and track products in 2007. Their study included VOCs, sVOCs and metals. The pathways included in the risk assessment were the ingestion of the tire crumbs via hand to mouth or surface to mouth and dermal contact. They concluded that risk levels were below the *di minimi*s level of 1×10^{-6}.
http://www.calrecycle.ca.gov/publications/Documents/Tires%5C62206013.pdf

CPSC 2008

The U.S. Consumer Product Safety Commission investigated the potential hazards from lead in some artificial turf sports fields across the country. The study focused on ingestion of lead from the material that transfers to the mouth from the skin after contact with the lead containing turf. The study concluded that exposure to children playing on the field would not exceed 15 µg of lead/day.
http://www.cpsc.gov//PageFiles/104716/turfassessment.pdf

New Jersey Department of Health and Senior Services 2008

NJDHSS collected samples of artificial turf fibers from 12 fields. Ten fields with polyethylene fibers had very low Pb levels. Two fields with nylon fibers had 3,400 to 4,100 mg/kg of Pb. In addition, they collected artificial turf samples from consumer products that are used for residential lawns and play surfaces. Two of the products that were nylon or nylon/polyethylene contained Pb at 4,700 and 3,500 mg/Kg. These concentrations higher than the Residential Direct Contact Soil Cleanup Criteria (which is 400 mg/kg). "There is a need for a comprehensive and coordinated approach to evaluating the public health risks and benefits of artificial turf fields." http://www.nj.gov/dep/dsr/publications/artificial-turf-report.pdf

New York Department of Health Study 2008

In 2008, the NY Department of Health conducted a study where they reviewed data from 11 different risk assessments found in the literature on exposures to artificial turf and concluded that the levels found of the contaminants of concern did not result in an increased risk for human health effects as a result of ingestion, dermal or inhalation exposure to crumb rubber. They stated, however, that additional air studies at synthetic turf fields as well as background air measurements would

provide more representative data for characterizing potential exposures related to synthetic field use in NYC, particularly among children.
http://www.nyc.gov/html/doh/downloads/pdf/eode/turf_report_05-08.pdf

New York City Department of Health and Mental Hygiene March 2009
NYCDHMH conducted field sampling for VOCs, SVOCs, metals, particulate matter (PM2.5) in two synthetic fields, one grass field. They used stationary samplers on field during simulate playing conditions. The sampling was conducted during the summer under simulated playing conditions. Eight of the 69 VOC were detected, but concentrations were similar between upwind background and turf fields. None of the SVOCs were detected, including benzothiozole a "chemical marker" for synthetic rubber. Two of 10 metals were detected, but similar concentrations were found in upwind and grass field. PM was within background levels upwind and at grass field. The report concluded that air in the breathing zones of children above synthetic turf fields did not show appreciable levels from contaminants of potential concern contained in the crumb rubber and that a risk assessment from exposure through the inhalation route was not warranted.
http://www.nyc.gov/html/doh/downloads/pdf/eode/turf_aqs_report0409.pdf

New York State Department of Environmental Conservation May 2009
In 2008, NYDEC conducted a laboratory evaluation of four types of tire-derived crumb rubber to assess the release of chemicals using the simulated precipitation leaching procedure. Results indicated that zinc, aniline, phenol, and benzothiazole can potentially be release to ground water. Zinc, aniline, phenol were all below standards; there are no standards for benzothiazole. Lead concentration in the crumb rubber was below federal hazard standard for soil. Risk assessment for aquatic life indicated that zinc may be a problem for aquatic life. Air samples were collected above fields at two locations. Many of the analytes detected (e.g., benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbon tetrachloride) are commonly found in an urban environment. A number of analytes found were detected at low concentrations (e.g., 4-methyl-2-pentanone, benzothiazole, alkane chains. Public health evaluation at the two fields tested concluded measured air levels do not raise a concern for non-cancer or cancer human health Indicators. PM concentrations were not different from concentrations upwind from the fields. http://www.dec.ny.gov/docs/materials_minerals_pdf/crumbrubfr.pdf

EPA 2009
The overall objectives of EPA's study were to evaluate the methodology and protocols for monitoring and analyzing data needed to characterize the contribution of tire crumb constituents to environmental concentrations and to collect limited environmental data from playgrounds and synthetic turf fields. EPA analyzed air samples for 56 volatile organic compounds (VOCs), air particulate matter (PM_{10}) for selected metals and the relative contribution of tire crumb particles to the overall particle mass, wet surface wipe samples for metals including Pb, Cr, Zn, and others, and turf field tire crumb infill granules, turf blades, and playground tire crumb materials for metals. The study protocol was implemented at two synthetic turf fields and one playground. Conclusions: "On average, concentrations of components monitored in the study were below levels of concern." Concentrations for many of the analytes were close to background levels. Due to the limitations of the study, the authors concluded that "it is not possible to reach any more comprehensive conclusions without the consideration of additional data." The study did not evaluate semivolatile organic compounds such as PAHs because of resource limitations. No exposure or risk assessment was conducted by EPA. Potential exposure pathways include: ingestion of loose tire crumbs via hand to mouth or surface to mouth; dermal contact; and inhalation exposures of VOCs and PM_{10}.
http://www.epa.gov/nerl/features/tire_crumbs.html

Connecticut Department of Public Health study 2010
Connecticut Department of Public Health conducted a human health risk assessment of artificial turf in 2010. They collected data from one indoor and four outdoor artificial turf fields. The study focused on two pathways, inhalation of offgassed and particle-bound chemicals. The study included 27 chemicals (VOCs, sVOCs, leand and PM_{10}). Using conservative assumptions, Connecticut Department of Public Health Program found that cancer risks are slightly above *de minimis* in all scenarios, and two fold higher at the indoor field compared to outdoors and being higher for children than adults. The non-cancer risk estimate is below unity for all analytes in all scenarios.
http://www.ct.gov/deep/lib/deep/artificialturf/dph_artificial_turf_report.pdf

New Jersey Department of Environmental Protection 2011
In 2009, NJDEP tested 5 artificial turf fields. They tested for PM and metals including Pb using wipe samples as well as stationary sampling and mobile robot sampling. In addition, a 12 year old boy was recruited to simultaneously collect a personal breathing zone sample. The age of the fields ranged between 1 and 8 years. The testing was done during the summer time. No levels exceeded guidance or NAAQS values; robot air Pb value on one field was 71 ng/m^3 (approx 50% of NAAQS), remainder below 10 ng/m^3

Potential Future Activities

- Review additional reports and scientific literature that may provide information on the chemical constituents in artificial turf, and their bioavailability and toxicity, exposure pathways and factors, and potential human health risks.
- Examine more closely all the available data, especially for indoor fields where inhalation exposures may be higher.
- Determine if sufficient data exist to conduct an exposure/risk assessment with the available data. Given the uncertainties with some of the exposure factors assumptions (e.g., amount of material ingested, exposure frequency), several "what if" scenarios can be developed to determine for example the amount of material that would need to be ingested to exceed some health level. If an assessment cannot be done, identify key data gaps.
- Examine the exposure factor assumptions used by the studies in the literature to evaluate their "reasonableness."
- Study other factors that may influence exposure levels; for example; the age of the fields, uncertainties about the amount of material that can be inadvertently ingested, potential for dermal exposures, and exposure frequency and duration.
- Examine the literature for microbiological exposures and risks from exposures to the materials in these fields and playgrounds.

Commonwealth of Massachusetts

Office of Health and Human Services, Department of Public Heath and Bureau of Environmental Health.

Frequently Asked Questions: Artificial Turf Fields.

http://www.mass.gov/eohhs/docs/dph/environmental/exposure/faq-artificial-turf-0615.pdf

The Commonwealth of Massachusetts
Executive Office of Health and Human Services
Department of Public Health
Bureau of Environmental Health
250 Washington Street, Boston, MA 02108-4619
Phone: 617-624-5757 Fax: 617-624-5777
TTY: 617-624-5286

CHARLES D. BAKER
Governor

KARYN E. POLITO
Lieutenant Governor

MARYLOU SUDDERS
Secretary

MONICA BHAREL, MD, MPH
Commissioner

Tel: 617-624-6000
www.mass.gov/dph

Frequently Asked Questions
Artificial Turf Fields

1. What are artificial turf fields (ATFs)?

Artificial turf fields (ATFs) are synthetic alternatives to natural grass fields.

2. What are ATFs composed of?

Components of ATFs include artificial grass fibers (blades), crumb rubber infill, and sand infill overlaid on a carpet-like backing that holds the turf together. The grass fibers are typically made of nylon, polyethylene, or polypropylene, and the crumb rubber infill used to soften the surface is most often made of recycled tires.

3. Are chemicals present in ATF components?

Yes, ATF components, such as crumb rubber infill, have been found to contain chemicals including semi-volatile organic compounds (including polyaromatic hydrocarbons, or PAHs), volatile organic compounds (VOCs), and metals.

4. Have studies been done to determine if ATFs impact health?

Several studies evaluating potential exposure opportunities to constituents in ATFs have been conducted by state (e.g., California, New York, New Jersey, Connecticut) and federal agencies (e.g., U.S. Environmental Protection Agency), as well as academic researchers (e.g., Rutgers Robert Wood Johnson Medical Center).

5. How have these studies evaluated exposure opportunities at ATFs?

The studies that have been conducted measured concentrations of chemicals in the air above ATFs as well as in the components of the ATFs. In addition, some studies have evaluated the potential for these chemicals to actually enter the body and reach a susceptible organ (e.g., bioavailability studies).

6. How do public health agencies evaluate whether exposure can result in health effects?

Public health agencies evaluate concentrations measured in studies and compare them to well-established, health-based standards or guidelines (developed through comprehensive research by federal or state governments) or they conduct evaluations using standard risk assessment methods to estimate health risks from environmental exposures.

7. What is a risk assessment?

The term "risk assessment" refers to a process of assessing and evaluating the potential health effects that may result from an environmental exposure. Risk assessments take into consideration information about the toxicity of a contaminant, the estimated amount of contaminant that someone may be exposed to, the sensitivity of an individual to the contaminant (e.g., children are generally more sensitive to environmental contaminants than healthy adults), and other factors.

8. What assumptions have been used in risk assessments done for ATFs?

Exposure assumptions that have been used include assuming someone plays on the field for 3-5 hours a day, 4-5 days a week, 8-12 months a year, and 12 (child) to 30 years (adult). Such assumptions are designed to be conservative and consider worst-case scenarios.

9. What do the available studies that have been conducted on exposure opportunities to ATFs and health impacts show?

Although exhaustive research has not been completed, the available studies have shown that although ATF components contain chemicals in the material itself, exposure opportunities at levels measured do not suggest that health effects are likely.

10. What are the findings of studies that evaluated exposure opportunities based on measurements of constituents (e.g., in air, dust) at ATFs?

Results of samples taken at or above (e.g., air) ATFs and analyzed for VOCs, SVOCs, metals, and particulate matter that can be inhaled into the lungs suggested that adverse health effects were unlikely to occur. These include studies conducted by the Connecticut Health Department, the New York State Health Department, and the California Office of Environmental Health Hazard and Assessment.

11. What are the findings of studies that have evaluated ingestion or inhalation of, and/or skin contact with constituents in ATFs?

The Rutgers study evaluated whether exposures to SVOCs or metals in ATF components might suggest exposures of health concern via ingestion, inhalation, or dermal contact. They concluded that overall the opportunities for exposure to constituents in these fields presented very low risk among all populations that would use ATFs. Authors of a study in the Netherlands reported that results of urine testing indicted that uptake of PAHs among participants, following playing on an ATF with crumb rubber infill, was minimal.

12. What were the findings of the Rutgers study with respect to lead?

The Rutgers researchers found that lead concentrations in one of seven ATFs tested could potentially result in blood lead levels above the U.S. Centers for Disease Control and Prevention reference value for blood lead in young children (5 ug/dL). It should be noted, however, that the lead concentration in the materials used in this study included a sample of turf fiber with a lead concentration of 4,400 mg/kg, well above the US Consumer Product Safety and Improvement Act limit for lead content in children's products of 100 mg/kg.

13. Do all ATFs have lead?

No. Some ATFs are constructed with components that are certified as having no or low lead content. Use of ATF components that meet the Consumer Product Safety and Improvement Act limit of 100 ppm for lead in children's products would minimize exposure opportunities to lead.

14. What are the findings of studies that evaluated exposures to bacteria?

The California Office of Environmental Health Hazard and Assessment tested for bacterial contamination at both natural grass fields and ATFs. They found fewer bacteria detected on artificial turf compared to natural turf, and therefore less likely to result in infection risks to athletes using ATFs that may have skin abrasions.

15. Have epidemiological studies been conducted to determine if ATF exposures are associated with the occurrence of cancer in children?

Some recent media reports have raised concerns about the possible association between playing on ATFs and the development of cancers. It is important to note that the types of cancers reported are among those that have been more prevalent in children for many years. To date, no epidemiologic studies have evaluated the occurrence of cancer among athletes or others who play on ATFs.

16. How common is it for children to get cancer?

Although cancer is much less common among children than older adults, unfortunately 1 in 285 children in the U.S. will be diagnosed with cancer before the age of 20. Leukemia is the most common cancer diagnosed in children and teens, accounting for almost 1 out of 3 cancers in this age group. From 1975 to 2010, the overall incidence of pediatric cancer in the U.S. increased slightly, by an average of 0.6 percent per year.

17. Has the potential for the development of cancer been assessed using standard risk assessment methods for exposure opportunities associated with ATFs?

Several studies, including those conducted by officials in New York City, New York State, Connecticut, California, the U.S. Environmental Protection Agency, and Norway, have conducted cancer risk assessments based on opportunities for exposures at ATFs. These evaluations were based on testing results from different kinds of fields under a variety of weather and use conditions. These risk assessment studies all indicate that the use of ATFs is not associated with elevated cancer risk.

18. Does MDPH endorse the use of ATFs?

No, MDPH does not endorse any particular consumer product, including ATFs. MDPH routinely evaluates whether exposure opportunities to constituents in consumer products may pose health concerns and provides information to put risk in perspective.

19. What other exposure concerns have been raised about ATFs?

Concerns have been expressed in relation to the increased temperature of fields as outdoor temperatures rise. For these reasons, fields may be frequently watered to cool the surface, and athletes should increase hydration and take frequent breaks to reduce the potential for burns or heat stress.

20. Are there steps that can be taken to reduce exposure opportunities to ATF components?

Yes. MDPH recommends common sense steps to minimize potential exposures to chemicals that may be present, such as washing hands after playing on a field and before eating (particularly for younger children with frequent hand-to-mouth activity) and taking off shoes before entering the house to prevent tracking in any crumb rubber particles.

21. Who should I contact for more information?

If you have any questions about ATFs and health, you may contact the following:

Environmental Toxicology Program
Bureau of Environmental Health
Massachusetts Department of Public Health
250 Washington Street, 7th Floor
Boston, MA 02108
617-624-5757

Gale Associates Inc

Alternative Infills for Synthetic Turf

http://www.galeasssociates.org/wp-content/uploads/2015/03/Alternative-Infills-for-Synthetic-Turf.pdf.

Prepared by: Gale Associates Inc.
3/17/2015

Alternative Infills for Synthetic Turf - Properties as Infill Summary

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Type of Alternative Infill	Material	Color	Shape	Abrasiveness	Durability	[illegible]	Availability[4]	[illegible]	Irrigation Recommended	[illegible]	Typical Mixture By volume	Approximate Cost[5]	Comments
Crumb Rubber	Styrene butadien Rubber (SBR) Recycled tire rubber shreded	Black	Angular shaped granules	Low	Stable	2.25" - 2.50"	Readily Avalaible	No	No	Life of Carpet	50% Sand 50% Rubber	$50,000 per field	1. SBR Rubber and sand is the typical infill system used in the majority of synthetic turf fields installed since 1990's. 2. SBR rubber maintains its resiliency over a wide range of temperature and enviornmental conditions.
Silica Sand	Rounded Silica Sand	Tan/Brown	Rounded Particles	High	Stable	1.50" - 2.0"	Readily Avalaible	Required (See Comments)	No	Life of Carpet	100% Silica Sand	+$0 net for additional sand +$130,000 for resilient pad	1. Shock pad is required to provide shock attenuation (G-max) 2. Sand stays hard under cold/frozen conditions (regardless of shock pad) 3. Use turf stitch gage of 5/8" or less. 4. Consider turf thatch layer for fly up prevention.
Organic	Cork or Coconut Husk or rice hulls	Natural appearance (tan/brown)	Angular shaped granules	Low	Low Stability	1.50" - 2.50"	Limited Availability	Yes (See Comments)	Yes[6]	Unknown[2] ability to decompose	10%-15% Organic 90% to 85% Sand	+$180,000 for materials +$130,000 for resilient pad +$15,000 for irrigation +$325,000 total net add	1. Reports of early degredation and floating of particles 2. Organics can stay hard under frozen conditions (regardless of shock pad) 3. Shock pad recommended to provide shock attenuation over warranty period 4. Consider increased maintenance
Coated Crumb Rubber	SBR (Styrene butadien Rubber) Recycled tires shreded and coated with acrylic or EPDM	Custom colors available	Angular shaped granules	Low	Medium stability	2.25" - 2.50"	Readily Avalaible	No	No	Life of Carpet	50% Sand 50% Coated Rubber	+$220,000 materials	1. Still contains SBR Rubber 2. Manufacturers claim coating encapsulates outgasing of SBR rubber 3. Shock pad is not required, consider a combination of shock pad and other infill material to reduce quantity of needed material
EPDM (Ethylene Propylene Diene Monomer) Rubber	Virgin rubber produced for infill of ahtletic fields only	Custom colors available	Angular shaped Granules	Low	Medium stability	2.25"-2.50"	Limited Availability	No (See Comments)	No	Not proven long term	50% Sand 50% EPDM	+ $360,000 materials	1. Similar material to SBR rubber 2. Shock pad is not required, consider a combination of shock pad and other infill material to quanity of EPDM needed 3. EPDM is a generic term and quality can vary greatly. Proven source and propriety formulations are reconmended.
TPE (Thermoplastic Elastomer)	Extruded plastic pellets	Custom colors avalaible	Typically Uniform pellets Shape depends on manufacturer	Low to Medium	Stable	1.5"-2.50"	Limited Availability	Recommended	No	Not proven long term	50% TPE 50% Sand	+$360,000 materials +130,000 resilient Pad +490,000 total net add	1. Turf thatch layer is suggeted to help reduce fly up/displacement of material 2. Shock pad is not required, some owners have used combination of shock pad and TPE to reduce quantity of infill needed. 3. TPE is generic term - Quality can vary greatly. Proven source and propriety formulations are recommended
Coated Sand	Polymer Coated Silica Sand	Green	Fairly Round Particles	Med	Stable	1.50" - 2.0"	Limited Availability	Required (See Comments)	No	16 Year Warrentee (See Comment)	100% Coated Silica Sand Particles	+$150,000 to $250,000 for materials +130,000 resilient pad +380,000 total net add	1. Coating has been reported to last shorter than warrantee period 2. Shock pad is required. Some manufacturers suggest a mix with TPE to obtain required resiliency (Gmax). 4. Turf stitch gage of 5/8" or less is reconmended to prevent displacment. 5. Turf Thatch layers should be considered to
Nike Grind	Nike's Environmentally Perferred Rubber (Meets or exceeds restricted substance standards set for wearable consumer goods)	Mutiple Colors	Angular shaped granules	Low	Stable	2.25" - 2.50"	Very Limited Availability	No	No	Per Nike, Expected life 10 years of play at 40 hours per week	50% Sand 50% Nike grind	+$130,000 materials	1. Proprietary. 2. Reports that infill is not asthetically pleasing. 3. Has occasionally been used as a supplement to SBR rubber or in lieu of SBR to provide 'renewable' label since 1990's

Notes:

1. Information provided was compiled by available online data, manufacturers literature and conversations with turf and infill distributors. Gale has not conducted any independent testing of infill materials and does not guarantee the accuracy of information provided here in.
2. Installations of fields with alternative infill material (other than SBR Rubber and Sand) are somewhat limited and many have not been proven long term. Gale does not guarantee performance of any turf system.
3. Few older installations in U.S. More common in Europe. Only one supplier warranties for life of turf (geoturf) in U.S.
4. May become more or less available as demand and popularity fluxuates. Cost fluxuates with availabilty
5. Costs are generalized approximations. Costs are NET addition to cost of a typical sand/SBR turf infill system. Actual costs will vary based on depth of infill/turf depth, type of resilient pad used. Market costs can vary greatly due to materials demand and availabity.
6. Organic infill suppliers recommend keeping infill moist to aid with resiliency, improve longetivity, prevent compaction and material displacement

Prepared by: Gale Associates Inc.
3/17/2015

GALE

Alternative Infills for Synthetic Turf - Pros and Cons

Type of Alternative Infill	Material	Brand/Trade Names	Pros	Cons
Crumb Rubber	Styrene butadien Rubber (SBR) Recycled tire rubber shreded	None SBR rubber Ambient or Cyrogenic	Low Cost / Recycled Material Highly Analyized and Tested for safety, environmental and health concerns when as turf infill. Good Drainage Does not float Low Maintenance, High UV Stability - Maintains Resiliency Manufacturers Warranties Warm fields in freezing climates Readily available	Poor Reputation / Perception as "trash" Perception as Hazardous to Human Health "Heat" of play, Hot Fields / Concern in Warm Climates Static Cling - gets in Uniforms and Equipment
Silica Sand	Rounded Silica Sand	Sand None	Low Cost Highly Analyized as Infill Low Maintenance Good Drainage Common Mineral Manufacturers Warranties Adds Wieght/Stability to Infill Systems	Relative "hardness" Abrasive Cost (Requires Resilient Pad if used alone)
Organic	Cork or Coconut Husk or Rice Huls	ProGeo - Geoturf Purefill - Field Turf Geofill - Shaw Sports Natrafill	Natural Material / Renewable Perception as Natural Material Reported to reduce Heat Concerns as infill Natural Color & appearance Good Resilency Reported Common Use in Europe	High Cost - High materials Costs Cost - Resilient Pad Recommended Cost - must be kept moist - Requires Irrigation System Cost - Higher Maintenance costs/Shorter Life Cycle* Potential to Plug/affect drainage Freezes-Hard fields in freezing climates Potential for weed and mold growth Limited availability Floats - Should not be used in Flood Prone Areas
Coated Crumb Rubber	SBR (Styrene butadien Rubber) Recycled tires shreded and coated with acrylic or EPDM	Polytan RPU - Polytan Cushionfall Sport Coolfill - SprintTurf	Low Maintenance Good Drainage High UV Stability - Maintains Resiliency Coating reported to encapsulate SBR rubber outgassing & improve heat concerns Manufacturers Warranties Does not Float Variety of Colors - Reported to reduce heat concerns Does not require Resilient pad or irrigation	High Cost - High materials Costs Same chemical make-up & potentials as SBR Rubber Relatively little analysis as Turf Infill Limited availability
EPDM (Ethylene Propylene Diene Monomer) Rubber	Virgin rubber produced for infill of ahtletic fields only	EPDM Melos EPDM ST - APT Melos Bionic EPDM - APT Gezofill - Gerolan corp.	Low Maintenance Good Drainage High UV Stability - Maintains Resiliency Manufacturers Warranties Does not Float Variety of Colors - Reported to reduce heat concerns Does not require Resilient pad or Irrigation	High Cost - High materials Costs Very Similar chemical make-up & potentials as SBR Rubber Relatively little analysis as Turf Infill Generic Material - Must use Proven - Proprietary formulations for quality Limited availability in quantities needed for fields
TPE (Thermoplastic Elastomer)	Extruded plastic pellets	EcoGreen - Field Turf Eco Max - Field Turf BionPro - Polytan Futrfill - Target Indust.	Low Maintenance Good Drainage High UV Stability Manufacturers Warranties Variety of Colors - Reported to reduce heat concerns Does not require Irrigation Common plastic used widely in medial, food and toy manufacture Some Older U.S. Installations	High Cost - High materials Costs Cost - Use of Resilent Pad Recommended Relative hardness - Needs Resilient Pad Generic Material - Must use Proven - Proprietary formulations for quality Limited availability in quantities needed for fields Limited analysis for use as infill
Coated Sand	Polymer Coated Silica Sand	Flexsand Envirofill	Low Maintenance Very Good Drainage Manufacturers Warranties Variety of Colors - Reported to reduce heat concerns Does not require Irrigation Does not float Can add wieght/stability to infill systems	High Cost - High materials Costs Cost - Use of Resilent Pad Recommended Relative hardness - Needs Resilient Pad Generic Material - Must use Proven - Proprietary formulations for quality Limited availability in quantities needed for fields Limited analysis for use as infill Unproven - Limited use as infill
Nike Grind	Nike's Environmentally Perferred Rubber (ground sneakers) (Meets or exceeds restricted substance standards set for wearable consumer goods)	Nike Grind Eco-grind - Field Turf	Low Maintenance Very Good Drainage Good resiliency & Life cycle Recycled Material Does not require Irrigation or Resilient Pad Has been used for years with SBR or as stand alone infill additive	High Cost - High materials Costs Very Limited Availability No color choices - Poor aesthetics - can look 'trashy' Very Similar chemical make-up & potentials as SBR Rubber Static Charge - sticks to equipment and clothing

Notes:

This Summary is assembled from available information some of which was obtained from materials vendors literature

This summary is intended as a general reference, is not specific in nature, and is not intended as a stand alone docment.

UMass Lowell Toxics Use Reduction Institute (TURI)

Athletic Playing Fields and Artificial Turf: Considerations for Municipalities and Institutions

https://www.turi.org/content/download/10990/179677/file/Turf%20Fact%20Sheet%20June%202016.pdf

Athletic Playing Fields and Artificial Turf: Considerations for Municipalities and Institutions

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 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.

The Massachusetts Toxics Use Reduction Institute (TURI) at UMass Lowell has worked with municipalities and other institutions to facilitate the adoption of turf management practices that are cost-effective and preferable for human health and the environment. This fact sheet introduces some of the considerations that are relevant to evaluating natural grass and artificial turf alternatives. TURI is also developing an alternatives assessment for sports turf, which will provide a detailed assessment of these factors.

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.[1] For these reasons, it is particularly important to make careful choices about children's exposures.

Artificial turf: chemicals in infill

Artificial turf is composed of several elements, including drainage materials, support and backing materials, synthetic fibers to imitate grass blades, and an infill that takes the place of soil. A number of concerns exist regarding chemicals in the artificial grass blades and infill. Here, we briefly review issues related to chemicals in infill. Toxic chemicals such as lead are also found in the artificial grass blades in some cases.[2]

Crumb rubber infill made from recycled tires. Crumb rubber made from recycled tires, also referred to as styrene butadiene rubber (SBR) infill, is currently the most widely used type of infill. This type of infill contains a large number of chemicals that are known to be hazardous to human health and the environment. These include polyaromatic hydrocarbons (PAHs); volatile organic compounds (VOCs); metals, such as lead and zinc; and other chemicals. Some of the chemicals found in crumb rubber are known to cause cancer.[3] Because of the large number of chemicals present in the infill, as well as the health effects of individual chemicals, crumb rubber made from recycled tires is the option that likely presents the most concerns related to chemical exposures.

Other synthetic materials. Other synthetic materials used to make artificial turf infill include EPDM rubber, thermoplastic elastomers (TPE), and Nike Grind (a proprietary rubber product made from recycled athletic shoes). These alternatives are sometimes marketed as safer alternatives. Relatively little information is available on the chemicals present in, or emitted from, these infills. Preliminary information suggests that these materials do contain some hazardous chemicals, but that they may generally pose less of a concern than crumb rubber made from recycled tires.[4] There is an urgent need for more information on these alternatives.

Mineral-based and plant-derived materials. Other materials used as infill can include sand, cork, and coconut hulls, among other materials. Again, these materials are likely to contain fewer hazardous chemicals than crumb rubber infill made from recycled tires, but the materials have not been well characterized or studied thoroughly.

The Toxics Use Reduction Institute is a multi-disciplinary research, education, and policy center established by the Massachusetts Toxics Use Reduction Act of 1989.
University of Massachusetts Lowell ● 600 Suffolk Street, Suite 501 ● Lowell, Massachusetts 01854
Tel: (978) 934-3275 ● Fax: (978) 934-3050 ● Web: www.turi.org

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.[5] Research indicates that all synthetic turf reaches higher temperatures than natural grass, regardless of the infill materials.[6]

- A report by the New York State Department of Environmental Conservation found that surface temperatures on a synthetic turf field were 35°F to 42°F higher than those on natural grass.[7]
- Another study found that the highest temperature measured on synthetic turf was 60.3°F greater than that observed on natural grass.[8]
- In another study, artificial turf fibers reached temperatures of 156°F under direct sunlight, while the crumb rubber infill reached 101°F.[9]
- Measurements taken by sports managers at Brigham Young University found that the surface temperature of synthetic 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.[10]

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 synthetic turf, but temperatures rebound quickly under sunny conditions.[11] Another study found that irrigation could lower temperatures by 10 to 20 degrees, for a period of at least 20 minutes.[12] Another found that irrigation lowered the surface temperature from 174°F to 85°F; however, the temperature rebounded to 164°F after 20 minutes.[13]

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.[14]

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.[15]

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.[16] 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.

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).[17] WET is a methodology for assessing the aquatic toxicity effects of an effluent stream as a whole.[18]

Current federal and state studies

A number of studies have examined the chemicals present in synthetic turf, with a particular focus on chemicals found in crumb rubber made from recycled tires. However, federal and state officials have identified a need for additional information. At the time of publication of this fact sheet, two key government studies are under way.

The California Office of Environmental Health Hazard Assessment (OEHHA), an office within the California Environmental Protection Agency, is conducting a three-year study of the potential health effects of exposure to synthetic turf as well as playground mats made from recycled waste tires. The project began in June 2015 and will be completed in June 2018. In the study, OEHHA will review the existing literature on chemicals in synthetic turf and playground mats; analyze samples of new and used synthetic turf and playground mats; develop exposure scenarios; and publish a risk assessment based on this information. OEHHA will also develop plans for a possible future study that would examine people's actual exposures through measurement of biological specimens or use of personal monitors.[19]

Three federal agencies have also recently begun a one-year assessment of potential health effects of exposure to synthetic turf. The agencies working on the study are the U.S. Environmental Protection Agency (EPA), the Consumer Product Safety Commission (CPSC), and the Agency for Toxic Substances and Disease Registry (ATSDR) within the Centers for Disease Control. Working with experts at OEHHA and elsewhere, the federal agencies will identify chemicals of concern found in crumb rubber made from recycled waste tires, as used in artificial turf fields and playgrounds; consider exposure scenarios; and identify areas for future study. The agencies will issue a draft status report by the end of 2016.[20] As background on the need for this study, the EPA website notes 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."[21]

Natural grass

Natural grass fields can be the safest option for recreational space, by eliminating many of the concerns noted above. Natural grass can also reduce overall carbon footprint by capturing carbon dioxide. 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.

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 to 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.[22]

- **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 out-compete 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**: Turf health is maintained through specific cultural practices, including appropriate mowing, aeration, irrigation, and over-seeding. Trouble spots are addressed 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 and 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.

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.[23]

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.[24]

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 about $4,000/year in materials plus 300 hours of labor, while maintenance of a natural grass field may cost $4,000 to $14,000 per year for materials plus 250 to 750 hours of labor.[25]

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.[26]

Natural grass maintenance: Conventional vs. organic costs. 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.[27]

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.[28] Those estimates yield $426,563–$511,875 for a 65,625 square foot field and $552,500–$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 the table below.[29] Another study, conducted by an Australian government agency, found that the 25-year and 50-year life cycle costs for synthetic turf are about 2.5 times as large as those for natural grass.[30]

Table 1: Comparison of annualized costs

Field type	16-year annualized costs
Natural soil-based field	$33,522
Sand-cap grass field	$49,318
Basic synthetic field	$65,849
Premium synthetic field	$109,013

Source: Brad Fresenburg, "More Answers to Questions about Synthetic Fields – Safety and Cost Comparison." University of Missouri.

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Environment and Human Health, Inc (EHHI)

Synthetic Turf Report
Industry's Claims Versus the Science

A Careful Analysis of Studies that Industry Uses to Justify Safety Claims

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See link below to view the 112 page Synthetic Turf Report

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SYNTHETIC TURF

INDUSTRY'S CLAIMS VERSUS THE SCIENCE

A CAREFUL ANALYSIS OF STUDIES THAT INDUSTRY USES TO JUSTIFY SAFETY CLAIMS

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EHHI

ENVIRONMENT & HUMAN HEALTH, INC.

1191 Ridge Road • North Haven, CT 06473

Phone: (203) 248-6582 • Fax: (203) 288-7571

www.ehhi.org

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Nancy Alderman, MES
PRESIDENT
ENVIRONMENT AND HUMAN HEALTH, INC.

Patricia Taylor
DEPUTY OUTREACH DIRECTOR
ENVIRONMENT AND HUMAN HEALTH, INC.

David R. Brown, ScD
CONSULTANT
ENVIRONMENT AND HUMAN HEALTH, INC.

EDITING AND GRAPHIC DESIGN
Jane M. Bradley, MALS
MEDICAL/SCIENCE WRITER
ENVIRONMENT AND HUMAN HEALTH, INC.

EDITING ASSISTANCE
Susan Addiss, MPH, MUrS
EDITOR
ENVIRONMENT AND HUMAN HEALTH, INC.

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I. Introduction

The synthetic turf industry continually states publicly that numerous studies show that synthetic turf fields with crumb rubber infill are safe.

A CAREFUL ANALYSIS OF STUDIES INDUSTRY USES TO JUSTIFY SAFETY CLAIMS

Studies the Synthetic Turf Council and the Synthetic Turf Industry Say Prove that Fields Are "Safe"

- The synthetic turf industry continually states publicly that numerous studies show that synthetic turf fields with crumb rubber infill are safe. Environment and Human Health, Inc. (EHHI) concluded that those studies needed to be carefully read and analyzed to see if they actually proved the safety of the fields, as they claimed.

- The Synthetic Turf Council (STC) continually changes its list of studies.[1] The list that EHHI has worked with and analyzed was compiled by STC in 2016. It has taken a year to analyze the listed studies, which were current when this project was undertaken.

- The STC lists their studies chronologically, so they appear in this report in the same way. The website showing the full study, along with EHHI's summary and analysis of each original study, is included in this report. The abstract and URL of each study cited are listed in the Appendix.

Comments from the Synthetic Turf Council (STC)

- In STC's Executive summary of March 3, 2016, it states: "In early 2015, in response to increased public interest in the potential health effects of synthetic turf sports fields with recycled rubber infill, the Synthetic Turf Council began compiling a list of available studies and making them more readily accessible to the public."[1]

A sampling of comments from the synthetic turf industry

- More than 50 independent and credible studies from groups such as the U.S. Consumer Product Safety Commission, and statewide governmental agencies such as the New York State Department of Environmental Conservation, New York State Department of Health and the California Environmental Protection Agency, have validated the safety of synthetic turf..."[1] – Synthetic Turf Council

- "Studies exist that indicate that exposure to rubber tires is greater for humans while standing roadside in any urban area than on a synthetic turf field. The rubber particle size utilized in synthetic turf fields is too large to be airborne, while the microscopic particles that come off tires from vehicles as they drive the road are microscopic. If tire rubber were ever going to become a concern, the use of vehicles and exposure roadside would be a tremendous cause for concern."[2] – Mark Nicholls of Turf Industries

- "Based on the more than 90 scientific studies that have already looked into the safety of synthetic turf fields and other surfaces with recycled rubber infill, we believe the answers are already out there."[3] – Safe Field Alliance and the Synthetic Turf Council

EHHI concluded that those studies needed to be carefully read and analyzed... It has taken a year to do so.

[1] http://c.ymcdn.com/sites/www.syntheticturfcouncil.org/resource/resmgr/Docs/STC_CRI_ExecSummary2016-0303.pdf
[2] http://www.niaaa.org/assets/Synthetic-turf-is-safe.pdf
[3] http://www.businesswire.com/news/home/20170103005986/en/Safe-Fields-Alliance-Synthetic-Turf-Council-Issue

EHHI has always maintained, and continues to maintain, that a product that contains as many carcinogens as synthetic turf does is not safe for children, students or athletes to play on.

Comments from Environment & Human Health, Inc. (EHHI)

- Most of the studies that the STC says proves the fields are safe find numerous chemicals, some of which are carcinogenic, in the fields, though some of the studies report that the chemicals are not at levels high enough to be available for intake and to cause health issues.
- What all the studies fail to explain is what it means to be exposed to multiple chemicals at the same time—even if each individual chemical is found to be at a low level.
- EHHI has always maintained, and continues to maintain, that a product that contains as many carcinogens as synthetic turf does is not safe for children, students or athletes to play on.

Comments from the National Institute of Environmental Health Sciences (NIEHS)

- Chemicals can sometimes act together to cause cancer, even when low-level exposures to individual chemicals might not be cancer-causing, or carcinogenic.[1]
- This important finding emerged from an international task force of more than 170 cancer scientists, known as the Halifax Project, who collaboratively assessed the carcinogenic potential of low-dose exposures to chemical mixtures in the environment. This is the concern about synthetic turf with crumb rubber infill, which is why EHHI considers it a danger to human health.
- The following studies are those listed by STC as of 2016 and will be listed in chronological order. Each study has been read thoroughly and summarized with the study's limitations and EHHI's conclusions. The original study's abstract can be found in the Appendix, along with the original study's website.

[1] https://www.niehs.nih.gov/news/newsletter/2015/7/science-exposure/index.htm

Grass Roots Environmental Education

Independent Science on Public Health Concerns Regarding Synthetic Turf

http://grassrootsinfo.org/pdf/syntheticturfscience.pdf

GRASSROOTS
ENVIRONMENTAL EDUCATION

Fostering positive and lasting change in environmental health through science and advocacy

Current Issues:
Synthetic Turf

Independent Science on Public Health Concerns Regarding Synthetic Turf

I. Crumb Rubber Chemicals

A. 1,3 Butadiene

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1. "Development of a unit risk factor for 1, 3-butadiene based on an updated carcinogenic toxicity assessment." Grant, RL, et al. *Risk analysis* 29:12 (2009) 1726-1742.

2. "Risk of leukemia in relation to exposure to ambient air toxics in pregnancy and early childhood." Heck, JE, et al. *International journal of hygiene and environmental health* 217:6 (2014) 662-668.

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1. "Arsenic exposure at low-to-moderate levels and skin lesions, arsenic metabolism, neurological functions, and biomarkers for respiratory and cardiovascular diseases: review of recent findings from the Health Effects of Arsenic Longitudinal Study (HEALS) in Bangladesh." Chen, Y, et al. *Toxicology and applied pharmacology* 239:2 (2009) 184-192.

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3. **"Association between exposure to low to moderate arsenic levels and incident cardiovascular disease: A prospective cohort study."** Moon, KA., et al. *Annals of internal medicine* 159:10 (2013) 649-659.

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5. **"Long-term low-level arsenic exposure is associated with poorer neuropsychological functioning: a Project FRONTIER study."** O'Bryant, SE, et al. *International journal of environmental research and public health* 8:3 (2011) 861-874.

6. **"Arsenic exposure and motor function among children in Bangladesh."** Parvez, F, et al. *Environmental health perspectives* 119:11 (2011) 1665.

7. **"Increased lung cancer risks are similar whether arsenic is ingested or inhaled."** Smith, AH, et al. *Journal of exposure science and environmental epidemiology* 19:4 (2009) 343-348.

8. **"Arsenic exposure transforms human epithelial stem/progenitor cells into a cancer stem-like phenotype."** Tokar, EJ, BA Diwan and MP Waalkes. *Environmental health perspectives* 118:1 (2010) 108.

9. **"Health effects of early life exposure to arsenic."** Vahter, Marie. *Basic and clinical pharmacology & toxicology* 102:2 (2008) 204-211.

10. **"Kidney cancer mortality: fifty-year latency patterns related to arsenic exposure."** Yuan, Yan, et al. *Epidemiology* 21:1 (2010) 103-108.

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1. **"Cancer incidence and mortality among workers exposed to benzidine."** Brown, SC, R Alberts, and M Schoenberg. *American journal of industrial medicine* 54:4 (2011) 300-306.

2. **"Cancer mortality and occupational exposure to aromatic amines and inhalable aerosols in rubber tire manufacturing in Poland."** de Vocht, F, et al. *Cancer epidemiology* 33:2 (2009) 94-102.

3. **"Establishing a total allowable concentration of o-toluidine in drinking water incorporating early lifestage exposure and susceptibility."** English, JC, et al. *Regulatory toxicology and pharmacology* 64:2 (2012) 269-284.

4. **"Biomonitoring of human exposure to arylamines."** Richter, E. *Frontiers in bio-science* 7 (2015) 222-238.

5. **"Elevated 4-aminobiphenyl and 2, 6-dimethylaniline hemoglobin adducts and increased risk of bladder cancer among lifelong nonsmokers—The Shanghai Bladder Cancer Study."** Tao, L, et al. *Cancer epidemiology and prevention biomarkers* 22:5 (2013) 937-945.

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1. **"Urinary biomarkers of exposure and of oxidative damage in children exposed to low airborne concentrations of benzene."** Andreoli, R, et al. *Environmental research* 142 (2015) 264-272.

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1. **"Tire tread wear particles in ambient air--a previously unknown source of human exposure to the biocide 2-mercaptobenzothiazole."** Avagyan, R, et al. *Environmental science and pollution research international* 21:19 (2014) 11580-6.

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2. "Phthalate exposure and asthma in children." Bornehag, CG, and E Nanberg. *International journal of andrology* 33:2 (2010) 333-345.

F. Butylated Hydroxyanisole (BHA)

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1. **"Environmental factors and allergic diseases."** Jenerowicz, D, et al. *Annals of agricultural and environmental medicine* 19:3 (2012).

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1. **"Cadmium exposure and cancer mortality in the Third National Health and Nutrition Examination Survey cohort."** Adams, SV, MN Passarelli, and PA Newcomb. *Occupational environmental medicine* 69:2 (2012) 153-156.

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P. Toluidine

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Delaware Riverkeeper Network

Alternative Infills for Artificial Turf Fact Sheet.

http://www.synturf.org/images/DRK3_Artificial_Turf_Alternative_Infill_Fact_Sheet_10.18.16_0.pdf

DELAWARE RIVERKEEPER NETWORK

Alternative Infills for Artificial Turf
Fact Sheet

As the health and environmental concerns over the **crumb rubber infill**[i] used in artificial turf gain traction within the US□ with increasing reports of its link to cancer, professional athletes and coaches condemning its use, municipalities and major cities across the country placing bans, politicians voicing concerns, and a federal multi-agency health study on artificial turf currently underway□ manufacturers of artificial turf are responding with infill alternatives to the traditional crumb rubber infill. There are many new and emerging variations in the different products□composition and their manufacturers□claims□ with some aimed at reducing the release of toxic substances, some at heat concerns, etc. Each of these materials offers their own apparent advantages, disadvantages, and questions□ which are outlined below. Generally, these alternatives, their performance as turf, and their impact on human health and the environment are not yet well studied, documented, or proven. Ultimately, especially when considered in their larger context as one component of an artificial turf system, infill alternatives pose greater environmental and health risks than natural grass turf.

Artificial turf infill: Artificial turf infill is the material used in an artificial turf system to hold artificial grass blades upright and to cushion the surface. Crumb rubber has long been the industry standard for infill material. As a result of the increasing environmental and health concerns associated with crumb rubber, the artificial turf industry is producing infills made from alternative materials.

Alternative infill materials: Alternative infill products generally consist of one or more of the following components:

Silica sand: Sand is generally combined with other infill components listed below at various ratios (though it is also occasionally used on its own with a shock pad).

- **Toxicity:** The crystalline silica sand that is generally used in artificial turf infill contains silica dust, which can cause silicosis (hardening of the lungs through inflammation and the development of scar tissue) and cancer when inhaled. Crystalline silica is known by the state of California to cause cancer[ii] OSHA recently finalized stricter rules for occupational exposure to crystalline silica dust;[iii] and the International Agency for Research on Cancer (IARC) has classified silica as a carcinogen.[iv] However, there are currently no standards for non-occupational exposure and silica sand is used frequently in playgrounds and artificial turf fields.
- **Performance:** Silica sand is abrasive and relatively hard, especially under cold or frozen conditions.[v]

Thermoplastic Elastomers (TPEs):[vi] TPE is a generic term for extruded plastic pellets made from a rubber and plastic polymer. While TPEs are often advertised as made from □virgin□(not recycled) materials, there is wide variability amongst the quality and chemical makeup of the many TPEs on the market.[vii]

- **Toxicity:** While many TPEs are advertised as free of lead, zinc, and other toxic materials, some have been shown to contain heavy metals. TPEs are often composed of ethylene, butadiene, and styrene

DELAWARE RIVERKEEPER NETWORK
925 Canal Street, Suite 3701
Bristol, PA 19007
Office: (215) 369-1188
fax: (215)369-1181
drn@delawareriverkeeper.org
www.delawareriverkeeper.org

copolymers.[viii] Styrene and butadiene, two of the main components in crumb rubber, are classified as carcinogens by the World Health Organization. The effects of human exposure to these substances from turf infill are not adequately studied.[ix] Dangerous chemical □fillers,□UV stabilizers, and flame retardants are often added. Very few toxicological and risk assessment studies exist, leaving insufficient data on the composition, off-gassing, leaching, and associated health effects.[x]

- **Temperature stability and performance**: There is no consistency amongst TPEs for these categories. Generally, TPE hardens over time.[xi] Many TPE fields that have been installed have had to be replaced due to the low melting point of the material resulting in a □gum-like substance that sticks to cleats and sticks the [grass] fibers together.□[xii]
- **Industry examples**: EcoGreen, Eco Max, BionPro, FutrFill

EPDM Rubber (Ethylene Propylene Diene Monomer): EPDM is a synthetic rubber polymer that can be made from either □virgin□or recycled rubber.[xiii] However, it is a similar material to SBR rubber, the standard crumb rubber infill. EPDM is a generic term and the source, formulation, and quality can vary greatly.[xiv]

- **Toxicity**: Some studies show that newly manufactured rubber also contains levels of hazardous substances; in the case of zinc and chromium the levels of recycled and newly manufactured rubber are comparable.[xv] EPDM rubber can be similar in composition to crumb rubber[xvi] and also contains UV stabilizers, flame retardants, and other chemical additives.[xvii] Very little analysis has been done on EPDM as an infill.[xviii]
- **Temperature and Performance**: EPDM is often produced in lighter colors to reduce heat concerns.[xix]
- **Additional issues:** Several manufacturers in Europe have had to replace a large number of fields due to a reaction between the EPDM and the carpet fiber that causes a breakdown of the fiber.[xx] There are reports of premature aging and degradation of the infill due to high levels of chemical □fillers.□[xxi]

Acrylic/Polymer Coated Sand: Silica sand coated in acrylic or another polymer. The chemical contents of the polymer coatings vary by manufacturer.

- **Toxicity**: The polymers used to coat the silica sand vary greatly. Some contain heavy metals and other toxins.[xxii] Limited data is available and coatings are thought to contain additional chemicals of concern.[xxiii]
- **Temperature stability and performance**: Reported to stay approximately 20 degrees cooler than crumb rubber, but to get hotter than natural grass.[xxiv] [xxv] Both the acrylic coating and sand are very hard and require a shock pad and are recommended to be combined with a softer filler material. Low Resiliency and shock absorption.[xxvi]
- **Additional issues**: Coating is reported to dissolve in water and not last as long as manufacturers guarantee. Sand particles can □gel□together.[xxvii][xxviii]

Recycled Sneakers: Ground athletic shoes and leftover materials from sneaker manufacturing that are marketed as safer than crumb rubber because they meet restricted substance standards set for wearable consumer goods.

- **Toxicity**: The actual composition of the rubber and other materials in the sneakers used is not actually known, but is thought to be very similar to that of crumb rubber. May contain heavy metals. Similar chemical exposures to carcinogens and neurotoxins as those from crumb rubber are suspected.[xxix] [xxx] [xxxi]
- **Performance**: Reported to cause contact injuries[xxxii] and hold static charge, sticking to clothing and equipment.[xxxiii] Can also cause extreme heat exposure.[xxxiv]

Organic materials: Several municipalities concerned with the health risks of crumb rubber have decided to install artificial turf fields with organic infill materials. These infills consist of any combination of one or more of the following: coconut fiber, coconut husk, coconut peat, cork, rice husks, walnut shells, etc.

- **Toxicity**: No apparent chemical toxicity in the infill materials themselves. However, other components of an artificial turf system (including polypropylene fiber carpets and SBR shock pads). Organic materials may also require treatment with pesticides, insecticides, antimicrobials or anti-static chemicals.[xxxv xxxvi]
- **Temperature**: Reported 20-50 degree cooler than crumb rubber, though still higher than natural grass.[xxxvii]
- **Performance**: Weather can impact playability as organic materials become saturated and freeze. Reports of early degradation and compaction.[xxxviii]
- **Other Issues**: Organic infills require irrigation and regular maintenance, including de-compaction twice a year and replacement of 10% of infill every 2-3 years.[xxxix] Materials harden, blow away, and float□ leading to migration and accumulate in waterways, reduced performance capability and higher potential for injury. There is potential for weed and mold growth and decomposition. Not recommended for flood prone areas.[xl xli xlii]

Variations: examples of variations on these materials include□

- **Coated crumb rubber:** marketed as □safer□and more heat resistant than crumb rubber. Crumb rubber may be coated with EPDM, colorants, or other sealants. The coatings may contain additional chemicals of concern; and their effectiveness in □sealing□off the toxins in crumb rubber has not been well studied.[xliii]
- **Extruded Cork Composite (ECC):** Natural cork, polyethylene and elastomers. These composites contain many of the same harmful chemicals in other plastic and rubber alternatives.[xliv]

Summary and Recommendations: Very few toxicological and risk assessment studies regarding the health and environmental impacts of emerging alternative infill options have been completed but from the data that is available there are many concerns to be had. While there is insufficient data on the chemical composition, off-gassing, leaching, and associated health and environmental effects that may result, the data that is available demonstrates many reasons for concern. For these reasons, the precautionary principle should be used to avoid the unnecessary and potentially devastating harms to those who would come in direct contact with the infills and the environment surrounding them.

All alternative infill options are significantly more expensive than traditional crumb rubber; with all artificial turf systems (including those with crumb rubber infill) costing more than natural turf grass.[xlv] There is no proven record of the durability, performance, and lifespan of these infills to warrant the cost□ and many anecdotal references from schools and municipalities throughout the country illustrate flaws.

While shock absorption and temperature stability of different alternative infills vary, natural grass fields are still preferable and safer playing surfaces for athletes. And while organic infill materials will likely eliminate most or all chemical exposure concerns due to the infill itself, other components of an artificial turf system are still likely sources of chemical exposure to players and surrounding ecosystems, in addition to other environmental concerns□ including increased stormwater due loss of pervious surface and/or evapotranspiration; toxins leaching from synthetic grass fibers and/or pads; migration of infill materials and turf fibers into waterways; leaching of algaecides, pesticides, disinfectants; and an increased greenhouse gas footprint.[xlvi]

Overall, when considering health, the environment, and the costs□ natural grass turf is safer choice.

[i] Crumb rubber refers to Styrene-Butadiene-Rubber, or SBR, made from recycled tires. For an overview of environmental and health concerns associated with crumb rubber infill, see DRN fact sheet: Artificial/Synthetic Turf. *Delaware Riverkeeper Network*. Fact Sheet, September 9, 2007. Web. 18 Oct. 2016. Available at: http://www.delawareriverkeeper.org/sites/default/files/Artifical%20Turf%20Fact%20Sheet.pdf

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[xlvi] In reviewing available literature on Artificial Turf, The Staff Work Group from Montgomery County Public Schools, Montgomery County Department of Parks, Montgomery County Council, Montgomery Department of Environmental Protection, and Montgomery County Department of Health and Human Services found that □the impacts of material transportation, construction, maintenance, and loss of carbon sequestration result in artificial turf fields adding GHG to the atmosphere when compared to natural grass fields.□

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Jason J. Bass
Weber State University, jasonjbass@gmail.com

David W. Hintze
Weber State University, davidhintze@msn.com