Summary of Research
Assessing the Impacts of Artificial Turf
Annotated Bibliography – Dr. Christi Davis for SHFPC

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Heat: Research has documented that the surface temperature on artificial turf is dramatically higher than the surrounding land uses including asphalt. Concerns regarding the excessive temperatures range from the implications for players who are already exerting themselves to the implications for burns when players or pedestrians come into contact with the hot surfaces.

1. Petrass, L. A., et al. (2014). Comparison of surface temperatures of different synthetic turf systems and natural grass: Have advances in synthetic turf technology made a difference. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*.

a. A comparison of surface temperatures of third-generation synthetic turf with a cool climate product that claims to reduce surface temperatures to surface temperatures of natural grass.
b. Although surface temperatures were lower for the cool climate field compared to other synthetic turf, both types of artificial turf fields were considerably hotter than natural grass with temperatures that were between 12° C (53° F) and 22° C (72° F) hotter.

2. Reasor, E. H. (2014). Synthetic Turf Surface Temperature Reduction and Performance Characteristics as Affected by Calcined Clay Modified Infill. Master's Thesis, University of Tennessee. Available at: http://trace.tennessee.edu/utk_gradthes/2750

a. Surface temperatures of artificial turf were between 31° C (88° F) and 57° C (135° F).
b. Although irrigation reduced surface temperatures of artificial turf, increases of 74 to 102% of the pre-irrigation temperature were observed within 30 minutes after irrigation.
c. Surface temperatures returned to pre-irrigation temperature on all of the treatments between 60 and 120 minutes after irrigation. Therefore, the cooling effect of irrigation will not last the entire length of an athletic competition.

3. Thoms, A. W. et al. (2014). Models for Predicting Surface Temperatures on Synthetic Turf Playing Surfaces. *Procedia Engineering*, *72*, 895-900. Available at: http://www.sciencedirect.com/science/article/pii/S1877705814006699

a. Artificial turf surface temperatures ranged from -9.8 to 86.4° C (14 to 188° F) to when ambient air temperatures ranged from -0.4 to 37.1° C (31 to 99° F).
b. Absorption of solar radiation results in increased temperatures on artificial turf surfaces, and high rates of solar radiation are absorbed with minimal light reflectance. Therefore, air temperature in conjunction with solar radiation explained most of the variation in artificial turf surface temperatures.

4. Penn State's Center for Sports Surface Research (2012). Synthetic Turf Heat Evaluation- Progress Report. January 2012. Available at: http://plantscience.psu.edu/research/centers/ssrc/documents/heat-progressreport.pdf

a. This study measured surface temperatures of artificial turf fields between 140.2 and 173.4° F when air temperatures were between 73 and 79° F.
b. Looking at various color options for infill and temperature, no product significantly reduced surface temperatures. Small reductions in temperature are insignificant when surface

temperatures still exceed 150° F. This study concluded that "[w]hile marketing materials may claim lower surface temperatures, no scientific reports exist that substantiate such claims."
c. Research has not found a good solution for excessive heat levels of turf.

5. Serensits, T. J. et al. (2011). Human health issues on synthetic turf in the USA. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *225*(3), 139-146.

a. High surface temperatures found on artificial turf fields can contribute to physiological stress and cause "serious heat-related illnesses" including heat stress, heat stroke, and burns.
b. The "New York City Department of Health and Mental Hygiene recognizes excessive surface temperatures as the most important health concern associated with infilled synthetic turf."
c. Irrigation of excessively hot artificial turf surfaces only provides cooling benefits for about 20 minutes, with a rebound to within 10 degrees of the pre-irrigation temperature within 3 hours.
d. The use of white crumb rubber as the infill does not resolve the heat issue.

6. Sciacca, T (2008). The Thermal Physics of Artificial Turf. SynTurf.org. Available at: http://www.synturf.org/sciaccaheatstudy.html

a. A study comparing temperatures on artificial turf temperatures with air temperature found that artificial turf ranged from 58 to 75° hotter than measured air temperature.

7. SportsTurf Managers Association (STMA) (2008). A Guide to Synthetic and Natural Turfgrass for Sports Fields: Selection, Construction and Maintenance Considerations. 2nd edition. Available at: http://www.stma.org/sites/stma/files/STMA_Synthetic_Guide_2nd_Edition.pdf

a. Artificial turf gets dramatically hotter than surrounding land uses including asphalt with surface temperatures as much as 95 to 140° F hotter than natural grass fields whereas the temperature of natural grass rarely rises above 85° F, regardless of air temperature

8. Williams, C. F., & Pulley, G. E. (2002). Synthetic surface heat studies. *Brigham Young University*. Available at: www.wellesleyma.gov/pages/WellesleyMA_SpragueResources/Synthetic%20Surfaces%20Heat%20Study.doc

a. Temperature measurements were taken at the surface, above the surface, and below the surface of artificial turf, natural turf, bare soil, asphalt, and concrete.
b. Surface temperatures of synthetic turf were 37° F higher than asphalt and 86.5° F hotter than natural turf.
c. Two inches below the surface, synthetic turf was 28.5° F hotter than natural turf.
d. Although irrigation of synthetic turf resulted in a reduction of close to 90°F, temperatures rose 35° within five minutes and returned to the starting temperature within 20 minutes.
e. "The hottest surface temperature recorded was 200º F on a 98º F day. Even in October the surface temperature reached 112.4º F."
f. Brigham Young University has set a surface temperature guideline which restricts play on synthetic turf fields when surface temperatures are potentially hazardous to athletes. This reduces the playing season and eliminates any continuous play benefit that is typically mentioned in favor of artificial turf.

9. Beard, J. B., & Green, R. L. (1994). The role of turf grasses in environmental protection and their benefits to humans. Journal of Environmental Quality, 23(3), 452-460. Available at:

https://www.landcarenetwork.org/legislative/TheRoleofTurfgrassesinEnvironmentalProtection.pdf

a. Synthetic surfaces can be up to 39° C (102° F) hotter than natural turf. Natural turf grass provides a natural cooling affect and helps to dissipate heat from neighboring developed areas.

Health: The impacts of inhalation or ingestion of chemicals continues to be a concern for those playing on artificial turf. Direct human exposure to the hazardous substances contained in the rubber in-fill of artificial turf is believed to occur via inhalation, skin contact, and/or ingestion. Furthermore, there are concerns for increased injuries and bacterial infections when playing on artificial turf.

1. Kim, S., Yang, J.-Y., Kim, H.-H., Yeo, I.-Y., Shin, D.-C., & Lim, Y.-W. (2012). Health Risk Assessment of Lead Ingestion Exposure by Particle Sizes in Crumb Rubber on Artificial Turf Considering Bioavailability. Environmental Health and Toxicology, 27, e2012005. http://doi.org/10.5620/eht.2012.27.e2012005.

a. Researchers considered the risks for lead exposure from children ingesting rubber powder resulting from exposure to crumb rubber infill artificial turf and found that elementary school students had a hazard index that exceeded 0.1, a level that is considered a "potential for hazard", with middle and high school students also suffering exposure levels.

2. Balazs, G. C., et al. (2014). Risk of Anterior Cruciate Ligament Injury in Athletes on Synthetic Playing Surfaces A Systematic Review. *The American journal of sports medicine*, 0363546514545864.

a. A systematic review of available literature on the risk of ACL rupture on natural grass versus artificial turf found that there is an increased rate of ACL injury on synthetic playing surfaces for football players.

3. Celeiro, M., Lamas, J. P., Garcia-Jares, C., Dagnac, T., Ramos, L., & Llompart, M. (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.

a. The presence of a large number of hazardous substances were found in both the runoff and vapor phase of recycled tire playground surfaces.

b. Nine polycyclic aromatic hydrocarbons (PAHs) were detected in the runoff/ cleaning water with total PAH concentrations in the ppm (parts per million) range.

c. The most toxic PAH, benzo[a]pyrene was detected in extracts from playground surfaces.

d. "The presence and the high concentration of these chemical compounds in playground should be a matter of concern owing to their high toxicity."

4. Laible, C., & Sherman, O. H. (2014). Risk Factors and Prevention Strategies of Non-Contact Anterior Cruciate Ligament Injuries. *Bulletin of the Hospital for Joint Diseases*, *72*(1), 70-5. Available at: http://www.nyuhjdbulletin.org/mod/bulletin/v72n1/docs/v72n1_7.pdf

a. Since shoe-surface interaction is important for injury prevention, "the optimal surface to prevent injury is outdoors on natural grass."

b. Artificial turf has a higher friction coefficient and greater ground reaction force, both conditions that increase the risk for injury.

c. Furthermore, as temperature increases the shoe-surface friction interaction increases and exposes athletes to greater risk of injury.

5. Bass, J. J., & Hintze, D. W. (2013). Determination of Microbial Populations in a Synthetic Turf System. Skyline-The Big Sky Undergraduate Journal, 1(1), 1. Available at: http://skyline.bigskyconf.com/cgi/viewcontent.cgi?article=1000&context=journal

a. Abrasions, even insignificant ones, from artificial turf can create an entry site for pathogens.

b. The higher abrasion rate for synthetic turf increases the risk of infection, and the microbial populations found within synthetic turf are a source of pathogens when abrasions occur.

b. Older turf fields have higher microbial populations, as well as higher levels in the higher traffic areas such as the sidelines. These results indicate that artificial turf poses a greater risk for the spread of pathogens and infections among student athletes.

6. Llompart, M., Sanchez-Prado, L., Lamas, J. P., Garcia-Jares, C., Roca, E., & Dagnac, T. (2013). Hazardous organic chemicals in rubber recycled tire playgrounds and pavers. *Chemosphere*, *90*(2), 423-431. Available at: http://www.elcorreodelsol.com/sites/default/files/chemosphere_maria_llompart.pdf

a. An analysis of surfaces containing recycled rubber tires confirmed the presence of hazardous substances including PAHs, phthalates, antioxidants (e.g. BHT, phenols), benzothiazole, derivatives, and other chemicals.

b. The vapor phase above the samples confirmed volatilization of many organic compounds demonstrating that these chemicals can enter the human body through inhalation.

c. The use of recycled rubber tires for play areas, especially facilities for children, should be restricted or prohibited.

7. Serensits, T. J., McNitt, A. S., & Petrunak, D. M. (2011). Human health issues on synthetic turf in the USA. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *225*(3), 139-146.

a. Synthetic turf is more abrasive than natural turf grass, therefore, “breaks in the skin are more common, creating a pathway for infection when in contact with an infected surface.”

8. Shalat, S.L. (2011). An Evaluation of Potential Exposures to Lead and Other Metals as the Result of Aerosolized Particulate Matter from Artificial Turf Playing Fields, Final Report. Submitted to NJ Department of Environmental Protection, July 14, 2011. Available at: http://www.nj.gov/dep/dsr/publications/artificialturf-report.pdf

a. In air samples collected from artificial turf during various levels of activity, researchers detected arsenic, cadmium, chromium and lead, all metals with known human toxicity.

b. This research demonstrates that activity by players on the fields could suspend contaminated particulates into the air that could be inhaled and therefore, human exposure from artificial turf fields is not limited to dermal.

c. These results “raise some concerns with regard to the potential hazards that may exist for individuals and in particular children who engage in sports activities on artificial turf fields.”

9. Van Ulirsch, G. et al. (2010). Evaluating and regulating lead in synthetic turf. *Environmental health perspectives*, *118*(10), 1345. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2957910/pdf/ehp-118-1345.pdf

a. Artificial turf can degrade to form lead containing dust at levels that pose a health risk to children.

b. Due to the lack of research, “…physicians should be aware of synthetic turf as one potential source of exposure for young children…” and “Health officials investigating elevated blood lead in children should also be aware of synthetic turf as a potential source of lead exposure.”

10. Center for Disease Control and Prevention. (2008). CDC Health Advisory. Potential exposures to lead inartificial turf: Public health issues, actions, and recommendations. June 18, 2008. Available at: http://www.dhhr.wv.gov/oeps/disease/Documents/Advisory_00275.pdf

a. Artificial turf made of nylon or nylon/ polyethylene blend fibers contain lead and pose a potential public health concern.
b. The risk for lead exposure is higher for artificial fields that are old, frequently used, exposed to the weather, or demonstrate signs of abraded, faded, or broken fibers. As turf ages, lead is released in dust that could then be ingested or inhaled.
c. CDC does not know how much lead the body will absorb. However, lead can cause neurological
development symptoms and behavioral problems. Children less than 6 years old are more affected by lead than adults and absorb lead more easily.
d. CDC does not understand the potential risks associated with lead exposure from artificial turf but recommends precautions including aggressive hand and body washing after playing on fields,
washing clothes immediately to avoid tracking contaminated dust to other places, and discouraging eating and drinking while on turf products.

11. Han, I. K., Zhang, L., & Crain, W. (2008). Hazardous chemicals in synthetic turf materials and their bioaccessibility in digestive fluids. Journal of Exposure Science and Environmental Epidemiology, 18(6), 600-607. Available at: http://www.nature.com/jes/journal/v18/n6/pdf/jes200855a.pdf

a. Samples from rubber granules and from artificial grass fibers were taken at fields of different ages and analyzed for polycyclic aromatic hydrocarbons (PAHs), zinc, chromium, arsenic, cadmium, and lead. These samples were then analyzed to determine their bioaccessibility in synthetic digestive fluids.
b. The rubber granules found in artificial turf fields had PAH levels above health-based soil standards. Although levels appear to decline over time, this trend can be altered by the fact that new rubber can be added periodically to compensate for the loss of infill material.
c. There was a “slightly worrisome” level of chromium found in artificial turf fiber samples.
d. Lead in artificial fields can come from the blades of artificial grass, the pigment used for the field markings and lines, and the infill material. Although there were relatively low concentrations of lead measured, the researchers were careful to point out: “some health scientists believe that any Pb [lead] is harmful to children’s neurocognitive development, and that no new Pb should be added to their surroundings.” Furthermore, the lead present in the rubber granules, while at low levels, was “highly bioaccessible” to synthetic gastric fluid.

12. Brown, D.R. (2007). Artificial Turf: Exposures to Ground-up Rubber Tires. Environment & Human Health, Inc. (EHHI). Available at: http://www.ehhi.org/reports/turf/turf_report07.pdf

a. Direct human exposure to the hazardous substances contained in artificial turf occurs via three pathways: inhalation as chemicals off gas from the turf, skin contact, or ingestion including by
children or infants who come into contact with the material. In the case of allergies (i.e. latex allergies), inhalation could result in a systemic response, as opposed to a contact response.
b. Extreme temperatures or solvents are not needed to release metals (including zinc, selenium, lead and cadmium), volatile organic compounds, or semi-volatile organic compounds from the rubber infill of artificial turf into the air or water – release takes place in ambient air and water temperatures.

c. While, “the status of the information about human exposures to recycled tire crumb rubber in-fill … is not sufficient to determine the safety of the use of the product in situations that involve
continuous episodes of human exposure;” “the available information is sufficient and strong enough to raise plausible questions with respect to acute toxicity for susceptible persons, and for
cancer risks.”

13. California Office of Environmental Health Hazard Assessment (OEHHA) (2007). Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Report prepared for the Integrated Waste Management Board. Available at:
http://www.calrecycle.ca.gov/publications/Documents/Tires%5C62206013.pdf

a. Based on a review of 46 studies, 49 chemicals that are released from tire crumb were identified.
b. Of the 49 chemicals identified, “seven of the chemicals leached from tire shreds were carcinogens.”
c. OEHHA calculated a cancer risk of 1.2 in 10 million based on a one-time ingestion of the tire crumb rubber over a lifetime.
d. Chrysene, a PAH and carcinogen, was found to be ingested as the result of hand-to-surface-to mouth transfer from playground surfaces made with recycled tires. Assuming playground use for an 11 year period (from age 1 to 12) there was found to be an increased cancer risk of 2.9 in one million from the general cancer risk gauge of one in one million
e. Only 31% of the playground surfaces made of recycled tires tested passed the California State mandated Head Impact Criterion (HIC) of <1,000. In this same study 100% of the playground surfaces made of wood chips passed the same standard.

14. Crain, W. and Zhang, J. (2007). Rachel’s Democracy and Health News #992: Hazardous Chemicals in Synthetic Turf, Follow-up Analyses, April 12, 2007. Available at:
http://www.precaution.org/lib/07/prn_synthetic_turf.070405.htm

a. Testing on two sites in New York where synthetic turf has been used (the large, 3 year old, Parade Ground in Brooklyn; the relatively small 5 month old Sara D. Roosevelt Park in Manhattan) found PAHs at hazardous levels (as per New York standards). Dibenzo (a.h)anthracene, a probable human carcinogen, was also found at hazardous levels, with two other PAH forms, both possible human carcinogens, found at hazardous levels at the Parade Ground site.
b. Research into the pathways by which these substances may be absorbed into the bodies of children and athletes via skin contact, ingestion or other pathways, is very limited with additional research needed.

15. Epstein, V. (2007). Texas Football Succumbs to Virulent Staph Infection from Turf. Bloomberg Press, December 21, 2007. Available at:
http://www.bloomberg.com/apps/news?pid=newsarchive&sid=alxhrJDn.cdc

a. Artificial turf is linked with serious and potentially life threatening staph infections including MRSA (methicillin-resistant staphylococcus aureus). MRSA can exploit minor skin injuries such as turf burn, and therefore, MRSA infection rate among players is 16 times higher than the national average.

16. KEMI, Swedish Chemicals Agency (2007). Facts: Synthetic Turf. April 2007. Available:

http://www2.kemi.se/upload/trycksaker/pdf/faktablad/fbsyntheticturf.pdf.

a. Tires contain up to 60 different substances which may be bioaccumulative, carcinogenic, reprotoxic, mutagenic and/or endocrine disrupting.
b. Most PAHs are persistent, bioaccumulative and carcinogenic.
c. Among the metals found in tires that may be of concern are zinc, lead, copper, chromium and cadmium. Zinc and copper are harmful when absorbed at high levels. Lead can affect reproduction and development of the nervous system leading to poor cognitive development. Chromium is carcinogenic and mutagenic. Cadmium is toxic to humans and can contribute to poor liver and kidney function, as well as osteoporosis.

17. Mattina, M. I., Isleyen, M., Berger, W., & Ozdemir, S. (2007). Examination of crumb rubber produced from recycled tires. *The Connecticut Agricultural Experiment Station, New Haven, CT.* Available at: http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/examinationofcrumbrubberac005.pdf

a. Multiple compounds out-gas and leached into water from synthetic turf rubber crumb under ambient temperatures including benzothiazole (a skin and eye irritant), butylated hydroxyanisole (a "recognized carcinogen, suspected endocrine toxicant, gastrointestinal toxicant, immune toxicant, neurotoxicant, skin and sense-organ toxicant"), n-hexadecane (a severe irritant), and 4-(t-octyl) phenol ("corrosive and destructive to mucous membranes").

18. Anderson, M. E. et al. (2006). A case study of tire crumb use on playgrounds: risk analysis and communication when major clinical knowledge gaps exist. Environmental health perspectives, 114(1), 1. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1332647/pdf/ehp0114-000001.pdf

a. A Case Study conducted by a group of physicians and public health professionals working with the U.S. Environmental Protection Agency's Region Pediatric Environmental Health Specialty Unit found that the research and information necessary is not available to establish "the safety in use with children" of tire crumb used as playground surfaces.
b. "The use of recycled tire crumb products on playgrounds has had little health investigation. The major unresolved concern is the potential for latex allergy with short-term dermal exposure."

19. Crain, W. and Zhang, J. (2006). Rachel's Democracy and Health News #871: Hazard Chemicals in Synthetic Turf. September 7, 2006. Available at: http://www.precaution.org/lib/06/prn_toxins_in_synthetic_turf.060831.htm

a. Analyses conducted at the Environmental and Occupational Health Sciences Institute of Rutgers
University found the crumb rubber from artificial turf to contain high levels of PAHs, as well as zinc and arsenic.
b. PAHs found to be contained in the crumb rubber "were above the concentration levels that the New York State Department of Environmental Conservation (DEC) considers sufficiently hazardous to public health to require their removal from contaminated soil sites. It is highly likely that all six PAHs are carcinogenic to humans."
c. "The analyses also revealed levels of zinc in both samples that exceed the DEC's tolerable levels."
d. The researchers associated with these findings were careful to state "We want to emphasize that the findings are preliminary. PAHs in rubber might not act the same way as in soil, and we do not yet have information on the ease with which the PAHs in these rubber particles might be absorbed by children or adults -- by ingestion, inhalation, or absorption through the skin.

However, the findings are worrisome. Until more is known, it wouldn't be prudent to install the synthetic turf in any more parks."

20. Kazakova, S. V. et al. (2005). A clone of methicillin-resistant Staphylococcus aureus among professional football players. New England Journal of Medicine, 352(5), 468-475. Available at: http://www.nejm.org/doi/pdf/10.1056/NEJMoa042859

a. In a study of professional football players from the St. Louis Rams team, all MRSA infections developed at sites of turf burns.

b. Players reported a higher frequency of abrasions when playing on artificial turf compared to natural grass.

21. Begier, E. M. et al. (2004). A high-morbidity outbreak of methicillin-resistant Staphylococcus aureus among players on a college football team, facilitated by cosmetic body shaving and turf burns. *Clinical infectious diseases*, *39*(10), 1446-1453. (a study conducted for the Connecticut Department of Public Health, Student Health Services of Sacred Heart Univ, Centers for Disease Control and Prevention, Minnesota Department of Public Health, and the Los Angeles County Department of Health Services).

a. In a study of MRSA outbreaks involving college football players, infection was associated with turf burns from artificial grass. Turf burns increased the risk of infection regardless of the type and timing of care provided the burn. Turf burns may be facilitating infection by acting as a pathway for infection.

22. Shorten, M. R., & Himmelsbach, J. A. (2003). Sports surfaces and the risk of traumatic brain injury. Sports surfaces. University of Calgary, Calgary, 49-69. Available at: http://biomechanica.com/docs/publications/docs/Shorten%20-%20Head%20Injury%20Risk.pdf

a. There is double the risk of head traumas such as concussions associated with artificial turf compared to natural turf, and artificial turf presents a 5 times greater risk of more severe head injury.

b. Concussions (formally described as Mild Traumatic Brain Injury or MTBI) resulting from sports has, according to the US Centers for Disease Control, reached "epidemic proportions," and these 'mild' head traumas, especially a series of concussions, can have long term, negative effects on cognitive function.

23. Naunheim, R., et al. (2002). Does the use of artificial turf contribute to head injuries?. *Journal of Trauma-Injury, Infection, and Critical Care*, *53*(4), 691-694.

a. The impact-attenuating properties of two artificial fields were compared to a grass outdoor practice field. Both artificial surfaces were harder compared to the outdoor grass field. It was concluded that the low impact attenuation of the artificial turf may be contributing to the high incidence of concussion.

24. Guskiewicz, K. M., et al. (2000). Epidemiology of concussion in collegiate and high school football players. The American Journal of Sports Medicine, 28(5), 643-650.

a. In a survey of both high school and collegiate certified athletic trainers representing over 17,000 football players, contact with artificial turf was associated with more serious concussion than contact with natural grass.

The true impact of chemical exposure could take decades to be measured.

25. EPA: *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures, 2000*
http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=4486

EPA Risk Assessment Forum Technical Panel. (2000). Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures. Washington DC: U.S. Environmental Protection Agency.

The guidelines define a complex mixture thus: "A mixture containing so many components that any estimation of its toxicity based on its components' toxicities contains too much uncertainty and error to be useful. …. Risk assessments of complex mixtures are preferably based on toxicity and exposure data on the complete mixture..." Appendix B p.2

Thus far, risk assessments on crumb rubber, a complex chemical mixture, have not been done in a manner consistent with these guidelines.

Since toxicity data on crumb rubber is not available, component-based methods have been used to estimate risk. While the findings of these assessments have been reported, the reality that the data quality was too poor to justify a quantitative risk assessment has not been reported.

The risk assessments have been based on only about **half of the *identified* compounds** contained in crumb rubber because there is no governmental toxicity testing on the other half. The information on the other half of the chemicals is often limited. Therefore, risk assessments have included data extrapolated from animal studies to human health effects, assumed that two related chemicals have identical toxicities, used toxicities for which there is at least 100-fold degree of uncertainty, and used oral and dermal exposure data to predict inhalation toxicity. The risk assessments have assumed that there are no interaction effects between the dozens of chemicals that are off-gassed from crumb rubber.

There are also problems with the exposure estimates. Many of the measurement were taken using stationary monitors, often located away from active play. This is problematic because players on a field constantly disturb the infill, re-suspending dust (PM 2.5, PM 10, carbon black) and potentially changing the levels of VOCs and SVOCs in the atmosphere. There are no estimates of exposure to carbon black, a known carcinogen, on outdoor fields. Exposure estimates to fine particulate matter on outdoor fields are extremely limited, and relied exclusively on stationary monitors.

26. Highsmith, R., Thomas, K., & Williams, R. (2009). A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds. National Exposure Research Laboratory, U.S. Environmental Protection Agency.

This study was readily available on the EPA's servers during the summer of 2015**, along with warnings that the results could not be generalized beyond the four sites sampled in the study**. However, that page was removed and access to the study from the EPA website was temporarily not possible. Now there is a link to the study from the EPA's Tire Crumb and Synthetic Turf Field Literature and Report list. **All warnings about the limitations of the study have been removed.**

This study examined airborne PM 10 and VOCs at four outdoor fields and one outdoor playground. Additionally the extractable heavy metals from surface wipes, the crumb rubber and the turf blades from each location were also measured. Bioaccessibility of the lead in the crumb rubber was

estimated using the protocols for assessing the bioaccessibility of lead in soil. The study protocols forage sampling on the turf fields did not mimic real world conditions. The protocols for the playgrounds were more realistic because the air samples were taken while the playgrounds were being actively used by children.

http://www.libertytire.com/Libraries/Documents/USEPA-Study-Synthetic-Turf-Fields-Playrgounds-Nov-2009.sflb.ashx

27. Pavilonis, B., Weisel, C., Buckley, B., & Lioy, P. (2013). Bioaccessibility and Risk Exposure to Metals and SVOCs in Artificial Turf Field Fill Materials and Fibers. Risk Analysis.

Based on their findings, the authors stated that, "Since it is possible that children may be exposed to potentially high concentrations of lead while using artificial turf fields we recommend, at a minimum, all infill and fibers should be certified for low or no lead content prior to purchase and installation."

It was very concerning that extremely high levels of lead and chromium were found in some of the samples of the tire crumb, the plastic turf and the biofluid extracts of these materials. The authors also noted the extreme variability of lead and chromium in the samples.

"Lead was detected in almost all field samples for digestive, sweat, and total extraction fluids with digestive fluid extract of one field sample as high as 260 mg/kg. Metal concentrations were not markedly different across the three different sample types (new infill, new turf fiber, tire crumb field sample). However, one of the new turf fiber samples contained relatively large concentrations of chromium (820 mg/kg) and lead (4,400 mg/kg) compared to the other samples tested...the variability of lead contained in the infill material is large and can span more than two orders of magnitude. One field [tire crumb] sample did contain a high lead level (260 mg/kg) which was on the same order of magnitude as the NJ DEP cleanup value (400 mg/kg)."

Other toxicants were also detected at low levels. However, this study likely significantly underestimated the levels of bioaccessibility of toxicants in the crumb rubber and turf. The study did not use biologically relevant crumb rubber particle sizes or incubation times when determining the bioaccessibility of SVOCs and metals in simulated biofluids. The dust and tiny particulates less than 10 microns in diameter that are most relevant, not the relatively large crumbs. Athletes are inhaling particulate matter often only a few microns in diameter and the particulate matter may stay lodged in the lungs for months, not 24 hours. Dust particles stick to the skin far more effectively than crumbs and are much harder to spit out when they accidentally get into the mouth. Surface area is a key factor in determining bioavailability. The toxicants in dust are far more bioavailable than those in crumbs. The initial study on the Ironbound Athletic Fields in New Jersey by the New Jersey Department of Health, the EPA, and the ASTDR analyzed the dust on the fields for lead content. Those researchers clearly recognized that the dust was the key to assessing the health risks posed by those fields. It is unclear why these authors would analyze tire shreds when dust is clearly the relevant particle size.

27. Marsili, L. C. (2016). Release of Polycyclic Aromatic Hydrocarbons and Heavy Metals from Rubber Crumb in Synthetic Turf Fields: Preliminary Hazard Assessment for Athletes. Environmental & Analytical Toxicology.

This study clearly demonstrated that both the temperature at which off gassing is measured and the model which is used to assess risk dramatically affect the conclusions of a risk assessment. When a risk assessment was done at 25 degrees Celsius, using the Lifetime Average Daily Dose to calculate cumulative excess cancer risk lead to estimates well below the de minimus level. However, when the risk assessment was conducted with the crumb rubber heated to 60 degrees, and a toxic equivalent quotient model was used, the exposure was up to 1,000 times the virtually safe dose of B(a)P in food.

Ariana Eunjung Cha, *The Washington Post*, 6/17/15 https://www.washingtonpost.com/news/to-your-health/wp/2015/06/16/ddts-breast-cancer-legacy-pregnant-mothers-exposure-linked-to-four-fold-increase-in-daughters-risk/ and http://press.endocrine.org/doi/10.1210/jc.2015-1841)

Other studies have raised serious concerns about tire crumb and lead exposure.

A 2014 study found lead and other toxins in the both the plastic rug and tire crumb infill. Lead was also was found in simulated body fluids meaning there is little or no protection of any kind against the lead getting out of the material into the body. "Since it is possible that children may be exposed to potentially high concentrations of lead while using artificial turf fields we recommend, at a minimum, all infill and fibers should be certified for low or no lead content prior to purchase and installation."

("Bio-accessibility and Risk of Exposure to Metals and SVOCs in Artificial Turf Field Fill Materials and Fibers" Brian T. Pavilonis, Clifford P. Weisel, Brian Buckley, and Paul J. Lioy http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4038666/pdf/nihms565643.pdf 2014)

No two fields are alike because each field contains 30,000 to 40,000 ground up tires, which come from a multitude of manufacturers.

"Every turf field has to be analyzed in detail to be sure it doesn't have a problem,' said Paul Lioy, a professor of environmental and occupational medicine at the Robert Wood Johnson Medical School in New Jersey." [Emphasis added.] ("Feds promote artificial turf as safe despite health concerns," by Thomas Frank *USA Today*, 3/16/2015 http://www.usatoday.com/story/news/2015/03/15/artificial-turf-health-safety-studies/24727111/)

Artificial turf fields create "heat islands" – an environmental hazard.

> The extreme heat "is not only a hazard for users, but also can contribute to the 'heat island effect,' in which cities become hotter than surrounding areas because of heat absorbed by dark man-made surfaces such as roofs and asphalt." ("Synthetic Turf: Health Debate Takes Root" by Luz Claudio, Environmental Health Perspectives 2008 March; 116(3): A116–A122. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2265067/

> "Columbia University climate researcher Stuart Gaffin analyzed thermal images generated from NASA satellite maps of New York City. He wanted to figure out how urban trees may help cool down neighborhoods. When **Gaffin noticed a bunch of hot spots on the maps, he assumed they were rooftops**…two turned out to be turf fields" says Gaffin. In retrospect, he says he should have realized that, because they're a perfect sunlight-absorbing system." ("High Temps On Turf Fields Spark Safety Concerns," by Allison Aubrey, National Public Radio, 8/7/2008 http://www.npr.org/templates/story/story.php?storyId=93364750)

Artificial turf appears to contribute to elevated levels of zinc in the water.

> "There is a potential risk to surface waters and aquatic organisms associated with whole effluent and zinc toxicity of stormwater runoff from AT fields." ("Artificial Turf Study, Leachate and Stormwater Characteristics," July 2010 Conn. Department of Environmental Protection

> "Crumb rubber derived entirely from truck tires may have an impact on aquatic life due to the release of zinc. For the other three types of crumb rubber, aquatic toxicity was found to be unlikely." Pg. 2

> "Zinc concentrations are higher than the surface water standards." Pg. 29

> ("An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-rubber Infilled Synthetic Turf Fields" May 2009 from staff at NY State Department of Environmental Conservation)

Plastic artificial turf blades will likely disintegrate and degrade with some ending up in bodies of water and in the food of wildlife either directly or via landfills; plastics of various sizes are already threatening aquatic life. The impacts of larger sized plastics is more widely known, but now more is being discovered about the serious effects of microplastics. ("Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L)." by Browne MA1, Dissanayake A, Galloway TS, Lowe DM, Thompson RC, *Environmental Science & Technology*, 7/1/2008 http://www.ncbi.nlm.nih.gov/pubmed/18678044)

"As plastic breaks into smaller pieces, it is more likely to infiltrate food webs. In laboratory and field studies, fish, invertebrates and microorganisms ingest micrometer-sized particles…" ("Classify plastic waste as hazardous," by Chelsea M. Rochman, Mark Anthony Browne, Eunha

Hoh, Hrissi K. Karapanagioti, Lorena M. Rios- Mendoza, Hideshige Takada, Swee Teh, Richard C. Thompson. *Nature*, 2/14/13.)

Environment: The pollutant substances found in artificial turf contribute to contamination of soil, plants and aquatic ecosystems and pose a risk of toxic effects for aquatic and sediment dwelling organisms. The resulting environmental harm is on-going and long-term, happening over many years. The varying content of tires used for infill of turf systems makes this threat a moving target. A growing body of scientific analysis is documenting a concerning level of environmental threat and harm and is further demonstrating the need for more research regarding artificial turf and its ramifications for the environment.

1. Public Employees for Environmental Responsibility (PEER) (2012). Petition for a Rulemaking on Surface Heat from Artificial Turf, Submitted by PEER to Consumer Product Safety Commission, Sept 6, 2012. Available at: http://www.peer.org/assets/docs/doc/9_6_12_PEER_Petition_heat_rulemaking.pdf

   a. As well explained by an oft cited petition to the Consumer Product Safety Commission for rulemaking: "When tires are shredded and pulverized, their surface area increases exponentially, as does the particulate and gas yield from the tire material. Since tires are made of very harmful materials, including 24 gases found to be harmful to humans, carbon black, (a carcinogen which makes up 30% of tires), latex, benzothiazoles, phthalates, lead, mercury, cadmium, zinc and many other known toxins, when the fields heat up, they become increasingly dynamic. Of primary concern is the interaction of particles and gases, 'because when particles adsorb onto the surface of gases, they become 10-20 times more toxic than the materials themselves.'"

   b. Furthermore, artificial turf becomes more toxic as it heats up.

2. Sadiktsis, I., et al. (2012). Automobile Tires A Potential Source of Highly Carcinogenic Dibenzopyrenes to the Environment. Environmental science & technology, 46(6), 3326-3334. Available at: http://www.locchiodiromolo.it/blog/wp-content/uploads/2012/03/Sadiktsis-et-al-Automobile-Tires-Potential-Source-of-Highly-Carcinogenic-2012.pdf

   a. The variability in PAH concentrations between different tires is large.

   b. Due to "leaching of PAHs from recycled tire rubber material, tires are a source of environmental pollution of PAHs through their entire lifecycle."

3. Connecticut Department of Environmental Protection (2010). Artificial Turf Study: Leachate and Stormwater Characteristics, Final Report. Available at: http://www.ct.gov/deep/lib/deep/artificialturf/dep_artificial_turf_report.pdf

   a. Stormwater runoff from artificial turf contained zinc, manganese, and chromium at levels toxic to aquatic organisms.

   b. Therefore, there is a potential risk to surface waters from the installation of artificial turf. Zinc levels could cause exceedance of acute aquatic toxicity criteria. This risk is especially high for smaller watercourses.

   c. Best management practices and treatment (i.e. wetlands, wet ponds, infiltration structures, compost filter, sand filters, or biofiltration structures) should be used for stormwater runoff from artificial turf fields that discharge to surface waters.

4. Yaghoobian, N., et al. (2010). Modeling the thermal effects of artificial turf on the urban environment. *Journal of Applied Meteorology and Climatology*, *49*(3), 332-345.

a. An urban temperature model showed an increase in local atmospheric temperatures of up to 4° C (39° F) in areas where natural grass cover had been replaced with artificial turf.

5. Han, I. K., et al. (2008). Hazardous chemicals in synthetic turf materials and their bioaccessibility in digestive fluids. Journal of Exposure Science and Environmental Epidemiology, 18(6), 600-607. Available at: http://www.nature.com/jes/journal/v18/n6/pdf/jes200855a.pdf

a. Zinc was found to exceed soil limits and the leaching rate from rubber granules was up to 20 times more than the leaching rate from agricultural applications of manure and pesticides. "Runoff with high Zn [zinc] from synthetic turf fields may produce adverse effects to plants and aquatic life."

6. KEMI, Swedish Chemicals Agency (2007). Facts: Synthetic Turf. April 2007. Available: http://www2.kemi.se/upload/trycksaker/pdf/faktablad/fbsyntheticturf.pdf.

a. Hazardous substances found in tires may persist in the environment including polycyclic aromatic hydrocarbons (PAHs), phthalates, phenols, and certain metals.

b. Most PAHs are persistent, bioaccumulative and carcinogenic.

c. Phthalates and phenols are not chemically bound to the rubber and as a result can leach from the infill material. These chemicals are persistent and bioaccumulative and can have long-term effects on the environment.

7. Meil, J., & Bushi, L. (2006). Estimating the Required Global Warming Offsets to Achieve a Carbon Neutral Synthetic Field Turf System Installation. *Athena Institute. Ontario Canada.* Available at: http://sfrecpark.org/wp-content/uploads/AthenaICarbonOffsets.pdf

a. Artificial turf systems have a carbon footprint due to the greenhouse gases emitted during the life cycle of synthetic turf systems compared to natural grass surfaces.

b. To achieve a 10-year carbon neutral synthetic turf installation, 1861 trees would need to be planted to offset the field's carbon footprint.

8. Källqvist, T. (2005). Environmental risk assessment of artificial turf systems. *Norwegian Institute for Water Research*, 19.

a. Recycled rubber varies considerably in its chemical composition, even when from the same manufacturer.

b. Leaching of contaminants from artificial turf as the result of surface water runoff from precipitation is a great risk for the environment. It is predicted that chemicals leaching from synthetic turf materials occurs slowly, and as a result the environmental harms may take place over many years.

There is also a level of "erosion" that takes place and can result in fine particles that could be carried to local waterways. Chemicals have even been shown to leach from the artificial turf fibers.

c. The leachate from artificial turf can contain a variety of metals (including lead, cadmium, copper, mercury and zinc) and organic pollutants (including PAHs, phthalates, 4-t-octylphenol and isononyphenol).

d. The runoff from an artificial turf field poses "a positive risk of toxic effects on biota in the water phase and in the sediment."

e. Of the organic compounds at issue, octylphenol represents the greatest risk, and possibly could occur at levels where hormone disrupting effects are a concern.

f. The Norwegian Institute for Water Research has determined that it is “appropriate to perform a risk assessment which covers water and sediments in watercourses which receive run-off from artificial turf pitches.”

9. Thale, S.W. et al. (2004) Potential Health and Environmental Effects Associated with Synthetic Turf Systems final report. Byggforsk, Norwegian Building Research Institute. Available at: http://www.issssportsurfacescience.org/downloads/documents/vskyslv2qq_nbiengelsk.pdf

a. While recycled rubber is a greater source of pollution, 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.

b. The synthetic grass fibers can also be a significant source of pollution, albeit significantly lesser amounts leach from the synthetic grass than the rubber infill

10. Tucker, M.R. (1997). Ground Rubber: Potential Toxicity to Plants. Media Notes for North Carolina Growers, North Carolina Dept. of Agriculture & Consumer Services, April 1997. Available at: http://www.ncagr.gov/agronomi/pdffiles/rubber.pdf

a. When talking about the use of ground rubber as a supplement to planting soils, the North Carolina

Department of Agriculture and Consumer Services sent out a notice identifying the risk that zinc leaching from the rubber causes a decline in plant growth “directly attributable to zinc toxicity.”

11. Quoting Dr. Linda Chalker-Scott, Washington State University - Turfgrass Resource Center, Facts About Artificial Turf and Natural Grass. (n.d.) Available at: http://plasticfieldsfornever.org/ArtificialTurfBooklet.pdf

a. “There is no question that toxic substances leach from rubber as it degrades, contaminating the soil, flora, and fauna and aquatic systems.”

12. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 4 Ver. I (Jul- Aug. 2014), PP 07-11
www.iosrjournals.org “**Nano particles in Automobile Tires**”

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From introduction: “Driven by a growing demand for fuel efficiency, combined with strict automotive standards for safety, durability and noise, as represented by the new EU tire label, automotive tyre manufacturers are continuously seeking to create better and more ecological tires. For decades, rubber fillers, like carbon black and silica as nano-structured materials, were the drivers of improvements in tires. Recently, the innovation trend is moving down the supply chain to the material suppliers, with new additives and non-materials making their appearance, promising to expand further the ‘magic triangle’ of tires. Green tires have nowadays a market share of about 30% and the demand for tires of lower rolling resistance, lower weight and superior performance is likely to grow with the market uptake of electric cars. We are planning to add nanomaterial in all layers present in tire of an automobile thus to increase the life and to reduce the wear rate. “

The study examines various types of nanoparticles and how they are already used, often in complex layers, in tires to improve performance, grip, heat resistance, stiffness and decay.

13. Turfgrass Resource Center (n.d.) Facts About Artificial Turf and Natural Grass. Available at: http://plasticfieldsfornever.org/ArtificialTurfBooklet.pdf

a. Part of artificial turf maintenance is the regular replenishment of the infill. Some of the infill is merely settling, but some of it is washing away or literally “walking away” with players after use. The effects of this “runaway” infill are unknown and more research is needed to draw conclusions–where is it going and what impacts is it having?
b. Maintenance of artificial turf can include application of algaecides or disinfectants to keep the surface clean and application of fabric softener to mask the odor of the artificial turf. What is the final destination of these chemicals and their implications for the environment and those coming into contact with them while playing on the fields?
c. There is no indication that artificial turf drains more effectively for purposes of a stormwater infiltration system than natural grass. In addition, infiltration systems are designed to work with whatever surface coating they receive from natural grass to porous paving. Although there is no assumed benefit from an infiltration perspective of natural turf or artificial turf, in many cases the complex systems designed for artificial turf fields have experience problems, work incorrectly, or inefficiently.