CITY OF MARTINEZ
PARK, RECREATION, MARINA & CULTURAL COMMISSION AGENDA

AGENDA DATE: March 15, 2016

TO: PRMCC

FROM: Tim Tucker

SUBJECT: Measure H Update

RECOMMENDATION:
Accept report.

Hidden Lakes Soccer Field:
On February 2, 2016 the City opened bids for the grading, drainage and site improvements for the Hidden Lakes Soccer Field. Five contractors were prequalified based on experience, financial strength and other factors. The low bidder is Brothman Construction.

On February 4th the City also received three proposals to install the synthetic turf, infill material and underlayment matting. On February 29, 2016 the PRMCC Park Subcommittee reviewed the proposals. The Subcommittee recommends the City Council select Field Turf to install their 2" Revolution 360 with Cool Play top dressing, green coated SBR and Sand infill.

The Project is on an aggressive schedule so as to have the fields ready for play in late summer which coincides with the Pleasant Hill Martinez American Youth Soccer Association (PHM AYSO) season. The City Council is scheduled to award a construction contract to Brothman Construction on March 16th. The Council is also scheduled make a decision on the synthetic turf Subcommittee recommendation. Due to the timing of both the PRMCC meeting Council meeting staff has forwarded the Subcommittee's recommendation directly to the City Council. PRMCC discussions at the March 15th meeting can be provided to the Council during the staff presentation.

Attached is the draft Council Report with more detailed information on the Project.

CITY OF MARTINEZ **CITY COUNCIL AGENDA**
March 16, 2016

Date: February 10, 2016

To: Mayor and City Council

From: Tim Tucker, City Engineer

Subject: Hidden Lakes Soccer Field Renovation Project (C5020)

Recommendation

A. Adopt resolution accepting bids for the Hidden Lakes Soccer Field Renovation Project (C5020) and awarding the construction contract to Robert A. Bothman Construction, Inc., Santa Clara, CA, in the amount of $846,000; and
B. Adopt resolution selecting Field Turf as synthetic turf supplier and installer for the Hidden Lakes Soccer Field Renovation Project (C5020) and authorize the City Manager to negotiate and execute a construction contract not to exceed $569,000 for the 2" Revolution 360 turf with Cool Play top dressing, Green Coated SBR and sand infill installation; and
C. Adopt resolution authorizing the City Manager to execute an amendment to the consultant services agreement with Siegfried Engineering, Inc. for an additional $52,489 for construction phase services.

Background

In 2008, voters approved Measure H, which provides funding to improve parks and other City recreational facilities. The Hidden Lakes Park Soccer Field Replacement, Project C5020, is included in the City's Capital Improvement Program. This project consists of replacement of existing natural turf soccer field with a multi-use artificial (synthetic) turf sports field this was part of the vision by the Measure H committee as they developed this measure and identified facilities for improvements by this bond. The improvements also include ADA access upgrades, resurfacing of the existing one-quarter mile long asphalt concrete track, new drinking fountain, landscaping, fencing, under drain system and miscellaneous site work.

Projects of this type are often completed in two phases/contracts to reduce overhead costs and allow flexibility in choosing the synthetic turf, pad and infill materials. The actual synthetic turf installation will be completed, under a separate contract, by a contractor certified by the artificial turf supplier and approved by the City through a Request for Proposal (CMAS) process.

This project construction timeline is aggressive with the desire to have this facility available for the community and play in the fall of 2016.

Discussion

Site improvements: On November 4, 2015 the Council approved a motion directing staff to use the Bidder Pre-qualified process. Five firms were prequalified. Four of these firms provided construction bids. Bids were opened at 2:00 p.m. on Tuesday, February 2, 2016 for the construction of this project. The bids ranged from $846,000 to $1,153,789. The Engineer's Estimate was $900,000.

The following is a summary of the bid results:

Bidder	**Amount**
Engineer's Estimate	$900,000
Brothman Construction, Inc.	$846,000
O.C. Jones and Sons, Inc.	$972,459
Graniterock	$1,009,966
Interstate Grading & Paving, Inc	$1,153,789

Brothman Construction, Inc. is properly licensed and has successfully completed similar work for several other Bay Area agencies. Brothman Construction, Inc. was a City prequalified contractor. A check of their references provided favorable responses.

Synthetic Turf: On February 4, 2016 synthetic field suppliers/installers Field Turf; Astroturf; and Hellas/Limonta provided responses to the City's Request for Proposals (RFP). These firms are California Multiple Award Schedule (CMAS) companies. Each firm provided multiple options of turf and/or infill material. On February 29, 2016 the Park Subcommittee of the Parks Recreation Marina and Cultural Commission met and reviewed the proposals. The Subcommittee recommends the City Council select Field Turf to install their 2" Revolution 360 with Cool Play top dressing, green coated SBR and Sand infill.

During the regular City Council meeting on February 17, 2016, the Council requested some additional information about the Synthetic Turf Field portion of this project. Those issues were as follows:

1. Health and Safety of these types of "Turf" facilities.
2. Environmental Benefits
3. Infill alternatives
4. Initial costs and ongoing costs analysis.
5. Maintenance costs

Health and Safety of synthetic fields:

There has not been any conclusive research from studies conducted to date to determine a Synthetic Turf Field utilizing crumb rubber infill poses a health risk to individuals using the playing surface. Research to date has concluded that these fields result in little, if any elevated risk of exposure to toxic substances. (See attached studies/reports)

The State of California announced in 2015 that a new study would be undertaken to further explore the potential health hazards associated with the use of crumb rubber infill. The report is currently ongoing and is expected to be complete in June 2018.

Environmental Benefits:

In review of the UC Berkeley study in February 2010 that outlines the basis for the information below:

1. Synthetic fields do not require watering or the use of fertilizer to maintain the safe playing surface.
    a. Natural turf fields require approximately 70,000 gallons of irrigation water each week.
    b. Approximately 15 to 20 pounds of fertilizer each year per 1,000 square feet of turf, plus herbicides and pesticides.
2. No mowing is required – i.e. Reduction in fuel emissions

3. Creates a use for the recycled tires keeps hundreds of thousands of tires out of landfills each year, it is estimated that it takes between 20,000 and 40,000 tires to provide infill for soccer /football field.

Cost comparison

Below is a chart comparing the 10 year cost of natural turf fields to synthetic fields. The initial cost is higher for synthetic fields, but the cost savings over time, taking into consideration the significant increase in potential use, makes selecting synthetic turf fields a sound financial decision.

10 year cost

10 Year Cost per hours of play		
Cost	**Living Turf**	**Synthetic Turf**
Base Preparation	$250,000	$340,000
Material	$330,000	$569,000
10 Years of maintenance	$200,000	$ 50,000
Total	**$780,000**	**$959,000**
10 years hours of play	6,250	29,920

Average cost per hour of use	**$125**	**$32**

<u>Infill Alternatives</u>

By the request of the City Council we have explored and included various infill alternatives currently on the market that can replace or be combined with SBR rubber. We have included some additional information on the infill alternatives that were included within the project bid documents.

Domestic SBR Rubber- Within the industry, there have been many lab test results from across the country that have linked non-domestic SBR tire rubber to outlier test results that vary from domestic SBR rubber. These tests have show increased concentrations of chemical leachates. Project Specifications for Hidden Lakes Park specifically required Domestic Tire rubber only.
Additional Project Costs =$0.00
Additional Maintenance Costs =$0.00

Coated SBR Rubber- Coated SBR rubber is an alternative infill that encapsulates the domestic SBR granule with an acrylic coating that reduces typical leachates and PAH's by up to 80% of typical SBR rubber.
Additional Project Costs =$25,800 sf
Additional Maintenance Costs =$0.00

Organic Infill- There are multiple styles of organic infill that were explored for the project. The organic infill that we have seen to have the best test results and installation reviews that was explored for this project has a combination or cork and coconut. Organic infill does require additional maintenance and watering requirements as shown in the chart below.

Cool Play- Cool play is a product specifically engineered to combine the best qualities of an organic infills cooling properties and new virgin polymers maintenance and watering requirements. The infill is comprised of cork that in extruded with virgin polyethylene polymers. A comparison between Organic infill and Cool Play is below.

<u>Recommended infill material comparison vs. Organic infill materials (see attachment)</u>

<u>Material</u>	**<u>Organic</u>**	**<u>CoolPlay</u>**
Composition	Coconut fibers, cork, rice husk	Cork, Polyethylene and elastomers
Material Warranty	8-year limited warranty, Does not warrant fields over 1.5% slope	8-years, includes top dressing
Additional Cost	$1.30/sf ($110,000) plus additional irrigation system	$0.60/sf ($54,000)
Irrigation required?	Yes, 1-2 times per week. If moisture levels drop, filed needs to be shut down to not void warranty.	No.

Top Dressing required?	Yes, Yearly, not covered by warranty. 40% over lifespan of turf	Yes, 3-4 years. Covered by warranty
Temperature reduction?	Yes	Yes
Maintenance	Additional maintenance required	Normal

Chris Chisam of Siegfried Engineering, Inc., the project Landscape Architect will give a presentation to review these issues in detail and address any other questions the Council may have about the project.

Summary

1. Completes one of the Measure H identified projects.
2. Provides a new recreation facility. Creating another new community jewel – i.e. Aquatic complex.
3. Safe, quality facility for the residents of Martinez.
4. Reduced maintenance costs
5. Provides Residents and players that currently travel to use these types of fields in other communities a local facility.
6. Playability – increase in playable hours on a synthetic turf vs. grass turf. All weather availability - weather is less of an impact on synthetic turf fields.

Consultant Services Agreement:

Siegfried Engineering, Inc. prepared the plans and specifications for the project. The City developed a scope of work and selected a consultant team to perform the necessary design and bid phase service. As part of a competitive process, Siegfried Engineering, Inc. was selected as the most qualified. Staff proposes that the City's agreement with Siegfried Engineering be amended to include construction phase support services in the amount of $52,489. The majority of these construction phase support services involve construction staking, form checking and related activities. In addition, construction of synthetic sports fields requires specialized knowledge of under drain systems, sports field construction tolerances and sports field construction practices. Siegfried will work with the City's Construction Division to provide construction staking, inspect the work, reviewing shop drawings and submittals, respond to contractor questions and process Requests for Information (RFIs).

Fiscal Impact

The project is budgeted under Account No. C5020. The project is fully funded. The project budget and funding is as follows:

Budget	**Amount**

Design/Administration/Environmental	$ 170,000
Construction contract	$ 846,000
Contingency (8% +)	$ 70,000
Const. Support (Siegfried and materials testing)	$ 75,000
Construction Management/Inspection	$ 70,000
SUB-TOTAL BUDGET	**$1,231,000**
Field Turf synthetic turf, pad and infill	$ 569,000
TOTAL BUDGET	**$1,800,000**

Funding	**Amount**
Measure H	$1,800,000

Attachments:

1. Resolutions
2. Site Plan
3. Amendment No. 1
4. Infill material attachment
5. Referenced reports:

    1. Toxicological Analysis of performance infill for synthetic turf Fields according to EN 71-3 standard.
    2. The Connecticut Department of Public Health January 20, 2015.
    3. Gradient report May 26, 2015, George Kosovich Assist. Superintendent, Programs & Community Investments -Verdant Health Commission
    4. The commonwealth of Massachusetts. Office of Human Health services, Department of Public Health. March 23 2015

5. UC Berkeley study in February 2010

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March 23, 2015

Stephanie Bacon, Health Agent
Office of Board of Health
155 Village Street
Medway, MA 02053

Dear Ms. Bacon:

Thank you for your letter of February 24, 2015, in which you requested that the Massachusetts Department of Public Health, Bureau of Environmental Health (MDPH/BEH), evaluate health concerns related to the use of crumb rubber infill material for artificial turf fields in Medway, Massachusetts. As you are likely aware, our office had previously evaluated this issue in a series of letters to the Town of Needham Board of Health in 2008, 2011, and 2013.

In response, MDPH/BEH staff have evaluated more recent information on potential exposure opportunities to artificial turf components, including crumb rubber infill, and evaluated health concerns, including cancer, in relation to exposure to such turf. Recent media reports on soccer players, particularly goalies that have played on artificial turf, and the incidence of some cancers have been expressed. These reports raised concerns about the possible association between playing on crumb rubber fields and the development of cancers, notably, non-Hodgkin's lymphoma, Hodgkin Lymphoma, and osteosarcoma. We also evaluated information you provided on the content of the specific products used in Medway. Our review is summarized below.

Updated Literature Review

Our previous evaluations noted that crumb rubber infill has been found to contain chemicals, including polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and metals. We further stated that although these chemicals are in the material itself, information available at that time did not suggest significant exposure opportunities to the chemicals in the materials such that we would expect health effects. We noted that the most relevant study on this topic at the time was a study conducted by the California Office of Environmental Health Hazard Assessment (CA OEHHA).

Since that time, the CA OEHHA conducted additional evaluations of chemical concentrations in air above crumb rubber turf fields under active use (CA OEHHA 2010). Air samples were taken above fields and analyzed for VOCs and metals. Results suggested that adverse health effects were unlikely to occur from inhalation of VOCs or metals in particulates above these fields. To assess the potential for skin infections due to bacteria or to skin abrasions on these fields, tests for bacterial contamination were performed and the frequency of skin abrasions was assessed. Researchers found fewer bacteria detected on the artificial turf compared to natural turf, suggesting that the risk of infection to athletes using these fields was actually lower. However, more skin abrasions were observed in athletes using artificial turf fields than natural turf fields, and the study authors made various recommendations to help prevent skin abrasions (e.g., protective equipment or clothing) and prompt treatment of skin abrasions.

In another study, the state of Connecticut conducted air sampling at four outdoor artificial turf fields with crumb rubber infills (most relevant to Medway) under summer conditions (Simcox et al. 2011). Air measurements were taken using stationary air sampling monitoring devices as well as personal samplers (placed on people using the fields). They concluded that exposure opportunities to turf contaminants were not associated with elevated health risks and suggested that their findings were consistent with other studies available at the time. A letter prepared by the Connecticut Department of Public Health reiterates these conclusions (CTDPH 2015).

A 2014 study by researchers at the Rutgers Robert Wood Johnson Medical School in New Jersey evaluated opportunities for exposures to PAHs, semivolatile organic compounds (SVOCs), and heavy metals from exposures to artificial turf fibers and crumb rubber infills by measuring these constituents in simulated body fluids (digestive fluids, lung fluids, sweat) that represented different routes of exposure (ingestion, inhalation, dermal). This bioaccessibility study aimed to provide a better measure of the actual amount of these contaminants that might be absorbed into the body after exposure. The researchers found that PAHs were routinely below the limit of detection and SVOCs that have environmental regulatory limits to use for comparison were identified at levels too low to quantify. Some metals were detected but at concentrations at which health risks were low, with the exception of lead from the field sample collected. That sample indicated lead at levels in the simulated digestive fluids that the authors reported could result in blood lead levels above the current U.S. Centers for Disease Control and Prevention (CDC) reference value for blood lead in children (5 ug/dL). It should be noted that the lead concentration of the materials used in this study included a sample of turf fiber with a lead concentration of 4,400 mg/kg. This level contrasts with information on the Medway artificial turf components, which reportedly either contained lead at 39 mg/kg (crumb rubber infill) or had no lead (turf fibers) (see discussion later in this letter). Based on the lead result from this one field sample, the authors suggested that components of artificial turf fields should be certified for low or no lead content prior to use. Overall, however, the authors concluded that opportunities for exposure to constituents in these fluids presented very low risk among all populations that would use artificial turf fields (Pavilonis et al. 2014).

A study conducted in 2010 in the Netherlands assessed the exposure of soccer players to PAHs after playing sports on a rubber crumb field. Urine testing in participants indicated that uptake of PAHs by the participants following exposure to artificial turf with rubber crumb infill was minimal. If there is any exposure, the authors reported, uptake is minimal and within the normal range of uptake of PAHs from environmental sources and/or diet observed in healthy individuals (van Rooij and Jongeneelen 2010).

It is probably worthwhile to also note that MDPH/BEH reviewed testing data for artificial turf for the Town of Needham, as reported in our letters of 2011 and 2013 to the Needham Board of Health. The Town of Needham contracted with an environmental testing firm to conduct environmental tests including, air measurements of volatile organic compounds taken in the laboratory and heavy metals (arsenic, cadmium, chromium, lead, mercury, selenium, zinc) content of crumb rubber materials. Our review and conclusions for that testing, did not indicate exposures of health concern.

Material in Medway

MDPH/BEH reviewed available information provided by the Medway Board of Health regarding the specific materials used in the Medway fields. These included the APT Gridiron turf system and Liberty Tire Recycling 10+20 BM Rubber Crumb Brantford, ON. Among the materials provided for these products were statements or test results for various constituents in these products.

APT submitted a written statement dated October 29, 2014, that reported that the APT Gridiron turf systems (essentially the grass fibers of the artificial turf) are manufactured and installed without the use of any lead or heavy metals. They reported that this included all materials used for the turf fibers and backings. No other documentation about this product, including any testing results, was provided to support this statement.

With respect to the 10+20 BM Crumb Rubber infill product, laboratory testing results were provided for this product, although it is not clear whether the testing was for the materials specifically used in turf applied in Medway. Testing was conducted for metals content as well as emissions of volatile organic compounds (VOCs). It appears that testing included the following: (1) testing for VOCs emitted into a confined air space in the laboratory after heating the product to 73 degrees F; and (2) content testing for eight heavy metals, including lead. The laboratory compared results to criteria established by the Greenguard certification program, part of Underwriters Laboratory, that uses among its criteria for certification health-based levels derived by the CA OEHHA.

Testing results for metals content of the product indicated a lead concentration of 39 mg/kg, which is less than the current Consumer Product Safety Improvement Act (CPSIA) limit of 100 mg/kg for lead in children's products (Ulirsch et al. 2010). No other metals were detected.

Test results measuring emissions off-gassing from heated material were provided in measurements that cannot be compared to any health-based standards or guidelines and thus, MDPH/BEH did not further evaluate this information. Typically, when certain products raise health concerns, health agencies review Material Safety Data Sheets (MSDS). An MSDS provides information on health risks associated with use of the product. An industry group, Synthetic Turf Council, provides a sample template MSDS for crumb rubber infill material (Synthetic Turf Council 2014). Although this sample MSDS is not specific to any particular product, it appears to be applicable to crumb rubber infill in general. In the section under "Hazardous Ingredients," the MSDS notes that the product can contain fine fibers that may cause irritation symptoms (e.g., itching, irritation of mucous membranes, eye irritation). The MSDS notes that the crumb rubber material is generally thought to be a nuisance dust.

Concerns About Cancer Among Soccer Players

As noted earlier in this letter, some recent news reports suggested that the incidence of cancers among soccer players, particularly goaltenders exposed to artificial turf, might be atypical. These reports included many cancer types, but some focused specifically on NHL, Hodgkin Lymphoma, and osteosarcoma in three individuals. We thought it would be helpful to provide additional information on cancers in general and known risk factors for NHL, Hodgkin Lymphoma, and osteosarcoma.

Cancer in General

Understanding that cancer is not one disease, but a group of diseases, is very important. Research has shown that there are more than 100 different types of cancer, each with separate causes, risk factors, characteristics and patterns of survival. A risk factor is anything that increases a person's chance of developing cancer and can include hereditary conditions, medical conditions or treatments, infections, lifestyle factors, or environmental exposures. Although risk factors can influence the development of cancer, most do not directly cause cancer. An individual's risk for developing cancer may change over time due to many factors and it is likely that multiple risk factors influence the development of most cancers. In addition, an individual's risk may depend on a complex interaction between their genetic make-up and exposure to environmental agents, including infectious agents and/or chemicals. This may explain why some individuals have a fairly low risk of developing a particular type of cancer as a result of an environmental exposure, while others are more vulnerable.

Cancers in general have long latency or development periods that can range from 10 to 30 years in adults, particularly for solid tumors. In some cases, the latency period may be more than 40 to 50 years. It is important to note, however, that latency periods for children and adolescents are significantly shorter than for adults.

Hodgkin Lymphoma

Hodgkin Lymphoma is most common in young adults between the ages of 15 and 40, especially in individuals in their 20s. Among adolescents, it is the most common type of cancer.

Hodgkin Lymphoma occurs specifically in a type of B lymphocyte (or white blood cell) called the Reed-Sternberg cell while other lymphomas (non-Hodgkin's types) occur in different cells.

Established risk factors for Hodgkin Lymphoma include: exposure to the Epstein-Barr virus (EBV); a previous diagnosis of mononucleosis (mono is caused by the EBV); family history; and certain hereditary conditions (such as ataxia telangiectasia) associated with a weakened immune system. The Epstein-Barr virus is very prevalent in the general population. Even though most of us have been exposed to the virus (which remains latent in our bodies), most people do not develop mononucleosis or Hodgkin Lymphoma. EBV is thought to account for about 20% or 25% of the diagnoses of classical Hodgkin's in the US.

Higher socioeconomic status is also a possible risk factor. This is thought to be due to delayed infectious exposures in childhood.

Occupational exposures as risk factors have been studied extensively and none have emerged as established risk factors. Likewise, there is very little evidence linking the risk of Hodgkin Lymphoma to an environmental exposure, other than the EBV.

Non-Hodgkin Lymphoma (NHL)

NHL refers to a diverse group of cancers that are characterized by an increase in malignant cells of the immune system. Each subtype of NHL may have different risk factors associated with its development. The specific cause of NHL in most individuals is unknown.

Although some types of NHL are among the more common childhood cancers, more than 95% of diagnoses occur in adults. Incidence generally increases with age, and most diagnoses occur in people in their 60s or older.

Established risk factors for NHL include a weakened immune system, associated with various medical conditions, and exposure to various viruses. An increased risk is faced by individuals taking immunosuppressant drugs following organ transplants; individuals with autoimmune disorders, such as rheumatoid arthritis and lupus; and individuals who have taken certain chemotherapy drugs for other cancers. Several viruses have been shown to play a role in the development of NHL, including the human immunodeficiency virus (HIV), the human T-cell leukemia/lymphoma virus (HTLV-1), and the Epstein-Barr virus.

Exposure to high-dose radiation (for example, by survivors of atomic bombs and nuclear reactor accidents and possibly by patients who have received radiation therapy for a previous cancer) may pose an increased risk. Some studies have also suggested that exposure to chemicals such as benzene and certain herbicides and insecticides may be linked with an increased risk of NHL. Smoking has been associated in some studies with certain types of NHL.

Osteosarcoma

Osteosarcoma is a type of malignant bone cancer which accounts for about 2% of childhood cancers in the United States. It is the most common type of cancer that develops in bone and comprises about 66% of malignant bone tumors in children in Massachusetts. Most osteosarcomas occur in children and young adults between the ages of 10 and 30. Teenagers comprise the most commonly affected age group and are at the highest risk during their growth spurt. However, osteosarcoma can occur in people of any age, with about 10% of all osteosarcomas occurring in people over the age of 60.

Established risk factors for osteosarcoma include certain inherited syndromes (such as retinoblastoma, the Li-Fraumeni syndrome, and others) and certain bone diseases (such as Paget disease of the bone and hereditary multiple osteochondromas). Individuals with these syndromes and bone diseases have an increased risk of developing osteosarcoma. People who have received radiation treatment for a previous cancer may have a higher risk of later developing osteosarcoma in the area that was treated. Being treated at a younger age and with higher doses of radiation both increase the risk. Because the risk of osteosarcoma is highest between the ages of 10 and 30, especially during the teenage growth spurt, experts believe that there may be a link between rapid bone growth and the risk of a bone tumor. Children with osteosarcoma are often tall for their age, which supports the link with rapid bone growth. Other than radiation, there are no known lifestyle or environmental risk factors associated with osteosarcoma. Asides from these risk factors, the causes of most osteosarcomas are unknown.

Summary

In summary, the scientific literature continues to suggest that exposure opportunities to artificial turf fields are not generally expected to result in health effects. Testing results on the crumb rubber infill indicated lead content less than CPSIA statutory limits established for children's products. For the turf fibers, APT provided a statement that this material did not have lead used in its manufacture, but no additional documentation was provided.

With respect to cancer concerns reported in media stories, it is important to note that the reports of cancers were of a wide variety of different types, each with its own set of risk factors. In addition, our staff reviewed cancer incidence data for the Town of Medway. The Massachusetts Cancer Registry (MCR) is a population-based surveillance system that began collecting information in 1982 on Massachusetts residents diagnosed with cancer in the state. All newly diagnosed cancer cases among Massachusetts residents are required by law to be reported to the MCR within six months of the date of diagnosis (MGL, c.111, s.111B). This information is kept in a confidential database and reviewed for accuracy and completeness.

Available information on the occurrence of cancers in children living in Medway indicates no diagnoses of Hodgkin Lymphoma, NHL, or osteosarcoma have been reported to the MCR in a search of their files from 2006 to the present. Although it is possible that a very recent diagnosis may not yet have been reported to the MCR, the fact that there are no reports of such cancers is reassuring.

Although available resources cannot support MDPH conducting environmental testing of this material, we would be happy to assist the Town of Medway in developing a sampling and analysis plan as well as provide technical support in interpreting results, similar to the assistance that we provided to the Town of Needham.

As we stated in our letters to Needham officials, while available information does not indicate exposure opportunities of health concern, MDPH/BEH continues to recommend common sense ways to minimize any potential exposure to chemicals that may be contained in synthetic turf fields made of crumb rubber. MDPH/BEH suggests washing hands after playing on the 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. Also, there are studies that indicate heat levels on artificial turf fields may rise as outdoor temperatures increase (New York State 2009). Thus, for protection of the players, MDPH/BEH recommends increasing hydration, taking frequent breaks, and watering down the field to cool it on hot days to prevent the potential for burns or heat stress. Finally, based on recent work in California, MDPH/BEH recommends that steps be taken to minimize the potential for skin abrasions (e.g., protective equipment) and that skin abrasions be treated promptly to prevent potential infections.

We hope this information is helpful to you and Medway residents. If you have any questions, please feel free to contact us at 617-624-5757.

Sincerely,

Suzanne K. Condon, Associate Commissioner
Director, Bureau of Environmental Health

References

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UNIVERSITY OF CALIFORNIA, BERKELEY
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Review of the Impacts of Crumb Rubber in Artificial Turf Applications

Rachel Simon
University of California, Berkeley

February 2010

Prepared For:
The Corporation for Manufacturing Excellence (Manex)

manex
Business Transformation. Delivered.

Prepared By:
UNIVERSITY OF CALIFORNIA, BERKELEY
LABORATORY FOR MANUFACTURING AND SUSTAINABILITY

LMAS

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Founded in 1995, The Corporation for Manufacturing Excellence (Manex) provides a broad array of proven advisory and implementation solutions exclusively to manufacturers, distributors and their supply chains, enabling them to increase growth, productivity, quality and profitability. Manex delivers high-impact solutions in four key areas: strategy, people, process and performance. Meaningful, rapid impact and ROI are achieved through a modular-yet-holistic approach encompassing corporate strategy and planning, innovation, marketing strategy, training and development, lean manufacturing, supply chain and logistics, Six Sigma, ISO and performance management systems.

Manex is a public-private partnership and the Northern California affiliate of the National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership (MEP) program. We work in concert with MEP to solve industry challenges by advancing best practices in manufacturing strategy, innovation, operations, methods and processes.

For more information about Manex, visit www.manexconsulting.com

About UC Berkeley's Laboratory for Manufacturing and Sustainability (LMAS)

Research at LMAS is concerned with the analysis and improvement of manufacturing processes, systems and enterprises and the development of tools to analyze their sustainability. Research is focused on: metrics and analytical tools for assessing the impact of processes, systems and enterprises, modeling sustainable, environmentally-conscious manufacturing processes and systems, green supply chains, manufacturing technology for reduced impact manufacturing, technology for producing advanced energy sources or storage, cleantech and sustainable products and systems. Specific projects include: design for sustainability, green machine tools, sustainable packaging, impact and life cycle assessment tools for manufacturing (including embedded energy, materials, water, consumables), metrics for assessing green technology ROI (e.g. GHG ROI, Energy payback time, etc.), risk assessment for energy and resource use and enterprise carbon accounting.

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EXECUTIVE SUMMARY

There are many characteristics of infill systems that have lead to resurgence in the popularity of synthetic turf. The industry has been experiencing a period of growth with the development of crumb rubber infill system, which initially debuted in 1997. These systems are preferable to the carpet-like turf of the past because they more closely resemble natural grass.

Crumb from used tires have been used in artificial turf fields for over a decade, and even longer in playgrounds and tracks. The EPA's view is that scrap tires are not hazardous waste and approves the use of crumb from used tires for sports fields. Recycled tires that were used in this capacity prevented an estimated 300 million pounds of ground rubber from scrap tires from ending up in landfills in 2007 (Rubber Manufacturers Association, 2009). In addition, this application uses recycled material; scrap tires, which otherwise would have to be handled as waste. It typically takes between 20,000 and 40,000 scrap tires to produce enough infill to cover a football field (City of Portland, 2008). The EPA's decree has afforded the opportunity for 4.5% of U.S. scrap tire to be applied as crumb rubber in sports surfacing in 2007 (Rubber Manufacturers Association, 2009).

The Corporation for Manufacturing Excellence (Manex), a National Institute of Standards and Technology Manufacturing Extension Partnership (NIST MEP), in collaboration with the Laboratory of Manufacturing and Sustainability (LMAS) at the University of California, Berkeley have studied the benefits of crumb rubber in artificial turf applications, and provide research and insight as to why this material has grown in popularity. This analysis will also include the primary features, economic benefits and other advantages that have led to the widespread expansion and adoption of artificial turf that includes the crumb rubber.

Playability is one of the primary benefits of synthetic turf, with the newer generation of infill systems exhibiting improved playability over traditional synthetic varieties. The play quality of a field is most impacted by aspects of construction and maintenance. Irrespective of the field type, the quality of play can vary dramatically according to factors such as: moisture, hardness, grass cover and root density (Orchard, 2002), naps in the turf, the distribution and compaction of infill, and infill depth (James and McLeod, 2008). Most literature comparing the play quality of natural and synthetic fields suggests that the differences between them have miniscule affects on playability in comparison with variance in the set-up of the field itself. Where differences do emerge, data is out of date and not applicable to current generations of turf technology.

Research indicates that artificial turf provides a greater number of playable hours than natural turf. Studies suggest that average hours of playability in a three-season year for synthetic turfs range between 2,000 and 3,000 hours, with most research pointing towards 3,000 hours. Natural fields, on the other hand, provide far less playability, with studies estimating a range between 300 and 816 hours in a three-season year on average. Studies show, furthermore, that switching from natural to synthetic turf results in a drastic increase of play-time. This is due, in part, to the vulnerability of natural fields to fluctuations in weather. In addition, natural fields require rest, with managers recommending against using fields more than 20-24 hours a week. Natural fields are also vulnerable to poor management, which can detract significantly from use-time.

Synthetic turf is praised for its availability in all weather conditions: more use per year, and a quick install. This factor influenced the amount of use that can be had on the turf, and thus the payback on investment on the turf. It can be used quickly after installation, usually within a few days, rather than the weeks it takes for a sod to become robust enough for use. Also, it can be used in snow, and in general is not affected by precipitation due to the drainage system involved. However, high heat can create an obstacle for synthetic turf use, as the surface can become uncomfortable to play on. It has been shown that the difference between turf temperatures and the surrounding air can be significant. However, there are means to temper such effects, and the field can still be made useable. Also, the use of turfs are not typically greatest during the hottest parts of the year, as sports seasons typically fall in the late summer through the spring. These impairments do not compare to the degree to which natural fields are compromised during rain and snow. With all weather considered, artificial turf has greater availability over natural grass when taking weather into account.

The value of a field can be determined by its availability and by amount of maintenance a field requires. The Sports Turf Managers Association (2005) states that these costs depend on: the amount of use; the type of use (i.e. sports played); climate and weather; existing soil and terrain; irrigation and water needs; labor; field type; and field security (protection against vandalism, non-regulated play, etc.). Activities that can be classified as grooming are the most important components of maintenance for both turf types. In addition, debris control, additional cleaning, and needs-specific maintenance may be required. A brief review of suggested maintenance practices produced a list of over 22 possible pieces of equipment, and 8 possible supplies for field maintenance. In general the maintenance that is necessary for a synthetic field has a similar maintenance requirement on a natural field. However, natural fields require a more nuanced balance of activities such as mowing, fertilization, and aeration to ensure their health.

One of the primary concerns for organizations considering the implementation of synthetic turf is whether it poses any significant health or injury risks. Numerous studies have been conducted assessing the likelihood of injury on natural grass and synthetic turf. Some studies reveal that there is very little difference in the rate, type, severity, or cause of injuries obtained on natural grass or synthetic turf (Fuller et al. 2007a, 2007b). A more recent study by Meyers (2010) shows that the latest generation of synthetic surface, FieldTurf, is safer to play on than natural grass fields. Through the analysis of the various injuries that occurred over the course of 465 collegiate games, Meyers shows that FieldTurf has lower incidence of: total injuries, minor injuries (0-6 days lost), substantial injuries (7-21days lost), and severe injuries (22 or more days lost). FieldTurf also had significantly lower injury rates that natural turf when comparing across play or event type, grade of injury, or various field conditions and temperatures. In addition, there was no significant difference found in head, knee, or shoulder trauma between the two playing surfaces. Meyers' (2010) research is the most comprehensive study to date, and it addresses previous inconsistencies in findings on injury patterns.

The use of athletic fields made of recycled tires has also been called into question because of concerns regarding toxicity. Authorities are worried that because of the chemical content of the material, exposure by various means could endanger the health of field users, especially children. However, extensive research has pointed to the conclusion that these fields result in little, if any, exposure to toxic substances.

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. As part of this study, independent product test results were obtained and reviewed for crumb rubber produced by BAS Recycling of Moreno Valley, CA, a high volume producer of cryogenic crumb rubber for synthetic turf. Test results confirm that crumb rubber is safe for use in sports and athletic field environments.

In general, the environmental impacts of natural grass are more complex than those of synthetic turf. This is due in large part to the fact that natural grass requires the continual addition of inputs to sustain a field's health. As with any agricultural practice, draws on water and the addition of agrochemicals can become problematic. These practices draw on scarce resources and have the potential to effect surrounding ecosystems. Additionally, the maintenance of grass is associated with the use of large quantities of fuel, to mow grass down to the appropriate length. The Athena Institute sufficiently shows the weight of these impacts in regards to global warming. However it is recommended that a more comprehensive inclusion of material inputs into grass maintenance be calculated in any future life cycle assessments.

The environmental issues related to synthetic turf mainly revolve around the use and disposal of materials. Many see the use of recycled waste products for field infill as one of the primary benefits of artificial systems. However, such systems also require the use of many virgin materials. As such, the greatest greenhouse gas emissions of either two system types are the impacts associated with the production of synthetic turf components. These material impacts increase the total emissions by a multiplicative factor when considering the entire life cycle, due to related increases in processing and transportation needs.

1.0 INTRODUCTION

1.1 Background

Growth in the popularity of synthetic turf has been followed by increased scrutiny of its usage. The industry has been experiencing a period of growth with the development of crumb rubber infill system, which initially debuted in 1997. These systems are preferable to the carpet-like turf of the past because they more closely resemble natural grass. They consist of longer simulated grass blades that do not compact because of the infill material that supports it. As of 2008 over 3,500 new-generation synthetic turf fields had been implemented (Jackson, 2008). In addition over half of all NFL teams currently play on synthetic turf (Synthetic Turf Council, 2008a).

There are many characteristics of infill systems that have lead to resurgence in the popularity of synthetic turf. First, it is believed that infill systems perform better than traditional synthetic turf for athletic applications (Popke, 2002). Also, artificial turf is available year around and requires less monetary and natural resources than natural grass.

Crumb from used tires have been used in artificial turf fields for over a decade, and even longer in playgrounds and tracks. The EPA's view is that scrap tires are not hazardous waste and approves the use of crumb from used tires for sports fields. Recycled tires that were used in this capacity prevented an estimated 300 million pounds of ground rubber from scrap tires from ending up in landfills in 2007 (Rubber Manufacturers Association, 2009). In addition this application uses recycled material: scrap tires, which otherwise would have to be handled as waste. It typically takes between 20,000 and 40,000 scrap tires to produce enough infill to cover a football field (City of Portland, 2008). The EPA's decree has afforded the opportunity for 4.5% of U.S. scrap tire to be applied as crumb rubber in sports surfacing in 2007 (Rubber Manufacturers Association, 2009).

1.2 Objectives

The Corporation for Manufacturing Excellence (Manex) in collaboration with the Laboratory of Manufacturing and Sustainability (LMAS) at the University of California, Berkeley has been enlisted to study the benefits of crumb rubber in artificial turf applications, and provide research and insight as to why this material has grown in popularity. This analysis will also include the primary features, economic benefits and other advantages that have led to the widespread expansion and adoption of artificial turf that includes the crumb rubber.

1.3 Scope of Work

This study identified and assessed existing research on the benefits, advantages and safety concerns of crumb rubber. A sample from a California scrap tire recycler was also assessed to support and confirm key conclusions. Material was provided from a leading cryogenic crumb rubber producer, BAS Recycling, primarily for the purpose of reviewing and assessing safety concerns. Test results from an independent lab were obtained, and then reviewed, against some of the key health concerns regarding contamination. The research provided by Berkeley sought to confirm or invalidate the following findings from existing research/studies:

- **Excellent Playability** – synthetic turf does not inhibit or deflect the bounce or roll of balls. Traction, rotation and slip resistance, surface abrasion and stability meet the rigorous requirements of the most respected sports leagues and federations.

- **All-weather Availability** – synthetic turf can be used within hours of installation, in all types of weather. No significant downtime is required in case of rain, drought or other climate conditions. Increased availability equates to higher return on investment for owners, and more practice and skill development for players. Additional questions to be answered are: whether artificial turf can be utilized more per year without the rest that grass fields require, and what the maximum hour of playing time is for the two field types.

- **Increased Playing Hours** – in most climates, synthetic turf fields can be used 3,000 hours per year over a four-season window, with no damage to the turf. Natural turf fields become unplayable after 680 to 816 hours per year, and are typically available only for three seasons.

- **Reduced Maintenance** – natural turf fields require approximately 70,000 gallons of irrigation water each week, approximately 15 to 20 pounds of fertilizer each year per 1,000 square feet of turf, plus herbicides and pesticides. Synthetic turf maintenance costs are two to three times less than natural turf. No mowing, irrigation or chemicals are required.

- **Cost-effective Investment** – synthetic turf fields are typically warranted for about 3,000 hours of play per year, with no "rest" required. For schools with sufficient land, it would take three or four natural fields to withstand the usage of one synthetic turf field. Because of its consistent availability, a synthetic turf field is also a reliable source of rental revenue for schools and communities. In addition, the total cost of ownership for fields will be explored, including all of the maintenance resources (water, fertilizer, pesticides, labor, and equipment) needed to upkeep a field.

- **Generally Safe Application** – for most common and typical uses, the materials (e.g. crumb rubber) is a safe alternative to natural materials and landscaping. While the general public is exposed to articles suggesting the need to further assess the material, no conclusive study has proven these materials as unhealthy, nor have high incidences of physical harm occurred from approved and proper uses. Recent issues that have surfaced relate to Carbon Black and Lead, however, for the vast majority of applications, serious physical harm has not occurred from these particulates.

- **Fewer Injuries** – synthetic turf fields are far more uniform and consistent than the natural turf fields most schools and communities are able to maintain. Also, they are made of resilient materials that provide a level of impact attenuation that is difficult to obtain on hard, over-used natural turf fields. An NCAA study comparing injury rates during the 2003-2004 academic year showed that the injury rate during practice was 4.4% on natural turf and 3.5% on synthetic turf.

- **Environmentally Friendly** – using synthetic turf eliminates the need for water, pesticides, herbicides and fertilizers. The used auto tire rubber used as infill recycles 25 million used auto tires per year that would otherwise end up in U.S. landfills. The EPA encourages the use of recycled auto tires for playgrounds, running tracks and sports fields.

2.0 IMPACT ANALYSIS

2.1 Playability

Playability is one of the primary benefits of synthetic turf, with the newer generation of infill systems exhibiting improved playability over traditional synthetic varieties. Research suggests that the play quality of any particular field is determined more by how the field is constructed and maintained than by the type of field material that is used. Factors such as moisture, soil compactness, and root or infill density can cause wide variance in play quality, playing a greater role in determining quality than the type of field. Components of qualitative play factors can be organized into ball-surface interactions and player-surface interactions. (Bell, Baker, and Canaway, 1985; Schmidt, 1999)

A surface can decrease play performance and prevent players from achieving their objectives. Pasanen et al. (2007a) note that there are two factors that influence surface-related injuries: shoe-surface friction and surface hardness. Schmidt (1999) also includes surface evenness as a factor affecting player-surface quality.

Friction can impact play by leading to slippage, foot fixation, and increased running speeds resulting in collisions and ankle and knee injuries. Surface friction depends on multiple factors. Orchard (2002) notes that moisture, hardness, grass cover, and root density are turf properties that influence shoe-surface traction. Existing research comparing the rate of surface traction injuries on synthetic and natural fields is outdated, as it considers previous generations of synthetic turf rather than the current infill systems. For instance, Powell and Schootman (1992) compare injury rates of natural and synthetic fields from 1980-1989, and Orchard and Powell (2003) consider rates from 1989-1998. These studies predate the newer generation of turf, which was first implemented in 1997. In addition evaluations that attempt to compare field types may be difficult, as it has been shown other factors, such as weather, affect injury rates (Orchard and Powell, 2003). Findings such as these support the notion that shoe-surface traction impacts injury rates and play in general, but there is not sufficient evidence evaluating the affects of traction in the newer generations of synthetic turf.

Similarly, surface hardness can affect player-surface interactions. Ground reaction force is the impact energy caused by an athlete’s foot striking the playing surface. This force has been cited as a risk factor in causing acute and long-term injuries (Boden et al., 2000; Chappell et al., 2007; LaStayo et al., 2003). Surface hardness is one measure used to assess the ability of the surface to absorb foot striking impacts. Brosnan and McNitt (2008a, 2008b) note that natural and synthetic turfs have comparable surface hardness values. For natural surfaces, hardness is related to the amount of soil moisture, while for infilled synthetic surfaces, infill depth is a major factor in determining surface hardness. Synthetic turf tends to provide a fairly consistent playing surface. This is partially because surfaces are leveled before the application of synthetic turf. Furthermore, synthetic surfaces are less vulnerable than natural turf to play-related damage such as divots. While factors such as the distribution of infill can impact the uniformity of synthetic fields, synthetic turfs tend to be more even throughout.

Several aspects of ball-surface interactions have been identified for evaluating play quality. Schmidt (1999) cites rebound, spin, and roll as the principle characteristics of ball-surface interaction. Meanwhile, James and McLeod (2008) list roll, bounce, spin, and deceleration as important measures of playability. Holms and Bell (1986) note the interrelationship between eleven factors on play characteristics such as rebound resilience, traction, and deceleration for natural fields.

The play quality of a field is most impacted by aspects of construction and maintenance. Irrespective of the field type, the quality of play can vary dramatically according to factors such as: moisture, hardness, grass cover and root density (Orchard, 2002), naps in the turf, the distribution and compaction of infill, and infill depth (James and McLeod, 2008). Most literature comparing the play quality of natural and synthetic fields suggest that the differences between them have miniscule affects on playability in comparison with variance in the set-up of the field itself. Where differences do emerge, artificial turf appears to be equal to or better than natural turf, due to its greater consistency. While such findings are incomplete, because of the lack of studies that evaluate the newer generations of turf technology, there were no studies that contradicted the superiority of synthetic turf.

2.2 All-weather Availability

Playability can also be evaluated according to its availability to users. Maintenance, weather, and resting periods are all factors influencing the amount of time that can be spent on a field. In addition, use-time plays a role in evaluating its value and the return on investment for owners. Synthetic turf has been praised for its superior availability to natural turf, their quick installation, and accessibility in all climates and weather types.

Synthetic turf can be installed quickly and is usable within hours of installation. Several professional installers quote an installation time of about two to three days, a time that can be significantly longer if the field is initially in poor condition (e.g. requires the removal of a considerable portion of the existing field). The European Synthetic Turf Organization (2010) estimates that an installations can take as long as two to three weeks. Yet once a synthetic field is installed, it can be used almost immediately, unlike sod fields, which can take up to a month to be fully functional, and seeded fields, which take considerably longer to become fully rooted.

Additionally, synthetic turf can be used in almost any climate and weather, while natural turf is more limited. Natural turf has reduced availability during rain or snow, and precipitation can cause grass turfs to become soggy or muddy. Meanwhile, snow can be difficult to remove from these fields, and may permanently damages grasses. Comparatively, winter weather conditions and precipitation are not harmful to synthetic surfaces, and if necessary snow and ice can be removed for play.

However, the playability of synthetic turfs may be hampered by hot weather conditions. The New York City Department of Health and Mental Hygiene (2010) reports that synthetic turf fields may become too hot to play on when temperatures are high. The material in synthetic turf absorbs heat, resulting in surface temperatures that are greater than surrounding air and other surfaces. However, these affects can be mitigated. Williams and Pulley (2002) found that increases in surface temperature were more impacted by solar radiation than ambient temperatures. As a result, surfaces can be made cooler when they receive less direct light exposure, like when they are painted lighter colors or are shaded. Temperature increases can also be assuaged by irrigation. Yet these solutions do not entirely mitigate hot temperatures. The difference between turf temperatures and the surrounding air can be significant. In one study, Brakeman (2004) found turf temperatures to be over 100 degrees hotter than surrounding air temperatures. In another, Williams and Pulley (2002) found synthetic surface temperatures as high as 200 degrees. Cooling effects have brief results (Williams and Pulley, 2002; McNitt, Petrunak, and Serensits, 2008) and can result in a large increase in resource use and costs.

While high heat can create an obstacle for synthetic turf use, there are means to temper such effects. Also, use of turfs are not typically greatest during the hottest parts of the year, as sports seasons typically fall in the late summer through the spring. These impairments do not compare to the degree to which natural fields are compromised during rain and snow. With all weather considered, artificial turf has greater availability over natural grass when taking weather into account.

2.3 Increased Playing Hours

Artificial turf provides a greater number of playable hours than natural turf. The Synthetic Turf Council (2008), an artificial turf advocacy group, estimates that natural fields provide 680-816 hours of play in a three-season year, as compared with 3,000 hours for synthetic turf. Kay and Vamplew (2006) offer an alternative estimate with approximately 300 hours of play time for natural grass, 800 for reinforced turf, and 3,000 for artificial turf. James and McLeod (2008) calculate the usable hours of synthetic turf to be closer to 2,000 hours per year on average, with a range from 450 to 4,200 hours. They also note that the typical weekly hours of use for synthetic turf pitches were 44 hours, as compared to 4.1 hours for natural turf. In direct applications of synthetic turf, many note a measured increase in use-time of these field types. For instance, with a switch from natural to synthetic turf, the City of Newport Beach (2009) found a 49% increase in field availability, and the Charlottesville City Schools reported a 60% increase in available playing time.

Weather is an important factor in use-times for natural turf. While artificial turf fields recover quickly after precipitation, natural fields may take days before they become playable again. Weather-related losses in use-time can be considerable. Even in the relatively temperate climate of Newport Beach (2009), Recreation and Senior Services Department staff estimates that fields are unavailable an average of ten days a year because of rain. In addition to weather-related use-time loss, all natural fields must be given time to "rest" to allow for growth. The Synthetic Turf Council (2008) states that the managers of natural fields recommend against the use of natural fields beyond 20-24 hours per week, to avoid overburdening them. In addition, poor management can impact the availability of fields. If elements such as drainage systems and watering and maintenance schedules are improperly planned they can unnecessarily impede on the use-time of fields.

2.4 Maintenance

The maintenance required, along with the number of playing hours a surface can provide, are key factors in assessing the value that a certain turf type provides. Reduced maintenance is often cited as one of the major benefits for synthetic turf. However, artificial turf does require a minimum level of upkeep. The savings in maintenance are apparent when considering the useful hours that are returned on the cost and time required for maintenance. One estimate for an ideal level of maintenance for a synthetic field is one hour for each ten hours of use (James and McLeod (2008)). Below is a comparison of the typical maintenance requirements and their estimated durations for synthetic and natural turf.

The amount of maintenance that is needed for any field type can vary depending on a multitude of factors. The Sports Turf Managers Association (2005) states that these costs depend on: amount of use; type of use (i.e. sports played); climate and weather; existing soil and terrain; irrigation and water needs; labor; field type; and field security (protection against vandalism, non-regulated play, etc.). The proper upkeep of a field will ensure that it reaches its lifetime potential, thereby yielding a greater return on investment. Both natural and synthetic turfs require a minimum level of upkeep to preserve surface quality. Activities that can be classified as grooming are the most important components of maintenance for both turf types. In addition, debris control, additional cleaning, and needs-specific maintenance may be required.

For synthetic fields, grooming is needed to maintain optimal play quality and proper functionality. Grooming practices include upkeep of seams, fibers, infill, and the drainage system. A broom or brush can be implemented to align the direction of fibers. Top dressing equipment and spiking equipment are employed to re-dress, redistribute, and de-compact the crumb rubber. Debris removal is also extremely important and should be done as quickly as possible to prevent more complicated problems, such as blockages in the drainage system. Sweepers, blowers, and vacuums are used to remove these materials. Additional cleaning steps may be necessary to get rid of the contaminants that cannot easily be eliminated. Pressure washing and spraying can flush the field or apply chemical agents and disinfectants. Also, depending on the specific needs of a particular field, other maintenance and equipment may be necessary. For instance, painters and scrubbers might be required to add and remove painted lines for various sports. In more severe climates and weather, snow removal is done with a plow. Irrigation systems can be helpful in environments with high temperatures, or when specified in warranty agreements. Additionally, any chemicals needed for the weed control, cleaning, and static-minimization are applied through spraying equipment.

Maintenance for natural turfs is also primarily focused on grooming. Mowing, watering, fertilizing, plant-protectant application, aeration, and irrigation should be carried out as necessary to ensure the proper growth of grass. In addition, debris may need to be removed, although the impact of debris is generally of less consequence than for artificial systems. Again, much like synthetic turf, there may be special equipment required for the specifics use needs of a field, such as painters, plows and sprayers.

An expanded list of possible maintenance requirements and their associated equipment has been complied in Table 1 below. The information in this table has been collected from various studies that discuss the possible maintenance entailed for a synthetic or natural turf system. For the purpose of identification each reference was assigned a number, which is then listed in the table when the reference suggests a specific type of maintenance. Maintenance needs can be categorized into seven types: general needs; debris removal, grooming, surface maintenance, systems, turf restoration, and user specific needs. From these, 13 specific needs were identified, with 22 pieces of associated equipment and 8 supplies. Additional maintenance factors that were suggested for inclusion were labor, weeding, and seam repairs. We will assume that all maintenance will require labor, and the differences in labor costs are included in Section 2.5.3, Table 2.6. Weeding is an activity that has been suggested for synthetic turfs by the Turfgrass Resource Center (2008) and Patton (2009). This activity does not need to be individually considered, as it is covered by the inclusion of labor and hand tool equipment. Lastly, seam repairs may be necessary, but are assumed to occur only a few times over the life span of a synthetic turf. If such repairs are necessary, it is assumed that they will be done by a contractor, so as to not violate any warranty on the turf. These three aspects will not be considered for the remainder of this section.

Table 2.1: Equipment and Supplies Recommended for the Maintenance of Fields				
Category	**Purpose**	**References that Recommend Maintenance Type**		**Equipment & Supplies**
		Synthetic	**Natural**	
General	Transport	1, 3, 4, 5, 9	1, 4, 9	**Equipment**: tractor/utility cart for operating equipment
	Small Tasks	3, 4	4	**Equipment**: assorted hand tools (i.e. rakes, hammers, edger, etc)
Debris Removal	Clearing of Objects	1, 3, 4, 5, 6, 9	1, 4*, 9	**Equipment**: sweepers/blowers to remove surface debris
		1	4*, 9	**Equipment**: vacuum to remove small items
		5, 9		**Equipment**: field magnet dragged to capture metal objects
	Cleaning/ Clearing of Contaminants	1*, 3, 4*		**Equipment**: pressure washers/flushing equipment remove unwanted fluids or contaminants
		6, 9		**Supply:** chemical disinfectants
Grooming	Grass & Fiber Blades upkeep	1, 2, 3, 4, 5, 6, 9	9	**Equipment**: broom, brush or tine dragged to realign fibers and to distribute the crumb rubber
		5, 9	9	**Equipment**: roller keep fibers from forming grain
			1, 4, 9	**Equipment**: mower
Surface	Soil/Infill Compaction, Reapplication & Redistribution	1*, 3*		**Equipment**: spiking equipment: de-compaction, redistribution of crumb rubber
		1, 4, 9	1*,4*, 9	**Equipment**: top dressing equipment: for crumb rubber loss
		6, 9	9	**Supply:** top dressing (additional crumb/sand)
	Fertilizing		8, 9	**Equipment**: seed/fertilizer spreader
			1, 4, 9	**Supply:** fertilizer
	Aeration		1*	**Equipment**: de-thatching equipment
			1*, 4*, 9	**Equipment**: (deep tine) aerator
			4*	**Equipment**: core harvester: collect cores that are pulled to the surface following aeration. can be used to gather thatch, similar to a sweeper.
	Protectant application (Weeds, Static)	1, 4, 5, 9	1, 4	**Equipment**: spraying equipment: for the application of weed control, pest control, cleaning agents, wetting agents to lessen the static charge to aid in drainage.
			9	**Supply:** pesticides
		2, 6		**Supply:** sprays to reduce static (fabric softener)
Systems	Watering	1*, 4*	1*, 4*, 9	**Equipment**: irrigation system: for watering, cooling, and warranty requirements
		4*	4*	**Equipment**: hoses/nozzles: small scale irrigation (syringing)
		7, 9	9	**Supply:** water
Restoration	Lawn Renovation		1*	**Equipment**: groove or slit seeder
		7	8, 9	**Supply:** seeds/sod replacement
Needs Specific: Weather, Play Type	Painting	1*, 4*, 5, 9	1*, 4*, 9	**Equipment**: painters: adding lines
		6, 9	8, 9	**Supply:** paint
		4*		**Equipment**: mechanical scrubbers: cleaning painted lines on the synthetic turf.
	Snow Removal	3*	1*, 4*	**Equipment**: special rubber blade snow plow

*indicates the item was suggested as optional

References for Table 2.1

1) Sports Turf Managers Association (2005)
2) Patton (2009)
3) FIFA (2001)
4) Sports Turf Managers Association (2006)
5) "Synthetic Turf Maintenance Equipment" (Brakeman 2005)
6) "2004-2005 Maintenance Budget Synthetic Infill Field" (Brakeman 2005)
7) Chirillo (2008)
8) New Yorkers for Parks (2006)
9) Turfgrass Resource Center. (2008)

The primary purpose of Table 2.1 is to show the breadth of equipment that has been suggested for both field types. The inclusion of any item is not meant to suggest that it is a necessary item for the maintenance of a field. The next section will be dedicated to identifying which of these accessories are needed for the specific maintenance requirements of each field type. The premises upon which an inventory of equipment and supplies will be created is that it should: 1) be as comprehensive as possible; 2) identify items that are needed at a regular frequency; 3) identify items that are of environmental or financial consequence; 4) highlight the differences in requirements between the two field types.

Without financial constraints, the accessories that can be purchased to care for a field are virtually limitless. Therefore, some practicality must be employed to limit this analysis to the items and practices that are required to secure the health of the field, and thereby increasing its longevity. In addition, it is assumed that beyond what is identified, supplementary items will be needed to deal with unforeseeable circumstances. However, these instances will not be accounted for because they cannot be predicted to occur at any regular interval - or at all. Also, precautions can often be taken by turf managers to help minimize the risks and impacts of such occurrences that would require additional maintenance needs.

Table 2.2 below outlines the items deemed necessary for the maintenance for artificial and natural turfs. Also included is a discussion of the rational for the inclusion of any given items. Much of the equipment needed is necessary for both field types. Where differences in the equipment needs do occur between the two fields, it is generally because natural grass requires maintenance practices that artificial turfs do not (e.g. such as mowing, fertilization, and aeration) to keep them healthy.

Table 2.2: Equipment and Supplies Recommended for the Maintenance of Fields		
Maintenance Equipment & Supplies		Discussion
Synthetic	Natural	
Tractor/utility cart	**Tractor/utility cart**	A tractor or utility vehicle is useful for maintenance, and is often used as the primary machinery to which other equipment is attached.
Assorted hand tools	**Assorted hand tools**	Hand tools are the easiest way to ensure quick fixes to problematic spots in the field.
Broom, brush or tine		The regular dragging of a synthetic field is a key to the maintenance of its fibers. Similarly, drag brushes are useful to evenly spread infill. Equipment, such as a brush, broom, or tine is needed to carry out these tasks.
Sweepers/blowers	**Sweepers/blowers**	A sweeper or blower ensures the proper removal of debris for optimal play quality. While the accumulation of organic debris is more problematic on synthetic fields, inorganic debris is equally problematic for both turf types.
Roller		Frequent rolling is recommended to keep synthetic fibers from standing up and forming a grain.
	Mower	Blades of natural grass must be trimmed to ensure proper play quality. A mower is a necessary piece of equipment to keep blades at the appropriate length.
Top dressing	**Top dressing**	Top dressing for natural and synthetic fields is occasionally necessary, as soil and infill can be lost or displaced. On natural fields, topdressing promotes stronger root systems, a more resilient surface, and improved playing surfaces. On synthetic fields, infill and sand must be added when these materials get displaced.
	Fertilizer	Fertilizer is applied to most natural fields to ensure the growth of a robust and deep rooted field.
	Aerator	It is recommended that a lawn be aerated once or twice a year. Aeration needs depend on the presence of problematic elements (e.g. thatches), and the degree of soil compaction.
Spraying equipment	**Spraying equipment**	Spraying equipment serves a very particular purpose (i.e. liquid cannot be applied by hand with a shovel). Each field type requires the application of numerous liquids. For natural fields it is used to apply agrochemicals such as weed control and pest control. For synthetic turf it is used for cleaning, wetting, and static control of the surface.
Water	**Water**	Water is necessary for the survival of natural turf. In addition, synthetic turfs are often watered down to control temperatures, lubricate the surface, and stabilize infill and reduce migration.
Irrigation system	**Irrigation system**	In order to apply water, a method of irrigation is necessary.
	Seed/sod	One of the primary benefits of artificial turf is the infrequency with which it must be replaced. Thus, to fully consider the potential of artificial turf, the impacts of seed and sod replacement should be taken into account. Many lawns will benefit from a scattering of grass seed after top dressing and this will thicken the grass for the next year creating a dense healthy green lawn.
	Paint	For natural grass, field lines must be painted on. Also, these lines must be re-painted after as the painted lines are grown out and mowed away. For artificial fields, paint is used to make temporary lines when the field is used for diverse purposes. Permanent lines can be laid into the system, or can be painted on with fairly infrequent re-application.

In considerations of turf maintenance, the majority of the equipment suggested by the various authors was not deemed necessary for field maintenance or consequential to maintenance evaluations. Several items were excluded because they are needed relatively infrequently or on a circumstantial basis. For day to day upkeep, the needed equipment is fairly evident. However, for items that might only be used on an occasional basis or that serve to alleviate the build of long term problems, their necessity is highly subjective. Often, such items can be rented, or a contractor can be hired to do the job that the equipment is meant to serve. As such, the capital investment and storage required of these items may not be prudent. Examples of equipment used fairly irregularly are: field magnet, vacuum, and pressure washers or flushing equipment. Supplies that are used in small enough quantities in the long run to render any associated impacts negligible are: chemical disinfectants and liquids to minimize static on artificial turf. Similarly, on natural fields, pesticides should only be applied when needed, and are not recommend for application at regular intervals as a preventative measure. Bruneau et al. (2001) of North Carolina State University's Center for Turfgrass Environmental Research & Education notes that when a field is properly maintained, insects are seldom a problem.

Some of the suggested items that were disregarded serve very real field needs. However, in several cases, these needs can also be served by other equipment or additional labor. This is the case for devices such as spiking equipment, a groove or silt seeder, a core harvester, top dressing equipment, and a seed and fertilizer spreader. Other equipment is only needed in certain circumstances, which may not necessarily occur for any given field. For example, the need for painters, mechanical scrubbers, and rubber blades to plow snow and de-thatching equipment will vary from field to field.

Supply Use Rates

Equipment that is needed for maintenance will only have to be purchased a few times over the life time of a turf. On the other hand, supplies must be acquired at regular intervals. Quantities and associated impacts for any given supply can vary greatly. For a true comparison of turf requirements, the rate of use for each of these supplies will be evaluated below.

Fertilizer

Fertilizer requirements are determined primarily by the type of grass, climate conditions, and the percentage of nitrogen that a fertilizer contains. There is a slight variation in the suggested amounts of nitrogen per year. Multiple applications are usually necessary, as fertilizer can damage a field if applied in quantities greater than one pound of nitrogen per one thousand square feet. Pettinelli (2007) of the University of Connecticut suggests two to three pound of nitrogen per thousand square feet, depending on whether clippings are left on the field. Similarly, Johnson et al. (2002) suggests two to four pounds per thousand square feet. Reicher and Throssell recommend fertilizing 0.75-1.5 pounds per thousand square feet four times a year. For this study, we will assume a fertilization rate of three pounds of nitrogen per thousand square feet, broken up into two applications. Based on our assumptions, 225 pound of nitrogen should be applied to an 85,000 square foot field annually.

Water

The precise amount of water required for a natural field can vary dramatically. Irrigation needs will differ based on the climate the turf is located in: humidity, precipitation, and the temperature all play a role in determining the amount of moisture that must be added to a field. The condition of a natural field will also figure into its irrigation needs. Minimum levels of maintenance prevent the creation of problems such as thatches, which can impede water from reaching the soil. If systems are not kept in working order, the efficiency of irrigation will be compromised. Lastly, the way in which irrigation is carried out can change the amount of water needed. Demand on fresh water will change based on the time of day irrigation takes place (due to evaporation), and if alternative sources can be utilized. All of these factors can result in more or less water needed to achieve a static level of moisture. Duble (1993) provides a range of 12 to 36 gallons per square foot needed in Texas, depending on the irrigation needs for different regions. The Sonoma County Water Agency (2009) uses 22.5 gallons per square foot when watering city lawns.

Topdressing

Topdressing is the addition of sand, soil, compost, or other material to the turf surface. It serves to level the playing surface, promote stronger root systems, and create a more resilient surface. This is accomplished by the added material promoting the decomposition of the organic matter that is between the soil surface and the grass blades.

Generally the application of topdressing should be done following fertilization, especially in the spring. Chirillo (2008) notes that some fields might call for 2 to 3 applications per year. The Sports Turf Managers Association (2009) cites five applications per year for a sand based soccer field. For our purposes one application per year should be accounted for, while we acknowledge that additional applications may be necessary.

Rolawn (2010), a European supplier of topsoil and producer of cultivated turf, suggests that based on the time of year different quantities of topdressing be applied. They recommend that 1.5 liters of topsoil per square meter be applied in the summer, and twice that amount be applied in the spring and autumn.

For synthetic fields, topdressing consists of the addition of crumb rubber infill. Additional infill may be periodically necessary, as over time large quantities can be displaced. The Sports Turf Managers Association (2009) gives an estimated application rate of 10 tons of dressing, applied once during the year.

Paint

Field markings must be repainted on occasion to maintain the field’s usefulness for various sports. Hall (2004), of TruMark Athletic Field Marker, notes that five gallons of diluted acrylic latex paint will cover 1,000 linear feet that is four inches wide. He also estimates that a standard football field requires 4,600 linear feet of paint to apply four sets of hash marks, and five yard lines. This equates to around 25 gallons of paint that is needed, according to his approximations. However, for a NCAA Division I Football game, he calculates paint needs for basic lines are 60% higher, with 27.5 gallons necessary for out of bounds lines, and 12.5 gallons for yard lines. In addition, in this instance 55 gallons of colored paint was also used.

Hall’s (2004) figure may be a bit high when compared to the recommendations of others. The Sports Turf Managers Association (2007) suggests that for a regulation size football field seven and a half gallons of paint are needed for the hashes and field numbers. This figure is five gallons less than Hall's calculation. In another publication, the Sports Turf Managers Association (Natural Grass Athletic Fields 2009) suggests that for an 114,000 square foot sand based soccer field, around 100 gallons of paint are needed for 6 applications annually. Meanwhile, a provider of aerosol paint, the California Field Supply Company (2007), offers an even more conservative figure. They estimate that 3.36 gallons of aerosol paint is needed for the initial layout of the field—which must be reapplied a second time per year—and 1.68 gallons are needed for weekly over markings in a 30 week year (or half of that for lower volume fields). Although the California Field Supply Company does not indicate the size and purpose of the field they are considering, only indicating that it was a field of "standard dimensions."

The amount of paint required for an application of field markings becomes even more muddled when considering the actual materials that go into the painting of Florida State University's Football Field. Theacc.com (2005) estimates that 460 gallons of paint are applied to the field prior to each game. They note that approximately 100 gallons is used to apply white lines, numbers and hash marks. An additional 360 gallons is used on the sidelines, and to paint the team emblem midfield and in the end zones.

The amount of paint needed per application is difficult to determine, given the broad range of estimates suggested. However, the slight differences in the amount and type of paint needed for natural and synthetic fields are insignificant when comparing the number of applications required. Since natural grass is mowed frequently to maintain its proper length as it grows, lines must be reapplied at regular intervals. Most literature seems to suggest that paint should be reapplied to grass prior to each event. On the other hand, a synthetic turf needs far fewer applications of paint. In fact, the Sports Turf Managers Association (Natural Grass Athletic Fields 2009) only accounts for two applications per year on artificial fields. However, a field manager may choose to apply paint more frequently to meet more rigorous aesthetic needs.

Replacement Seed and Sod

It is assumed that over time natural grass will get old and need to be replaced. With that, new seed or sod will be required once the old turf is removed. The frequency with which this is expected to occur can also affect the costs and life cycle of the field. Another practice that consumes an excess of seeds is over seeding. Over seeding is done to make the surface greener in the winter, and to support sports that go later into the season (i.e. that are played late into the winter or in the spring). However, this practice is not recommended for general maintenance, as it can compromise the health of the existing grass that must compete with the additional seed grass variety.

2.5 Cost

In this section the cost of natural and synthetic fields will be explored for comparison. Estimates will be based on a sample field of 85,000 square feet. This field size is large enough for a regulation size American Football (57,600 sq. ft.) or International Soccer (69,300 sq. ft.) field plus side lines.

2.5.1 Installation Costs

The cost of turf construction varies dramatically based on numerous factors. As to be expected, the needs requirements for a field determine its associated cost. The size and type of play that will occur are the principle considerations when calculating construction costs. The drainage and irrigation systems necessary to suit the capacity of any particular field also must be taken into account when gauging expenses. The location of a field installation also factors into its total price, determining its costs related to labor and the difficulty of installation based on factors like soil and climate. For example, additional costs may result from the labor necessary to prepare a difficult surface or to offset weather-related delays in the construction schedule.

The construction price for a natural field can span a wide range depending on the properties of the land it is built on. If native soils are very sandy, they can support the installation of new turf without additional materials to improve the surface stability. Native soil fields are the least expensive of all natural fields. Of native soil fields, there are two options: seeding and sod. Seeding is the less expensive option, because it does not require the purchasing of sod or top soil. This option runs at about $1.20 per square foot. (Sports Turf Managers Association, 2008; Turfgrass Resource Center, 2008). Sod, on the other hand, costs about $2.25-$5.25 per square foot (Sports Turf Managers Association, 2008). Other types of natural turf require the addition of sand, and possibly other materials, to improve the robustness of the root zone for greater availability. The Turfgrass Resource Center estimates that basic sand-based field installations cost between $2.94 and $4.12 per square foot. However, they note that more elaborate sand-based systems can cost over $7 per square foot to install. Meanwhile, the Sports Turf Managers Association estimates the average cost of construction for sand based systems as $5.25 for a sand cap and $8.50 for a sand and drainage. Using these figures, estimates for a sample 85,000 square foot field are calculated in Table 2.3 below:

Table 2.3: Installation Cost for a 85k Square Foot Grass Field

Natural Field Type	Cost
Seed	$102,000
Sod	$191,250 - $446,250
Basic Sand	$250,000 - $350,000
High-End Sand	$722,500

Meanwhile, the cost of a synthetic turf varies based on many of the same aspects as natural turf. The existing condition of the field affects the cost of surface preparation, including: excavating the site, adding any necessary foundational materials, and compacting the foundation. The more material that must be removed, the greater the cost of installation will be. A proper drainage system is critical for artificial fields; without it, damage typically occurs from moisture that is trapped in the turf components. This is true even of indoor turfs, as liquids are often applied to clean and maintain their surface. Choices of turf components also influence price, including: the quality of fibers, padding, backing, and infill. In addition, specialized logos or sports lines have associated costs based on whether they are painted or sewn in. The price range of synthetic turf per square foot is $6 to $11.76. The Sports Turf Managers Association (2008) estimates that the construction cost for a synthetic turf runs between $6.50 to $11 per square foot. The Turfgrass Resource Center (2008) approximates installations to be on the higher end from $10 to $11.76 per square foot. Meanwhile, Sporturf, a synthetic turf provider, estimates that installing an artificial turf field costs from $6 to $8 per square foot. However, they also note that a

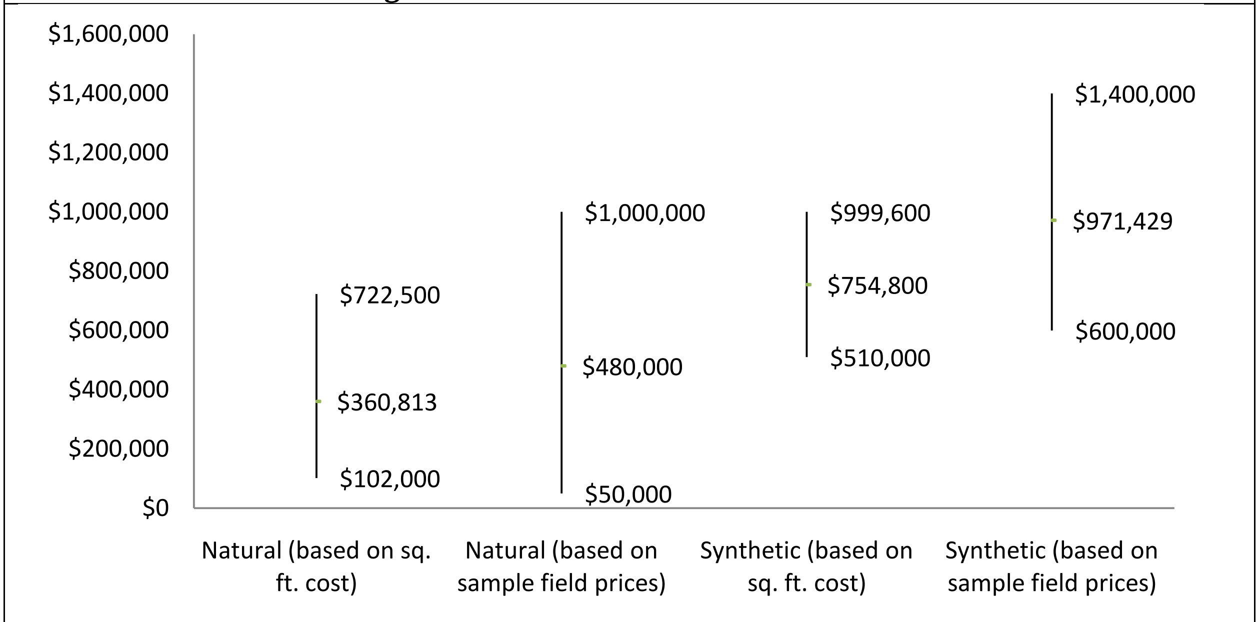
10,000 square foot "state-of-the-art fake grass" turf was installed in Shaw Park, GA for $30,000 (a price of $3 per square foot). Using these figures, the cost of an 85,000 square foot synthetic turf field ranges from $510,000 to $999,600. This figure is significantly higher than the range of $102,000 to $722,500 found for natural fields.

Comparisons of the costs to install natural and artificial fields in other studies show similar differences in price between the two field types. Several case studies provide estimates of the installation costs for the two types of fields without noting the size of the field. Despite this omission, these works provide insight into the potential construction costs of fields, as well as the difference in costs between synthetic and natural turfs. The price estimates from these various works are listed in Table 2.4. Of note is the minimum of all of these costs for natural fields, which has been estimated to be about half of the cost calculated above, at $50,000. Meanwhile, the prices quoted for synthetic turfs are on the higher end of the range found earlier. Furthermore, our calculations show synthetic field installations as costing from 0.7 to 9.8 times more than a natural field. Several of the additional studies show artificial fields as ranging from twice the cost of grass to 20 times the cost.

Table 2.4: Price Estimates for the Total Costs of Installation for Natural and Synthetic Fields				
Resource	**Context of Research**	**Synthetic**	**Natural**	**Number Of Times Greater Cost Of Synthetic Turf Installation as Compared To Natural Turf**
Turfgrass Resource Center (2008)	A publication that addresses concerns about synthetic turf using scientifically backed data for a non-profit trade association that represents the turfgrass sod industry.	$850,000 – $1,000,000	$50,000 – $600,000	1.4 to 20
Williams and Pulley (2002)	An investigation conducted at Brigham Young University for their football field, half of which is synthetic, and the other half which is sand-based natural field.	n/a	n/a	11.8
Powell (2005)	A conference presentation aimed at athletic field managers addressing the complexities of natural and synthetic turf. Powell is a turfgrass agronomist with the University of Kentucky.	*Basic:* $600,000 *High End:* $1,000,000	*Soil:* $50,000 *Sand:* $1,000,000	0.9 to 18:1
Claudio (2008)	A journal article in *Environmental Health Perspectives (EHP)*, a monthly peer-reviewed research and news publication by the U.S. National Institute of Environmental Health Sciences, National Institutes of Health, Department of Health and Human Services.	$1,400,000	$690,000	2.0
Skindrud (2005)	A case study for a installation at Springfield College in Springfield, Massachusetts, in an informational article comparing natural and synthetic fields for landscape contractors.	$800,000	$400,000	2

Using the information provided above, a precise estimate for the installation costs of different turf options will be determined for use in total system cost calculations. The range of comparative proposed prices can be seen graphically in Figure 2.1 below. This figure shows the minimum and maximum prices provided by various authors, as well as the mean price calculated for each proposed turf type. For our purposes, a single value is needed for a comparative analysis of the total cost of synthetic and natural turf systems. For this objective, the price per unit (i.e. per square foot) value is a more credible estimate because: 1) it is known to be a comparison of two fields of equivalent size, and 2) it is scalable by a known factor to achieve a specific case study field size. It should be noted that, regardless of whether the price per square foot or total price is used, the average cost for a synthetic field is twice that of a natural field. Using the square foot cost, the mean value of the research investigated will be used for cost calculations. Specifically, this is $8.88 per square foot of synthetic turf and $4.24 per square foot of natural turf, or $754,800 and $360,813 respectively for an 85,000 square foot field.

Figure 2.1: Initial Cost of Various Turfs



2.5.2 Equipment Costs

Equipment costs are calculated in large part by the equipment and supplies identified in the maintenance section of this report (see Section 2.4: Maintenance). The average cost associated with each of the identified items has been collected from various studies. These prices have been listed in Table 2.5 below. These estimates will be used to calculate the capital costs of maintenance.

Table 2.5: Suggested Cost for Equipment Based on Field Type		
Equipment:	**Synthetic**	**Natural**
Tractor/Utility Cart	$7,000 to $16,000 (a) $2,500 to $16,000 (b)	$7,000 to $18,500 (a)
Assorted Hand Tools	No cost estimate given	No cost estimate given
Sweepers/Blowers	$1,500 to 20,000 (a) $1,500 (c) $1,500 to $20,000 (b)	No cost estimate given
Broom, Brush Or Tine	$500-3,000 (a) $500 (c) $500 to $3,000 (b)	
Roller	$250 to $2,000 (a) $250 to $2,000 (b)	
Mower		$13,000 to $69,000 (a) $107* (d)
Spraying equipment	$1,000 to $35,000 (a) $1,000 to $35,000 (c)	No cost estimate given
Aerator		$3,500 to 17,000 (a)

*yearly cost for a five year lifetime

References for Table 2.5

a) Turfgrass Resource Center(2008)
b) "Synthetic Turf Maintenance Equipment" (Brakeman 2005)
c) "2004-2005 Maintenance Budget Synthetic Infill Field" (Brakeman 2005)
d) New Yorkers for Parks (2006)

The range of estimated prices given by any author can be quite large. For instance, spraying equipment is expected to run somewhere between $1000 and $35,000 (Brakeman, 2005). The equipment that is needed for the maintenance of both field types is assumed to be similar in price. These items—tractor/utility carts, hand tools, sweeper/blowers, and spraying equipment—are similar enough that for the purposes of estimations, they do not need to be differentiated , despite possible differences in the specific devices. In general, cost estimates will be made for equipment using the mean of prices provided. Where this is not the case, this will be noted. The specific price estimates that will be used are:

- A tractor/utility cart will be assumed to be around $10,375, the mean value of all suggested figures that range from $2,500 to $16,000.
- No estimates were given for the total price of hand tools. However, it is assumed that the cost of these is inconsequential in the comparative costs of artificial and natural fields. Therefore, these costs will not be included.
- The cost of a sweeper/blower will be assumed to be $7,667. The suggested prices range from $1,500 to $20,000.

- Some combination of a boom, brush, or twine will be assumed to be $1,333.
- A roller will be assumed to be $1,125, the mean value of all suggested figures that range from $250 to $2,000.
- It will be assumed that a quality mower will be needed given the frequency with which it will be used. The estimate given by New Yorkers for Parks (2006) will be disregarded, as it is questionable that the type of mower needed can be obtained for such a figure (i.e. $107 per year for five years). The midpoint price of $41,000 will be used in calculations.
- Spraying equipment is assumed to be $18,000.
- The suggested price for an aerator is $3,500 to $17,000. The mean of this, or $10,250, will be used in calculations.

Using these figures, the total equipment cost will be $38,500 for a synthetic field and $87,292 for a grass field.

2.5.3 Total Cost of Ownership

The table below provides examples of a 10-year total cost of ownership, comparing the cost to install and maintain natural sod turf versus synthetic turf. The example uses a 78,000 square foot field, private stadium.

Table 2.6: Total Cost of Ownership

	Artificial Turf	Sod
Installation Cost	$692,640	$330,720
Year 1 Costs	14,900	65,258
Year 2 Costs	14,900	65,258
Year 3 Costs	14,900	65,258
Year 4 Costs	14,900	65,258
Year 5 Costs	14,900	65,258
Year 6 Costs	14,900	65,258
Year 7 Costs	14,900	65,258
Year 8 Costs	14,900	65,258
Year 9 Costs	14,900	65,258
Year 10 Costs	14,900	65,258
10-Year Life cycle Cost	**$841,640**	**$ 983,300**
Uses during 10-Year Cycle	1,400	350
Cost per use	$ 601.17	$ 2,809.43

Key Assumptions:

Artificial turf cost of $8.88 per sq ft, $4.24 for natural turf (sod)
Includes general maintenance, equipment, and water costs (annualized average amounts)
Assumes field does not already consist of natural grass
Does not include "replacement" costs, which may or may not occur during mid-point of life of installation

2.6 Risk of Injury

One of the primary concerns for organizations considering the implementation of synthetic turf is whether it poses any significant health or injury risks. Numerous studies have been conducted assessing the likelihood of injury on natural grass and synthetic turf. Some studies reveal that there is very little difference in the rate, type, severity, or cause of injuries obtained on natural grass or synthetic turf (Fuller et al. 2007a, 2007b). A more recent study by Meyers (2010) shows that the latest generation of synthetic surface, FieldTurf, is safer to play on than natural grass fields. Through the analysis of the various injuries that occurred over the course of 465 collegiate games, Meyers shows that FieldTurf has lower incidence of: total injuries, minor injuries (0-6 days lost), substantial injuries (7-21days lost), and severe injuries (22 or more days lost). FieldTurf also had significantly lower injury rates that natural turf when comparing across play or event type, grade of injury, or various field conditions and temperatures. In addition, there was no significant difference found in head, knee, or shoulder trauma between the two playing surfaces.

Meyers' (2010) research is the most comprehensive study to date, and it addresses previous inconsistencies in findings on injury patterns. Prior studies on injuries suggest that rates for the two surfaces are similar, but that the type of injury varies (Meyers and Barnhill 2004; Steffen et al. 2007). Furthermore, there was no consensus amongst researchers on the difference in type and severity of injuries. Meyers and Barnhill (2004) found that injuries on natural turf tend to be more severe, with greater incidence of head concussions and ligament tears. Steffen et. al (2007), however, found that injuries on synthetic turf tend to be more long-term but occur at a lower rate than injuries on natural turf. Given this conflicting evidence, no major conclusions could be drawn about differences in risk levels between the two fields before the publication of Meyers' work.

The following section will discuss the specific health and injury risks posed by: surface hardness and traction, rates of abrasion, risk of staff infection, heat-related stress and injuries, and material safety.

2.6.1 Traction

Forces that resist shoe-surface motion have been termed traction forces, as they do not always obey the classical laws of friction (Shorten et al., 2003). If traction forces are too high, foot fixation may occur, placing a great deal of stress on lower extremity ligaments during movement (Shorten et al., 2003). This can result in an increased rate of knee injuries and collisions (Pasanen et al. 2007b). Several authors have noted that surface to shoe traction is correlated with increased incidence of injury (Pasanen et al. 2007A; Powell and Schootman 1992; Orchard and Powell 2003). Orchard and Powell show that cold weather reduced traction, leading to a lower injury rate, supporting the claim that traction plays a role in increased risk.

Research clearly points to a correlation between increased traction and greater rates of injury. Several researchers have noted that the more consistent, compliant surface that artificial turf offers is associated with lower shoe-surface traction (Noyes 1988; Schootman 1994). Meyers (2010) notes a lower incidence of injuries attributed to shoe-surface interaction during contact with synthetic turfs over natural grass turfs. In addition, Meyers attributes the lower incidence of ligament sprains on FieldTurf found by Ekstrand, Timpka, and Hagglund (2006) to the possibility of lower shoe-surface traction.

2.6.2 Hardness

Increased hardness is correlated with increased likelihood of severe head trauma. However, the hardness levels of synthetic fields, if set up correctly, fall well below these dangerous levels (McNitt and Petrunak, 2007c). Furthermore, it is easier to maintain an existing level of hardness on synthetic fields because hardness is related to infill depth. On the other hand, the hardness of natural fields varies according to soil-moisture, which is more labor-intensive to manipulate on an ongoing basis.

However, the solution is not to make fields as soft as possible. A surface that is not at the correct hardness level will affect athletes' performance, particularly by bringing on early onset of leg muscle fatigue (New York City Department of Health and Mental Hygiene, 2008). Set up should be carefully carried out to ensure proper hardness levels.

2.6.3 Abrasion

One of the major criticisms about synthetic turf is that it is seen by many to be more abrasive than natural turf. The old versions of synthetic turf elicited public complaint about incidence of abrasion (New York City Department of Health and Mental Hygiene, 2008). However, the newer versions have longer and softer fibers, making them less abrasive. At Penn State's Department of Crop and Soil Sciences, a study on synthetic turf systems included a measurement of the abrasiveness of the surface by pulling foam blocks over the turf's surface (ASTM Method F1015). The results, reported by McNitt and Petrunak (2007a), states that infill systems are less abrasive than older carpet-like turf generations. The abrasiveness was also affected by the grooming of the field surface (McNitt and Petrunak, 2007a).

Comparisons of the impacts of abrasions between natural and synthetic turfs are slightly favorable towards artificial fields. Unfortunately, the abrasiveness of natural fields has not been measured for contrast, as the ASTM Method F1015 is only applicable to synthetic surfaces. However, Meyers (2010) found that the rate of epidermal injuries caused by interaction with the surface were slightly lower on artificial turfs (1%) than on natural grass (1.3%). This research investigates some of the irregular injury patterns initially observed on artificial turf (Meyers and Barnhill, 2004). In this preliminary study, abrasion occurs more frequently on synthetic turf than natural turf (Meyers and Barnhill, 2004).

It should be noted that in and of themselves, abrasions are not usually severe injuries. However, these types of injuries can lead to more severe complications, including staph infections.

2.6.4 Staph Infections

Concerns have been expressed about the role that synthetic turf plays in facilitating staph infections. Methicillin-resistant Staphylococcus aureus (MRSA) is a drug-resistant bacterium that can result in severe, and sometimes fatal, infections. Due to increased outbreaks of MRSA in athletes, concerns have developed about whether turf fields increase the risk of such infections. While research suggests that abrasions from injury may play a role in the contraction of such infections, there has been no evidence of a causal relationship between synthetic turf and staph infections.

There are a variety of studies about the role that synthetic turf plays in the contraction of MRSA. All research indicates that synthetic turf is not a cause of MRSA. However, several authors point out that abrasions caused by turf may provide a means of entry for the outbreak of infection (Kazakova et al. 2005; The New York City Department of Health and Mental Hygiene 2008; McNitt 2008). The New York City Department of Health and Mental Hygiene claims that other factors are the primary cause of bacterial infections. Begier et al. (2004) reached similar conclusions, despite noting a seven-fold increase in the risk of MRSA contraction for athletes with turf burns. They concluded that it is not possible to assess the risk of outbreak associated with the playing surface because all players used artificial turf, and other factors, such as use of a poorly maintained whirlpool, which played a role in MRSA contraction. Furthermore, The New York City Department of Health and Mental Hygiene (2008) dismisses the associations that Begier et al. (2004) and Kazakova et al. (2005) make between synthetic turf and MRSA, because they did not compare them with abrasions caused by different sources. McNitt, Petrunak D, and Serensits (2008) determined that synthetic turf—and fields in general—do not provide an environment that is hospitable for hosting bacteria.

While infections may be associated with abrasions, not all abrasions result in MRSA. In addition, cases of MRSA have occurred in individuals who have not generally had contact with synthetic turf, such as dancers, wrestlers, fencers, and non-athletes. Furthermore, given that turf surfaces themselves do not harbor such bacteria, it is doubtful that there is an increased risk associated with abrasions that originate from synthetic turf surfaces over abrasions from other surfaces (McNitt, Petrunak D, and Serensits, 2008). However, since abrasions provide a means of entry for staph infections, rates of abrasion can be important to bear in mind (see the section on abrasion injuries).

Behavioral factors play a far greater role in determining whether staff infections will develop, including: the covering of wounds, physical contact with other players, and hygiene practices (McNitt 2008; Benjamin, Nikore, and Takagishi 2007; Nguyen, Mascola, and Bancroft 2005; Kazakova et al. 2005; Begier et al. 2004; Srinivasan and Kazakova 2004; Tobin-D'Angelo et al. 2003; Stacey et al. 1998).

2.6.5 Heat

There are two major concerns about the affect of heat on synthetic turf. The first is the material toxicity that can result from increased temperatures, a concern that will be discussed in the material safety section that follows. The second is the heat-related stress that can be caused by increased temperatures, such as heat exhaustion, heatstroke, burns, and blisters. We will examine these problems here.

Temperatures of synthetic turf do get higher than the surrounding air (see section on all-weather availability), which can play a factor in heat-related stress. There are two studies indicating that synthetic turf has resulted in heat blisters on players' feet (Williams and

Pulley, 2002; SI.com, 2007). However, behaviors play a more significant role in creating heat-related injuries, such as: reducing playtime and preventing dehydration (Anderson et al., 2000; New York City Department of Health and Mental Hygiene, 2008b). It has also been suggested that humidity plays a greater role in heat stress than temperature (New York City Department of Health and Mental Hygiene, 2008b).

As can be seen, there are a variety of concerns about the safety of synthetic turf for players. Evaluation of these concerns finds that these risks, in many instances, can be mitigated. There are some risks that people should be aware of, but there is no evidence that the dangers of synthetic turf greatly outweigh those of natural fields.

2.6.6 Injury Conclusions

Despite these findings which are generally favorable towards synthetic turf, there is still a strong public perception that it is more likely than natural turf to cause injury. A study shows that 91.2 percent of NFL players thought that artificial turf would be more likely to contribute to injury (NFL Association, 2004). However, this public perception could be rooted in a variety of factors beyond the grasp of science. Players may be used to other fields or associate new technologies with their earlier, less-developed versions.

2.7 Material Safety

The use of athletic fields made of recycled tires has also been called into question because of concerns regarding toxicity. For example, the state of New York has recommended a moratorium on future construction of such fields pending additional research. Authorities are worried that because of the chemical content of the material, exposure by various means could endanger the health of field users, especially children. However, extensive research has pointed to the conclusion that these fields result in little, if any, exposure to toxic substances.

On the face of it, concerns about the toxicity of crumb rubber fields is quite warranted. The raw material from which they are made – used car tires – is known to contain numerous toxic and potentially carcinogenic compounds. These chemicals include polynuclear aromatic hydrocarbons (PAHs), phthalates, volatile organic compounds (VOCs), zinc, iron, manganese, nickel, PCB, copper, mercury, lead, cadmium, volatile nitrosamines, benzothiazole, isononylphenol, and more.

These chemicals are of concern for various reasons. Many of the metals have been associated with damage to the nervous system, as well as irritation of the eyes, nose, and throat. PAHs have been identified as a cancer risk and as causing substantial organ damage. And VOCs have been implicated in causing organ damage, or symptoms of lesser consequence such as nausea, headaches, and sense organ irritation.

However, the mere presence of a substance is not necessarily cause for concern. For the most part, when these chemicals are present in tires, they occur in very small concentrations. Also, their presence does not automatically equal exposure. Tires are relatively, though not entirely, inert, and the vulcanization process that they undergo to prepare them for their second life as artificial turf, renders them more, rather than less, stable. Further, many of the chemicals of concern are already present at relatively high levels in urban environments, as a result of numerous human activities which are not presently considered controversial: driving, heating and cooling systems, and regular production of household and industrial waste. Even the consumption of certain foods has been noted to raise a person's exposure to substances such as PAHs (van Rooij and Jongeneelen, 2010).The primary issue is not whether artificial turf contains such materials, for this is undoubtedly true, but, whether there is sufficient human exposure to elevate the risk above accepted levels. While small increases in risk may not be insignificant, a generally accepted measure of danger should be adopted, namely the general scientific consensus in determining whether an elevated level of risk ought to be deemed significant.

Being in proximity to a substance is not in itself a risk. There needs to be a means through which one's body comes into contact with the substance – a path of exposure, if you will. For crumb rubber, as it is not radioactive, there are numerous possible paths of exposure through which a human could conceivably be subjected to potentially noxious chemicals. The first and most direct route of exposure would be through actual oral ingestion of pieces of the crumb rubber itself. Now, it is highly unlikely that most field users will decide to consume a chunk of the playing field. However, this is a valid concern when considering the most vulnerable portion of the population – very small children. It is entirely possible, and perhaps inevitable, that some small children will pick up infill pieces and swallow them.

Secondly, and more likely, would be hand-to-mouth exposure, especially of dust or small particles of crumb-rubber. If such matter got on the hands of a user of the field, and the user then touched his hand to his mouth, he could ingest infinitesimal amounts of crumb rubber particulate.

Thirdly, dermal exposure is highly likely. The skin of field users is bound to come into contact with the field's surface. Given the naturally protective qualities of skin, this is an unlikely route of exposure, unless the substance is abrasive to skin itself.

Fourth, there is concern about chemicals leaching off of the fields – especially if the fields are outdoors and subjected to periodic rainstorms (Moretto, 2007). Such chemicals, if water-soluble, could come to enter the groundwater or drinking water supply.

Finally, and perhaps most significantly, there is the possibility of inhalation of toxins from the field. Such inhalation would generally come about through one of two possible phenomena. The first is a process known as "out-gassing" or off-gassing." As noted above, recycled tires are substantially, though not entirely, inert. Some compounds within the material will, over time, come to be released from the material and to enter the air. This is a particular concern with so-called "volatile organic compounds," but also with PAHs. Secondly, repeated use of the field could cause atomized particles of the field to be produced as barely noticeable dust, or "particulate". Such particulate could be inhaled by users of the field.

The potential of toxic exposure along each of these pathways has been the subject of repeated inquiry. Numerous governmental agencies have carried out independent research into the toxic potential of crumb rubber, and we will review the results of this below. Generally, it has been found that crumb rubber fields do not present an elevated risk to health through exposure to toxic substances, but researchers have noted some areas of concern. More typically, though, they have noted the present existence of "knowledge gaps"; a lack of full understanding at the general theoretical level which renders the inquiries to some degree inconclusive.

2.7.1 Direct Ingestion

Two major studies of the potential for toxic transference through direct ingestion have been carried out. The first, by Birkholz, Beton and Guidotti (2003), involved immersing tire particulate in chemical solvent and testing the resulting chemical for increases in carcinogens. This test did not clearly demonstrate a significant increase in carcinogenic levels.

A similar study, by the California Integrated Waste Management Board (CIWMB, 2007), subjected 10mg of tire shred samples to a chemical environment that replicated the human digestive system. In all, 22 chemicals were released by the samples, but none at levels that were associated with significantly elevated risk levels. Scientists performing this experiment were particularly concerned with an elevated risk of cancer in children. The study found, though, that ingestion of a significant quantity of tire shred did not elevate a child's risk of developing cancer, relative to the overall cancer rate of the population.

2.7.2 Hand-to-Mouth Contact

This same study, by the CIWMB (2007), also evaluated increased risks due to hand-to-mouth exposure. For hand-to-mouth exposure, researchers took wipe samples from field surfaces and were able to identify five chemicals present in rates significantly higher than the general environment. Calculations were then made to determine the frequency with which these chemicals would or could enter the body through hand-to-mouth contact. Though a high degree of variability and uncertainty was acknowledged, researchers found that, on average, the degree of toxic exposure due to hand-to-mouth contact would be well below acceptable levels.

Lead ingestion is a matter of concern with crumb rubber fields, for it is well-known that lead is used in tire production. However, one mitigating factor should be pointed out: tires do not contain uniform amounts of lead, and it is therefore possible to selectively choose particles from tires with low lead concentrations.

The New Jersey Department of Health and Senior Services (2008) carried out a study subjecting tire particulate to a simulated gastric environment. This was done to determine whether the amount of lead which could be absorbed by human beings as a result of casual ingestion through hand-to-mouth contact with crumb rubber dust would release significant quantities of lead. The findings were that the amount of lead released through gastric processes was not significantly different from that of ordinary soil samples. However, in certain types of fields, particularly those which used nylon fibers, elevated lead levels were observed.

A similar study was undertaken by the Consumer Product and Safety Commission (2008). The CPSC analyzed wipes taken from various crumb rubber fields and assessed the risk of exposure to minors who might be using these fields. It was determined that in no case would exposure ever exceed chronic levels of ingestion of lead that could cause lead poisoning.

The Norwegian Building Research Institute's (2006) analysis of lead exposure similarly found that lead levels fell well within an acceptable range.

The US Center for Disease Control and Prevention (2008) has advised the careful selection of material for crumb-rubber fields. It is possible to select crumb rubber in which lead concentrations are low, and it is strongly advised that this be carried out.

PAHs are a source of concern for hand-to-mouth ingestion from artificial turf fields. The CIWMB (2007) investigated the possibility that four PAHs – such as the carcinogen chrysene—could be present at levels dangerous to humans. The study failed to show that this was the case.

2.7.3 Dermal Contact

In addition, PAHs have been studied for their risk associated with the dermal contact of crumb rubber. Such risks of PAH uptake have been determined as low amongst athletes (Hofstra 2007), based on certain assumptions regarding the circumstances of exposure and dermal bioavailability. Additional testing of real life exposure was conducted by Van Rooij and Jongeneelen (2010). Their study used biological monitoring (i.e. urine samples) to assess exposure. This method of assessment is advised when exposure can occur through multiple pathways, as is the case with PAHs. Their findings show that the uptake of PAH by athletes who have contact with crumb rubber synthetic turf is negligible. Additionally, diet and other environmental factors were identified as having the same level of PAH uptake as field exposure.

As far as dermal contact is concerned, the Norwegian Institute of Public Health and radium Hospital (2006) carried out an extensive analysis of possible health concerns. The only concern which they highlighted as potentially significant was the risk of allergic reaction to crumb rubber that contains latex, a well-known allergen. The study found, though, that there was no evidence to suggest that allergic reactions were caused by exposure to crumb rubber and speculated that latex in car tires was either "less available for uptake" or was "deactivated" as an allergen. The study acknowledges, however, the existence of knowledge gaps that make a full risk assessment in this particular area provisional.

2.7.4 Water Contamination

The question of whether chemicals will leach off of playing fields and enter the drinking or groundwater supply is of broader concern. Once again, the matter of whether or not such leaching ever takes place should not be the focus of concern. The question is: At what concentrations do chemicals leach off of fields, and will the natural environment be able to break down the chemicals at those concentrations?

Zinc is a metal of particular concern in this regard. Now, the simple presence of zinc is not necessarily problematic. Zinc is already present in significant concentrations in urban environments, and is in fact essential to the metabolism of most plants and animals. However, zinc at high concentrations can be quite toxic.

Three studies have looked into the presence of zinc as a result of leaching from crumb-rubber athletic fields. The first, carried out by the Norwegian Building Research Institute (NBRI)(Plesser, 2004), was the most critical. It noted that the concentration of zinc in granulate particles exceeded the Norwegian Pollution Control Authority's guidelines for "most sensitive land use." However, it should be noted that Norway's standard for this particular pollutant is unusually stringent; the report noted that the same concentration is deemed by Canadian Water quality guidelines to be well within acceptable range.

California's Integrated Waste Management Board (2007) tested the concentrations of zinc leaching from crumb rubber fields. Its analysis seemed to indicate that the levels detected were not a significant health or environmental concern.

New Jersey's Department of Environmental Protection (2007) carried out a review of the safety of crumb rubber fields that took careful account of the presence of zinc in water leaching from these fields. They noted that a Dutch study from 2007 indicated that the amount of zinc that could leach into water supplies would not be injurious to human health. It would fall below the level of toxicity advised against by the World Health Organization. However, the same study noted that the amount of zinc potentially leached into groundwater exceeded limits set by New Jersey's own environmental standards.

The Swedish Chemicals Inspectorate (2006) has confirmed this finding, noting that zinc levels exceed what is acceptable in runoff, for it could damage ground-dwelling organisms. For this reason the Inspectorate advised against the construction of new crumb-rubber fields, but did not urge the elimination of existing fields.

The Norwegian Institute for Water Research (2005) has indicated that not only zinc, but also but alkylphenols, and octylphenol in particular, are also predicted to exceed the limits acceptable for environmental health.

Birkholz, Belton, and Guidotti (2003) performed toxicity tests on four different aquatic species using crumb-rubber leachate. They determined that undiluted samples produced a moderate risk to all four species, but that diluted samples did not. Noting that the likelihood of undiluted rainwater runoff was slim to entirely unlikely, they concluded that crumb rubber leachate does not pose a risk to aquatic species. However, it should be noted that they specifically looked at toxin levels of lauryl sulfate and sodium chloride. Zinc exposure was not tested.

2.7.5 Inhalation

A particular concern when it comes to the potential of inhalation of toxins from crumb rubber fields is Volatile Organic Compounds, or VOCs. As discussed above, VOCs have been implicated in causing organ damage, nervous system problems, and irritation of eyes, throat and airways.

As pointed out by the New Jersey Department of Environmental Protection (2007), the likelihood of significant emission of VOCs from recycled tires is very low. This is because most VOCs would have already been emitted from tires while they were used for their original purpose of enabling automobile transit. The combination of frequently raised temperatures and long-term use would serve to eliminate most volatile gases from the material. Further, most tires spend up to a year in a scrap-yard between being discarded as tires and before being shredded for use in athletic fields. This additional year provides more opportunity for VOCs to be out-gassed. Studies serve to confirm these speculations.

The French National Institute for Industrial Environment and Risks (2007) carried out a study of the risk of exposure to VOCs from recycled tire athletic fields. The study found that the concentrations of VOCs emitted by such fields were low enough to not pose a risk to athletes using the fields, to officials, or to spectators.

The Norwegian Pollution Control Authority (2006) analyzed the levels of VOCs emitted from indoor fields to determine if a health hazard was indeed present. The finding was that, with adequate ventilation, these fields would not pose a health concern.

The New York City Department of Health and Mental Hygiene (2008b) commissioned a study of a number of the city's already-constructed athletic fields to determine if VOCs or metals were being out-gassed from the fields at significant levels. Though eight different VOCs were detected in the air, they were not at levels high enough to threaten human health. Additionally, it was not clear that the VOCs detected were indeed from the fields themselves, as there was no uniformity in the scores for the different fields, and VOCs were detected in control locations upwind from the sites.

The Norwegian Institute of Public Health and Radium Hospital (2006) analyzed the presence of VOCs emitted from fields and determined that there was no cause for concern. This includes the substance known as carbon black. Recent discussions have included the topic of carbon black, and the potential damage to the respiratory system. Carbon black is used in tires to provide the pigmentation, as well as to dissipate heat and maintain the shape (and life) of the tire. However, there have been no findings that carbon black in crumb rubber has been a serious health issue to users of playground surfacing. Similar research was performed by the California Integrated Waste Management Board in a subsequent, related study in 2007.

A preliminary test by the Connecticut Agricultural Experiment Station (Mattina et al., 2007.) showed that VOCs were indeed released from rubber pellets made from ground-up tires, the raw material for crumb rubber fields. Though the study noted that the levels of released VOCs did not appear to occur at a level clearly injurious to humans, further study was recommended.

The same study looked into the presence of volatile nitrosamines emitted by a sample of twenty different fields. Volatile nitrosamines are chemicals such as benzothiazole and 4-(tert-octyl) phenol. The study did not indicate that such chemicals were emitted at levels of concern. A similar Dutch study looked into the levels of nitrosamines emitted from vulcanized crumb rubber and determined that such levels did not pose a risk to humans.

Both the Norwegian Building Research Institute (2006) and the California Integrated Waste Management Board (2007) have carried out tests of exposure to numerous potentially toxic metals present in tires, such as mercury, PCBs, nickel, cadmium, and chromium. Both studies identified levels that were either below detection limit or were at levels insignificant to health considerations. However, concerns were raised about levels of chemicals such as dibutylphthalate (DBP) and diisononylphthalate (DINP), whose presence can exceed EU standards.

2.7.6 Sample Testing

To investigate the issue of the content of lead and other metals in cryogenically produced crumb rubber, samples were sent out for laboratory evaluation. Materials were provided by a market leader, BAS Recycling of Moreno Valley, CA, from one of its primary customers, Environmental Molding Concepts (EMC). Synthetic field samples were sent to St. Louis Testing Laboratories, Incorporated, an independent third-party commercial testing laboratory, and analysis was conducted in February, 2009. Evaluations were carried out to ensure compliance with the U.S. Consumer Product Safety Improvement Act for Children's Products Containing Lead (i.e. CPSIA, Section 101), which places limits on the heavy metals content in children's product. The metals regulated by this act include: lead, antimony, arsenic, barium, cadmium, chromium, mercury, and selenium. Testing was done in accordance with American Standard Testing Method (ASTM) E1613, "Standard Test Method for Determination of Lead by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES), Flame Atomic Absorption Spectrometry (FAAS), or Graphite Furnace Atomic Absorption Spectrometry (GFAAS) Techniques."

In total, 40 tests were conducted, for each of the eight metals on five different color samples. Five colors (i.e. blue, green, rust, black, and gray) of turf were evaluated in order to account for possible variability of outcomes from different source contributions. All testing for lead indicated that sample contents were below problematic detection levels. For the remaining tests, all but one came back in compliance with regulation standards. In a single instance, the sample with blue colorization had slightly elevated levels of Barium. This test measured barium at 1228 ppm, which is 328 ppm above the limit. High levels of barium exposure can be troublesome. However, it should once again be noted that the mere presence of a substance is not necessarily cause for concern. It simply indicates a possibility of a risk of exposure. Further testing would be needed to measure the risk of contact. On the other hand, the absence of above limit concentrations precludes the possibility of exposure. In other words, a person cannot be at risk of exposure, if a substance is not present. As such, our testing found that the presence of lead—which was previously identified as being potentially problematic— does not pose a significant risk to people, and children in particular. In fact, the samples provided by BAS contained virtually no lead, at 20 parts per million, which surpasses the upper threshold limit of 400. Levels of lead even in soil are also acceptable at up to 400 parts per million, which signifies the insignificance of lead in the recycled rubber based material. Overall, cryogenically produced crumb rubber performed well against product safety standards.

2.7.7 Material Safety Conclusions

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.

There remain a few objects of concern, though. First, the allergen potential of latex in tires used for athletic fields remains obscure. Though there has not been experimental confirmation of the risk of crumb rubber triggering a latex allergy, the possibility cannot be ruled out and needs to be investigated more thoroughly.

Second, lead exposure remains an object of some concern. The results of experimental evaluation of lead in these fields have been thus far inconclusive. Most studies have cleared the fields as safe in terms of lead risk, but others have noted an elevated presence of lead. Given the fact that lead levels in tires varies significantly according to production processes, it seems safe to conclude that given judicious selection of crumb rubber fill prior to constriction – that is, selection of material with low lead concentrations – lead exposure could be minimized significantly.

Finally, and most significantly, repeated testing has shown that the presence of zinc in leachate from crumb rubber fields remains problematically high. In many communities, these levels exceed what is allowable according to present environmental standards. Some studies have shown these levels to be acceptably low, and others have noted that certain governance areas – Canada's, for example – allow for higher levels of zinc in groundwater. However, generally speaking, it would appear that levels of zinc leaching into groundwater from crumb rubber fields are significant. Further research needs to be conducted into this question to determine whether it is a real concern, and if it is, greater innovation needs to be carried out at the level of product development to eliminate this concern. If this does not occur, the market for crumb rubber fields will be constricted to areas with relatively more relaxed groundwater-quality standards.

2.8 Environmental Impact

There are several issues that are encompassed in discussions of the environmental impact of a product or activity. Largely, these can be categorized into global warming impact, risks to human health (including toxicity), and disruption to ecosystems. The potential toxicity of synthetic turf, as well as its possible effects on human health was largely discussed in the previous sections (see Section 2.6: Injury, and 2.7: Material Safety). In addition, some of the aspects of ecological toxicity were also discussed in Section 2.7: Material Safety. The following section addresses additional environmental concerns related to natural and synthetic fields. The life cycle global warming impacts will be addressed specifically.

2.8.1 Environmental Concerns

Fertilizer

The environmental impact of fertilizers has garnered much attention in recent years, with growing concerns about bio-fuels. Fertilizers are made using very energy-intensive manufacturing processes to produce nitrogen. The basic feedstock for making nitrogen fertilizer is a petroleum product, natural gas. As a result, fertilizers can be the largest component of an agricultural product's energy consumption (Pimentel 1991; Shapouri et al., 1995; Pimentel 2002; Shapouri et al., 2002; Kim and Dale, 2004). With greater embodied energy, these products have a high global warming potential.

Given this, the amount of fertilizers needed for natural fields is an important environmental consideration. The global warming impact per pound of nitrogen in fertilizers has been shown to be 0.8 to 1.2 pounds of CO_2 (West 2002, Robertson 2000, Snyder 2007). Therefore, the carbon footprint associated with the fertilization of a natural turf field is between 204 and 306 pounds of CO2 equivalent. This is between 0.092532 and 0.138799 tons.

Fuel Consumption

In assessments of global warming impacts, evaluations are often done by means of energy use as a proxy. While energy consumption alone does not account for all of the aspects of green house gas emissions, it is one of the major contributors of direct and indirect emissions. In an inventory of natural turf emissions, Townsend-Small and Czimczik (2010) find that the single greatest source of emissions is fuel use. For turf maintenance, fuel is used in transport, for mowing, and leaf blowing. Some of these emissions can be reduced by selecting electrically based machinery.

Grass grows quickly, and it must be mowed regularly to maintain optimal play quality. It is often assumed that such fields are cut on a weekly basis. Townsend-Small and Czimczik (2010) estimate that 2700 gallons of gasoline were used by the city of Irvine per month to maintain two million square meters of park area. The impacts associated with fuel use were greater than any other impact considered by about a factor of three or more.

Recycled Content

Products made from recycled content are generally preferable to those made from virgin material in two respects: 1) they do not draw on resources that may be limited; and 2) they address issues of waste. The crumb rubber used as infill in artificial turf fields is made from used tires. Recycled tires that were used in this capacity prevented an estimated 300 million pounds of ground rubber from scrap tires from ending up in landfills in 2007 (Rubber Manufacturers Association, 2009). It typically takes between 20,000 and 40,000 scrap tires to produce enough infill to cover a football field (City of Portland, 2008). The EPA's decree has afforded the opportunity for 4.5% of U.S. scrap tire to be applied as crumb rubber in sports surfacing in 2007 (Rubber Manufacturers Association, 2009).

Water

With over two-fifths of the world's population currently facing serious fresh water shortages, water scarcity is becoming an increasingly important issue. This figure is expected to get worse, as populations maintain growth, and glacier derived supplies continue to dwindle as a result of climate change. Water shortage has become the single greatest threat to food security, human health, and natural ecosystems (Seckler, 1999). In addition, irrigation not only requires the resource of water, but also needs energy to deliver it to the end user.

From a water standpoint, synthetic surfaces are advantageous over natural grass. Irrigation is a key component in maintaining natural turf. Artificial fields, on the other hand, do not usually require irrigation. Depending on their location and use, synthetic turfs may need to be watered down for cooling in hot temperatures, but the amount of water used for cooling is far less than that used to irrigate grass fields.

In addition to irrigation demands for water, a field's ability to take in storm water is another environmental consideration. There are several environmental problems associated with storm water runoff. In general, natural habitats are better able than impermeable surfaces to absorb storm water. However, synthetic turfs include drainage systems that compensate for their inability to take in water, while grass is poor at absorbing large quantities of water. Duble (1993) notes that runoff can vary greatly due to the seasonal distribution of rainfall. For a mean annual precipitation of 30 inches, runoff can be measured for the following amount at different locations: 3 inches in Nebraska, 6 inches in Tennessee, 12 inches in New York, and 22 inches in the Rockies. The resulting runoff that is created can lead to polluted ecosystems, as the flowing water picks up sediment, petroleum products, pesticides, fertilizers, bacteria, and metals. For example, in 2004, the water quality at San Francisco city beaches fell below quality standards 12 times in a single month, and storm water overflow contributed to over 40 closures during that year (Heal the Bay, 2004). This pollution, as well as other water capacity issues, such as flooding and the need for infrastructure, places stress on financial resources which may be lessened by a natural surface.

While natural turf may result in greater runoff than synthetic surfaces, they result in less aggregate waste water because they are able to absorb and use some of the precipitation. When viewed at a national level, the accumulated affects of water distribution and removal are not inconsequential. In aggregate, 3% of national energy, or a 56 billion kilowatt hours annually, goes to water deliverance and removal (EPRI 2002). This results in the release of approximately 45 million tons of greenhouse gas, when assuming the average mix of energy sources in the country (USEPA 2008). So, between the two field types there is a tradeoff of impacts: natural turfs may contribute to the problematic aspects associated with storm water runoff, while synthetic turfs play a role in issues regarding wastewater management.

Heat Island

One concern with synthetic turf is its role in the heat island effect - the increase of urban temperatures due to the replacement of vegetation with impervious surfaces that radiate heat. (New York City Department of Health and Mental Hygiene, 2008; Turfgrass Resource Center, 2008; Rosenzweig et al. 2006; New Yorkers for Parks, 2006). This effect occurs when heat from direct sunlight is absorbed by surfaces and then dissipated, raising ambient air temperatures. Urban heat island has an adverse impact on the environment because it increases the demand for cooling energy, intensifies air pollution—such as ground level ozone, and increases heat-related health problems (New York City Department of Health and Mental Hygiene, 2008; Rosenzweig et al. 2006; San Francisco Recreation and Park Department, 2008). Since synthetic turf has been shown to be hotter than the surrounding air and other surfaces (see Section 2.2: All-weather availability), it is a contributor to the heat island effect. However, the New York City Department of Health and Mental Hygiene (2008) notes that in New York, where summer temperatures can be about seven degrees higher than surrounding areas, synthetic turfs only make up a small portion of absorbent surfaces in the city, and therefore is not the primary culprit for this phenomenon.

2.8.2 Life Cycle Analysis

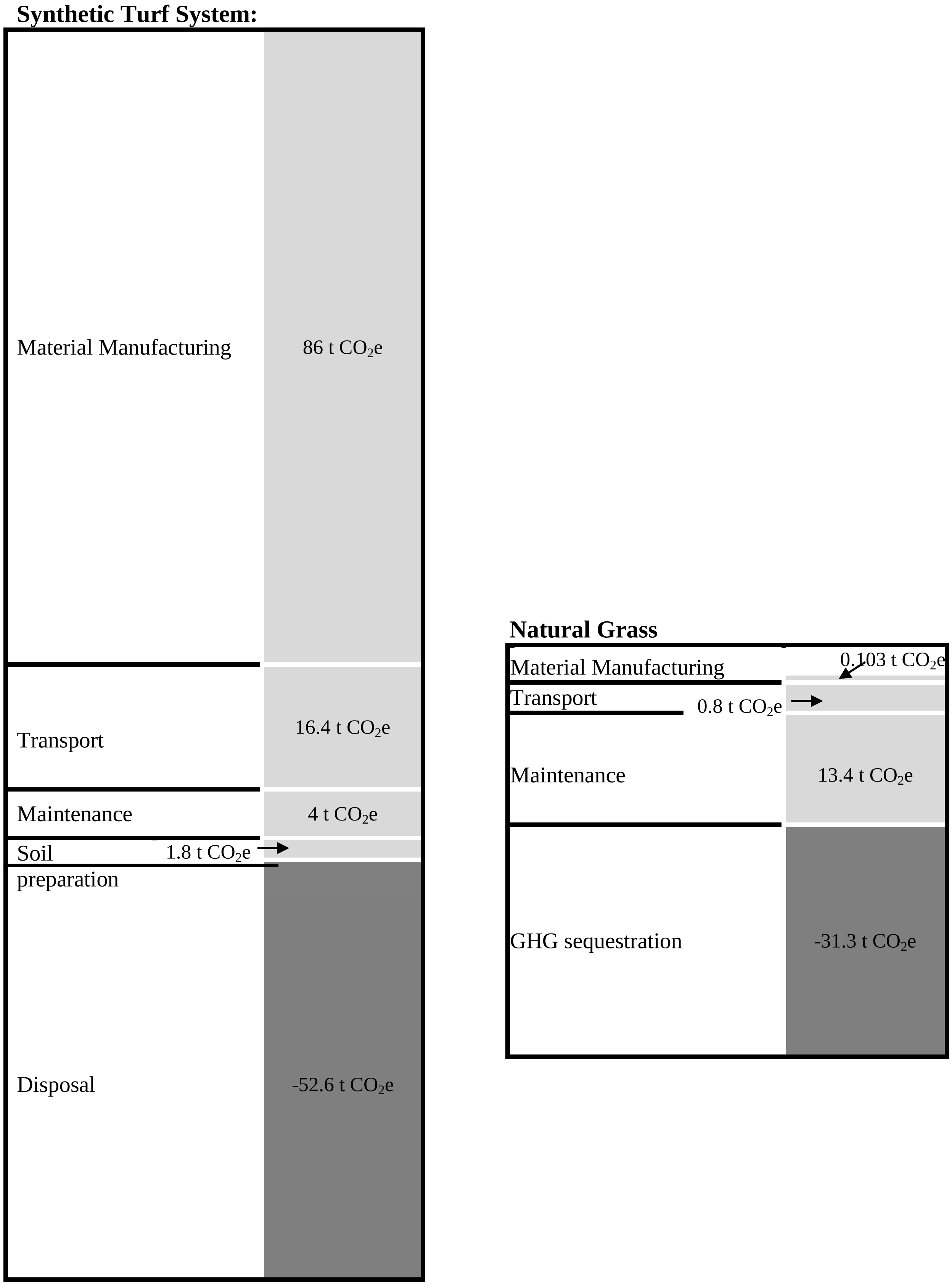
Various researchers have considered the emissions impact associated with turf systems, with much of this work focusing on calculating the capacity of natural grass to sequester carbon (Milesi, et al., 2005; Bandaranayake, et. al., 2003; Qian and Follett, 2002; Pouyat etal., 2009). Additional studies have investigated the N2O emissions of turfgrass (Guilbault and Matthias, 1998; Kaye et al., 2004; Bijoor et al., 2008; Hall et al., 2008). Townsend-Small and Czimczik (2010) note a lack of research investigating impacts of organic carbon storage and greenhouse gas (ghg) emissions. Additionally, studies exploring the emissions impacts of synthetic systems are lacking. One study by the Athena Institute (2007), a Canada-based nonprofit, compares the global warming impacts of natural and synthetic turf systems over the lifespan of the systems. This exploration of greenhouse gas inventories over the entirety of their life cycle will be utilized below to evaluate the emissions impacts of natural and synthetic turf systems. Given the scope of this study, our purpose here is not to conduct a comparative life-cycle analysis on turf systems, but rather, to provide some rough estimates of the comparative global warming impacts of natural and synthetic fields to see if we can clearly identify which field system has a lower impact.

The Athena Institute (2007) study considers the entire scope of the product's life-cycle by means of SimaPro 7 LCA Software (2006). Assessments take into account various aspects of a playing field's life-cycle, including: the manufacturing of system components; transportation; surface preparation; maintenance; and end of life considerations. Impacts were calculated using various databases in conjunction with the SimaPro 7 LCA Software, based on the location where impacts occurred. For instance, the primary backing material, "Thioback Pro," is made from substances manufactured in the Netherlands, and is evaluated using the prominent European Life Cycle Inventory database, EcoInvent Library v.1.2, to estimate associated emissions. The Franklin 98/01-update Life Cycle Inventory database from the SimaPro 7 LCA Software was also used in calculations.

The data for this research was gathered from a case study on the installation of a synthetic field in 2006 for Upper Canada College, a school serving elementary and secondary students. The size of the field being considered was nine thousand square meters, or approximately 96,875 square feet. Five pieces were identified in construction of synthetic turf fields: the turf itself, primary backing material, a secondary elastomeric coating, rubber granule infill, and PVC piping for drainage. Meanwhile, the only components determined for natural fields are seeds and sod. Transportation includes all emissions from supplier to installation. Maintenance levels for artificial turf systems are adopted from the FIFA (2001) Guide. These include the brushing and removal of debris and contaminants using equipment such as: drag brushes, mats, and nets, hand tools, high-pressure cleanser, and sweeping machines. In addition, watering is recommended as needed, as is the removal of any snow, weeds, algae, and moss. In contrast, the maintenance considered for grass was irrigation and cutting, although the specifics about the methodology, amount, and frequency were not explicitly stated. Lastly, it is assumed that at the end of the artificial turf's life, the system is recycled.

Figure 2.2 below shows a summary of the comparative impacts found by the Athena Institute. Following that is a discussion of their findings.

Figure 2.2: Athena Institute's Green House Gas Emissions Assessment for Field Turf Systems



Material Manufacturing & Transport

The Athena Institute considers the embodied energy for the components of natural and synthetic turf installations. In addition, transportation impacts for these components are calculated via the Upper Canada College case study.

For synthetic fields, the Athena Institute's calculations provide a good estimate for the impacts associated with the production of turf components. The parts that they considered were consistent with other descriptions of artificial turf systems. Also, evaluations for these impacts were conducted using widely accepted LCA software. At present, there is no other literature that considers the global warming impacts of synthetic turf systems. As such, it will be assumed that the Athena Institute's analysis of the impacts for manufacturing synthetic turf components has been adequately executed, and is equivalent to 86 t CO_2e.

For natural grass fields, meanwhile, the only components considered are the production of seeds and sod. The impacts of seed production have generally not been accounted for in research analyzing crop cultivation. This is especially true with urban fields. When evaluating the energy requirements of crop inputs, Moerschner and Gerowitt (2000) find that the effects of seed production are only a mere fraction of the total environmental impacts of fertilizer production. Flessa et al. (2002) cites the negligible contribution of seed production compared to the other agricultural product inputs as the reason for their exclusion in analysis. While attempts have not been made to account for the global warming emissions associated with seed production in grass fields, proposals for the inclusion of seed production have been made in the field of livestock production (Schils et al., 2007; Olesen et al., 2006), as well as in agricultural analysis in Europe (Weiske A., 2006; Kaltschmitt and Reinhardt, 1997).

It is unclear whether the entire scope of sod production is considered in the Athena Institute's analysis (i.e. whether the maintenance that goes into the production of sod is included). Much like seed production, there has been very little discussion of the emissions impacts associated with sod production. However, unlike seed production, the embodied global warming potential (gwp) of sod can be extrapolated from the maintenance requirements for grass fields. The next section will be dedicated to investigating whether Athena Institute's figure provides a good approximation based on some simplifying assumptions. First, to address their assessment, we must first explore the work of Townsend-Small and Czimczik (2010) for the data on the various maintenance impacts associated with natural grass turf.

In their study, Townsend-Small and Czimczik (2010) calculate the gwp of urban natural grass turfs, considering their organic carbon storage, direct N2O emissions, and the emissions associated with maintenance. The outcomes of these evaluations vary based on a number of factors, including: fertilization practices, soil moisture, temperature, and the existing soil organic carbon content. Their analysis of existing fields shows that the amount of organic carbon that is stored in natural grass fields is not enough to offset the direct and indirect emissions associated with the field. In fact, they found that in fields that absorb potential greenhouse gases, associated emissions are approximately three to four times greater. This is especially true in athletic fields, where it is assumed that turfs are installed with sod, instead of seeds--which is often used for ornamental fields. Based on this assumption, athletic fields offer no net sequestration of CO2. More specifically, the addition of transplanted sod results in the addition of organic carbon to the system. While the original soil where the sod was planted is capable of storing organic carbon, the soil on a field with transplanted sod can take up to three decades before it begins to store organic carbon. In addition, maintenance practices such as tilling, aeration, and the re-sodding of dead grass disrupt the storage of organic carbon. The estimates for this study are listed in the table below:

Table 2.8: Townsend-Small and Czimczik' (2010) gwp of Urban Natural Grass Turfs

Impact Considered	Description	GWP (g CO2/m2/yr)
Organic carbon storage	Estimates of the sequestration of organic carbon based on an analysis of physical samples.	513
N2O emissions	A measurement used to estimate some of the impacts of greenhouse gas emissions from turf soil.	45-145
Fuel	This figure includes the emissions associated with the actual fuel requirements to maintain the turf being sampled, totaling about 2x10 6 m2 of park area. The amount of fuel was estimated to be approximately 2700 gallons of gasoline per month. This fuel covers the transport, mowing, and leaf blowing for weekly trimmings and mulching. The global warming potential from this fuel use was then calculated using the EPA's (2005) estimates of 2421 g C for a gallon of gasoline, and Lal's (2004) assessment of combustion efficiency of 85%, which is similar to farm equipment.	1469
Water conveyance	The fields for this study were watered regularly, using recycled wastewater. Impacts associated with irrigation consider the energy required to pump water. Calculations are made using Schlesinger (1999) estimate of 53 g C/m2/yr for associated energy.	193
Fertilizer production	Fields are assumed to be fertilized from two to 15 times per year. Figures provided by Schlesinger (1999), of 1.436 moles of C per mole of N produced, were used in the calculation of embodied emissions associated with the production of fertilizers. The range of emissions impacts varies based on the number of fertilizations.	45-339
Total		**1752-2146**

We will use the data provided by Townsend-Small and Czimczik's (2010), together with Athena Institute's assessments, to make an approximation of what seed and sod production impacts should be. We begin by stating the assumptions used in our analysis. First, we assume that sod is grown for about a year before it is transplanted to a new field. Powell (1999) estimates that a sod crop can be harvested six months to two years after establishment. Next, we assume that, at the very least, sod requires irrigation to grow. If we assume that Athena Institute's measurements for the watering and cutting (i.e. the "maintenance") of a grass field are correct, then the emissions for growing sod should be at least one year's worth of the watering impacts (sod impacts should be higher than this figure, as there are additional maintenance requirements that have associated emissions). Townsend-Small and Czimczik's (2010) ratio of impacts from fuel and water conveyance are 1469:193 g CO2e/m^2/yr; or more simply put, the fuel related impacts are 7.6 times greater than those from watering. Then, if we apply this ratio to Athena Institute's maintenance associated emission of 13.4 t CO_2e, watering impacts should be 1.56 t CO_2e for 10 years. If, as stated, we assume that the average sod production period is one year, the rough estimate just proposed suggests that the calculation of 0.103 t CO_2e for seed and sod production might be a slight underestimate, when compared to one year of watering. This figure appears to be an even greater underestimate when considering that Athena Institute's estimate includes the impacts from seed production, and that sod is generally fertilized multiple times prior to being transplanted (Powell, 1999a). The apparent under-estimation of these impacts suggests that a more accurate estimate of emissions associated with seed and sod production should be investigated. However, in the scale of the natural turf's life cycle, the production stage emissions will always be dwarfed by the global warming potential of grass maintenance. Thus, research into more precise measurements of seed and sod production emissions will not be addressed within the scope of this paper, and will be left to future research.

Soil Preparation

Depending on the existing condition of a field, significant efforts might be required to excavate topsoil in preparation of turf installation. For the purpose of this report, it is assumed that emissions associated with excavation are significant, and that they should be incorporated into impact inventories. The Athena Institute's analysis includes impacts related to topsoil excavation. However, they do not explicitly outline what is considered in the accounting of these emissions. We speculate that these impacts are associated with the operation of machinery to dig up and haul away topsoil. This theory is supported by the fact that hauling-related emissions do not appear to be included with transport emissions, which are instead focused on the delivery of components to the location of installation. Therefore, having identified possible impacts related to the excavation of topsoil, which are not covered in other aspects of Athena Institute's evaluations, and without alternative assessments available from other research, we will assume that their calculations are an acceptable estimate for excavation related impacts. However, it should be noted that it might be possible to obtain a more accurate measurement from further investigation.

Maintenance

The maintenance requirements considered by the Athena Institute vary dramatically for the two turf types. The maintenance tasks for artificial turf were adopted from the FIFA (2001) guide. These include the brushing and removal of debris and contaminants using equipment such as: drag brushes, mats, nets, hand tools, high-pressure cleanser, and sweeping machines. In addition, watering is recommended as needed, as is the removal of any snow, weeds, algae, and moss. In aggregate, the emissions associated with these activities are 4 t CO_2e over ten years. In contrast, the maintenance considered for grass is irrigation and cutting. The emissions associated with these activities are 13.4 t CO_2e.

The Athena Institute does not state the underlying assumptions that were made in calculations of maintenance related emissions. It is therefore assumed that all of the various aspects relating to these activities were considered, and that calculations are as comprehensive as possible. For instance, evaluations can change based on factors such as: the frequency with which activities are carried out, the methodology used to accomplish a maintenance task, the quantity of materials applied, and the scope of the supply chain considered (i.e. transportation and embodied energy associated with any material used).

While far more maintenance activities are considered for synthetic fields, the global warming potential for the maintenance of natural fields is greater. The differences in these impacts are partially due to grass fields' continual need for additional supplies to sustain their health. Emissions related to the continual input of supplies accumulate over time. The findings of Townsend-Small and Czimczik (2010) show that much of the global warming impacts of grass maintenance are associated with fuel use. On the other hand, the maintenance of synthetic fields only generally requires a capital investment in equipment and labor to carry out tasks. It is customary in LCA research to exclude the impacts of labor. This means that any work done by hand on a field has no associated emissions.

To achieve a more comprehensive analysis, additional maintenance requirements should be considered, as per the maintenance related equipment and supplies identified in Section 2.4: Maintenance. Of particular interest are the additional impacts associated with the application of fertilizer to natural fields. However, it should be noted, that even with the additional consideration of these elements, the general finding by the Athena Institute will remain largely unchanged. That is, the maintenance impacts of natural turfs will be larger than those of synthetic turf, only to a greater degree. However, these impacts will still be much less than the material related emissions associated with the manufacturing of the components of synthetic turf. Any considerations of additional maintenance practices will result in greater emissions being associated with natural systems. This increase will result from the input of materials that are needed in greater quantities, and with greater frequency than for synthetic turfs.

Table 2.9 below lists the maintenance needs and materials identified by the Athena Institute, as well as additional recommendations obtained from the maintenance materials identified in Section 2.4.

Table 2.9: Maintenance Needs and Materials

	Synthetic	**Natural**
Activities Considered	Watering	Irrigation
	Brushing	Mowing
	High-Pressure Cleaning	
	Sweeping	
	Dragging	
Material Inputs Needed	Water	Water
		Fuel
Additional Recommended Input Considerations	Paint	Paint
	Top Dressing	Top Dressing
		Fertilizer

Green House Gas Sinks

Natural Grass

For natural grasses, the photosynthesis process involves the intake of carbon dioxide and results in carbon compounds that enter the soil with root growth or when a plant sheds or dies. These compounds can be stored long-term as soil organic carbon, as well as other soil organic matter. This is significant in the evaluation of global warming impacts because it results in a more permanent removal of carbon dioxide from the atmosphere. Also, in aggregate, the ability of turf to sequester carbon is not insignificant: in 2005, turfgrass covered approximately 1.9% of land in the continental U.S., making it the most widespread irrigated crop (Milesi et al., 2005). As such, any evaluation of the emissions of natural turfgrass should involve the most current and relevant measure that has been proposed for these impacts.

For the measurement of organic carbon storage, the Athena Institute uses the mean value of sequestration rates proposed by Qian and Follett's (2002) of between 0.9 and 1.0 tons of carbon per hectare per year. These estimates come from soil testing data on golf courses in Denver and Fort Collins, Colorado (Qian and Follett, 2002). Bandaranayake, et al., (2003) found similar sequestration rates when modeling organic carbon sequestration in various geographically-based scenarios. The average rate of accumulation over a 30 year period was found to be 1.2 and 0.9 t C/ha/yr for Fort Collins and Denver, respectively. As previously noted, the ability of soil to store organic carbon can be influenced by a multitude of factors. Post and Kwon (2002) showed this to be true in the case of soils that were previously disturbed, which were found to have a lower C sequestration rate of 0.33 t C/ha/yr. These studies indicate that the figure for organic carbon sequestration used by the Athena Institute may be a bit high for a newly installed field, but are acceptable for a life time analysis of the field.

However, one aspect that the Athena Institute neglects in their calculations is the direct ghg emissions that occur from natural grass. While research on the total impacts of greenhouse gases, including absorption and direct emissions, are somewhat nascent, several studies have looked into the N2O emissions of urban turfgrass. Considerations of these emissions do not measure the full impacts of the direct emissions from grasses. However, they do serve to account for some of the impacts of urban grass, and to illustrate the complexities involved in modeling their global warming impacts. Much like organic carbon storage, there are numerous factors that create variability in emissions rates. Several researchers have modeled annual fluxes of N_2O emissions based on their relationship to temperature, soil moisture, and soil organic carbon content (Scanlon and Kiely, 2003; Flechard et al., 2007). Spikes in N_2O emissions have been shown to occur in urban turfs after irrigation or fertilization of the field (Guilbault and Matthias, 1998; Kaye et al., 2004; Bijoor et al., 2008; Hall et al., 2008). Estimates of N_2O fluxes from urban turfs range between 0.05 to 0.6 g N per meters squared per year (Guilbault and Matthias, 1998; Kaye et al., 2004; Groffman et al., 2009; Townsend-Small and Czimczik, 2010). For our purposes, we will use the estimates provided by Townsend-Small and Czimczik for annual N2O emissions, which is the mean of 0.1 to 0.3 g N/m2/yr.

Recycling of Synthetic Turf at the End of Life

Calculations for the end of life of a synthetic turf are based on the assumption that all components, except the rubber granule infill, are 100% recyclable. Based on this assumption, an emissions credit is awarded by the Athena Institute for the end of life of the system. Calculations are made using ICF Consulting's (2005) report on the ghg emissions factor for plastic. The materials that are assumed to be recyclable in synthetic turf are: polyethylene from the turf and primary backing material; polyurethane from a secondary coating; and PVC piping.

The flaw in Athena Institute's estimates for the end of life emissions for synthetic fields is that materials may not be recycled just because they are capable of being recycled. In fact, the San Francisco Recreation and Park Department (2008) notes that the cost and a lack of infrastructure are an issue with the end-of-life recycling of artificial turf. They note that at the time of the report's publishing only one company in the industry recycled turf material. When turf is not recycled, a large amount of waste must be disposed of at the end of the field's useful life. According to the City of Larchmont, California, 400 tons of debris is created when an 80,000 sq. ft. field is replaced (San Francisco Recreation and Park Department, 2008). Given these concerns, the actual rate of recycling is highly questionable, suggesting that emissions credit should not be accounted for in synthetic turf systems.

2.8.3 Environmental Impact Conclusions

In general, the environmental impact of natural grass is more complex than those of synthetic turf. This is due in large part to the fact that natural grass requires the continual addition of inputs to sustain a field's health. As with any agricultural practice, draws on water and the addition of agrochemicals can become problematic. These practices draw on scarce resources and have the potential to effect surrounding ecosystems. Additionally, the maintenance of grass is associated with the use of large quantities of fuel, to mow grass to the appropriate length. The Athena Institute sufficiently shows the weight of these impacts in regards to global warming. However it is recommended that a more comprehensive inclusion of material inputs into grass maintenance be calculated in any future life cycle assessments.

The environmental issues related to synthetic turf mainly revolve around the use and disposal of materials. Many see the use of recycled waste products for field infill as one of the primary benefits of artificial systems. However, such systems also require the use of many virgin materials. As such, the greatest greenhouse gas emissions of either two system types are the impacts associated with the production of synthetic turf components. These material impacts increase the total emissions by a multiplicative factor when considering the entire life cycle, due to related increases in processing and transportation needs.

The validity of the greenhouse gas emissions sinks identified by the Athena Institute is in need of further consideration. It appears that the evaluations associated with these credits are either based on some faulty assumptions or do not take all considerations into account.

3.0 CONCLUSIONS

This report explored the various aspects of crumb rubber and addressed some of the claims made by various researchers. A look into the existing literature and data supported many of the assertions made about crumb rubber. Crumb rubber and synthetic turf have many traits that make it a beneficial choice for athletic surfaces. Some of the findings that were found indicated that synthetic turf has:

- **Excellent Playability** – Most literature comparing the play quality of natural and synthetic fields suggest that the differences between them have miniscule affects on playability in comparison with variance in the set-up of the field itself. Where differences do emerge, artificial turf appears to be equal to or better than natural turf, due to its greater consistency. While such findings are incomplete, because of the lack of studies that evaluate the newer generations of turf technology, there were no studies that contradicted the superiority of synthetic turf.

- **All-weather Availability** – Synthetic turf is praised for its availability in all weather conditions: more use per year, and a quick install. It can be used quickly after installation, usually within a few days, rather than the weeks it takes for a sod to become robust enough for use. Also, it can be used in snow, and in general is not affected by precipitation due to the drainage system involved. However, high heat can create an obstacle for synthetic turf use, as the surface can become uncomfortable to play on. Since there are means to temper such effects, the field can still be made useable. Also, the use of turfs are not typically greatest during the hottest parts of the year, as sports seasons typically fall in the late summer through the spring. These impairments do not compare to the degree to which natural fields are compromised during rain and snow. With all weather considered, artificial turf has greater availability over natural grass when taking weather into account.

- **Increased Playing Hours** – Studies suggest that average hours of playability in a three-season year for synthetic turfs range between 2,000 and 3,000 hours, with most research pointing toward 3,000 hours. Natural fields, on the other hand, provide far less playability, with studies estimating a range between 300 and 816 hours in a three-season year on average. Weather is an important factor in the reduction of use times for natural turf. Beyond the weather related losses in the capacity of grass fields, all natural fields must be given time to "rest" to allow for growth.

- **Reduced Maintenance** – The value of a field can be determined by its availability and by the amount of maintenance a field requires. Activities that can be classified as grooming are the most important components of maintenance for both turf types. In addition, debris control, additional cleaning, and needs-specific maintenance may be required. In general, natural fields require a more nuanced balance of activities such as mowing, fertilization, and aeration to ensure their health.

- **Cost-effective Investment** – synthetic turf fields are typically warranted for about 3,000 hours of play per year, with no "rest" required. For schools with sufficient land, it would take three or four natural fields to withstand the usage of one synthetic turf field. Because of its consistent availability, a synthetic turf field is also a reliable source of rental revenue for schools and communities. The study found that the total cost of ownership over a ten year period is 10% - 20% less than a natural turf field, while being 70% or even 80% less on a cost-per-use basis.

- **Generally Safe Application** – Extensive research has pointed to the conclusion that these fields result in little, if any, exposure to toxic substances. 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.

- **Fewer Injuries** – Numerous studies have been conducted assessing the likelihood of injury on natural grass and synthetic turf. A more recent study by Meyers (2010) shows that the latest generation of synthetic surface, FieldTurf, is safer to play on than natural grass fields. Through the analysis of the various injuries that occurred over the course of 465 collegiate games, Meyers shows that FieldTurf has lower incidence of: total injuries, minor injuries (0-6 days lost), substantial injuries (7-21days lost), and severe injuries (22 or more days lost). FieldTurf also had significantly lower injury rates that natural turf when comparing across play or event type, grade of injury, or various field conditions and temperatures. In addition, there was no significant difference found in head, knee, or shoulder trauma between the two playing surfaces.

- **Environmentally Friendly** – In general, the environmental impacts of natural grass are more complex than those of synthetic turf. This is due in large part to the fact that natural grass requires the continual addition of inputs to sustain a field's health. These practices draw on scarce resources and have the potential to effect surrounding ecosystems. Additionally, the maintenance of grass is associated with the use of large quantities of fuel, to mow grass to the appropriate length. The environmental issues related to synthetic turf mainly revolve around the use and disposal of materials. Many see the use of recycled waste products for field infill as one of the primary benefits of artificial systems. However, such systems also require the use of many virgin materials. As such, the greatest greenhouse gas emissions of either two system types are the impacts associated with the production of synthetic turf components. These material impacts increase the total emissions by a multiplicative factor when considering the entire life cycle, due to related increases in processing and transportation needs.

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May 26, 2015

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Re: Evaluation of Human Health Risks for Synthetic Field Turf

Dear Mr. Kosovich:

We are pleased to provide you with a screening level risk assessment and literature review related to the use of artificial turf fields at the former Woodway High School fields. As discussed in our proposed scope of work provided on May 13, 2015 this is a limited assessment that has focused on publically available data, supplemented in some cases by additional data provided by manufacturers. Our proposed scope of work originally specified that three different turf infills (FieldTurf SBR, GeoTurf, and NikeGrind) would be evaluated (in addition to our general review). Unfortunately, data from only the first two of the specific products were provided in time for inclusion in this report. However, we have evaluated some preliminary data for the NikeGrind product and its risk profile does not appear to be substantially different from the other products.

This evaluation is only intended to address potential risks from chemical exposures related to artificial turf products, and does not address ecological concerns, physical injuries, or heat stress. Our evaluation is intended to illustrate the current "state of the science" related to artificial turf infills. Where information was lacking we used the best information available to address data gaps and uncertainties.

In addition to providing the results of our risk assessment, we have provided an introduction to many of the concepts of toxicology, exposure evaluation, and risk assessment to help provide context for our work. Those sections, the results, and conclusions of our evaluation are provided below.

Based on the data publically available for this analysis, the chemical levels found in FieldTurf SBR and GeoTurf infill do not present a risk to people playing on or using the fields with these products. These conclusions are consistent with those of multiple regulatory agencies that have evaluated the risk from artificial turf products in general (*e.g.*, CalOEHHA, 2007; New York City Department of Health and Mental Hygiene, 2009; US EPA, 2009; Connecticut Dept. of Public Health, 2010; CalOEHHA, 2010), including evaluations that are more complex than this screening level assessment. Although there are limitations with a screening level risk assessment such as this one, the consistent conclusions from other evaluations that the data do not indicate an increased risk of health effects from chemical exposure lends additional support to our conclusion.

Introduction to Toxicology

Paracelsus, a founder of modern toxicology, was one of the first to understand that specific chemicals cause the toxic effects of a poison (EC, 2003). As such, toxicology is defined as "the study of how natural or man-made poisons cause undesirable effects in living organisms" (ATSDR, 2011). The degree to which a substance can cause damage is described as it's "toxicity", and the toxicity of a substance depends on several factors, including the amount (dose) entering the body, the route of entry into the body, and biological characteristics of the exposed individual (ATSDR, 2011; EC, 2003). These factors are critical to the study of toxicology, and are discussed in more detail below.

Dose

- The dose is the actual amount of a chemical that enters the body.
- Paracelsus postulated that the body's response to a poison was directly related to the dose received. He is best known for coining the phrase that is the fundamental assumption in toxicology, "All substances are poisons: there is none which is not a poison. The right dose differentiates a poison and a remedy." (Society of Toxicology, 2015).
  - Essentially, this means that all chemicals can be toxic and it is the amount taken into the body that determines whether or not they will cause poisonous effects. Therefore, toxicity is not caused solely by any exposure to a particular chemical, but by exposure to too much of it.
  - This concept is now referred to as the dose-response relationship, which correlates exposure and the spectrum of observable effects (EC, 2003).
- The amount of a substance that is necessary to elicit an effect can be established by measuring the response relative to an increasing dose using experimental animal, human clinical, or cellular studies (EC, 2003).
  - The dose level at which a toxic effect is first encountered is known as the threshold dose (ATSDR, 2011; EC, 2003). At doses below the threshold, the body can negate the substance's effects by detoxifying or repairing any injury. However, once these protective mechanisms are overwhelmed, the injury can no longer be prevented and the severity of the damage increases. Some regulatory agencies assume for substances that cause cancer there is no threshold (ATSDR, 2011); however, research has shown that thresholds may be dependent on how the carcinogen functions.
  - When looking at experimental data, the threshold is referred to as the lowest observable adverse effect level (LOAEL) and the dose below it in which there was no effect is referred to as the no observable adverse effect level (NOAEL) (EC, 2003). The NOAEL and the LOAEL are important doses used in risk assessment to develop health guideline levels.
  - The dose-response relationship can be visualized in Figure 1 below.

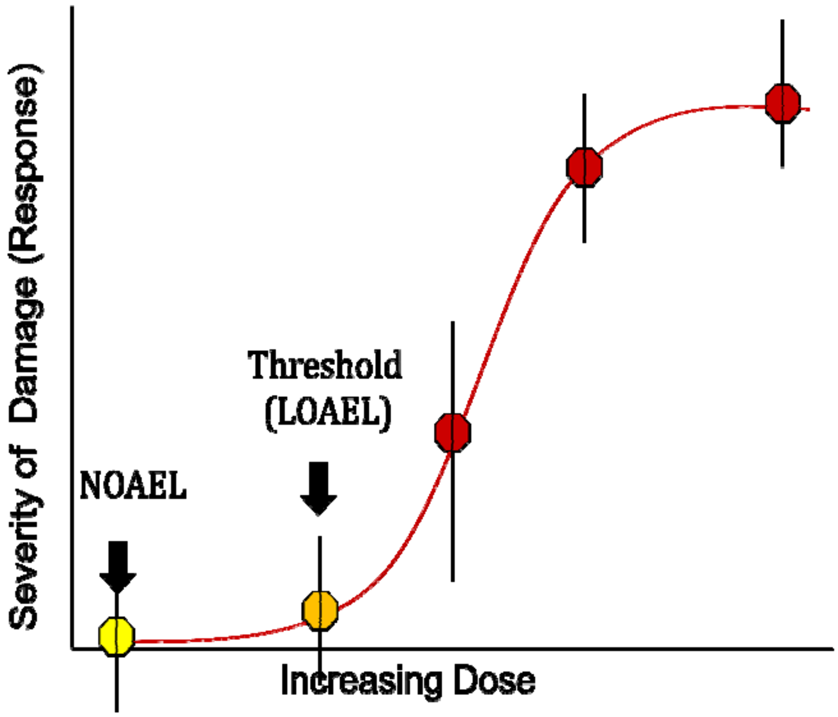

Figure 1 Dose-response Relationship. Circles indicate experimental observations, with the yellow circle indicating the dose at which no adverse effect was observed (NOAEL) and the orange circle indicating the threshold dose, also known as the lowest observable adverse effect level (LOAEL). Adapted from Lewandowski and Norman (2015).

- A real-world example of a substance that has an obvious dose-response relationship is aspirin. As shown in Figure 2, low doses of aspirin (~1-2 tablets) are recommended as a therapeutic dose as a prophylactic against heart disease and to alleviate headaches. However, once this threshold has been met, adverse effects occur, and the severity of effect increases with dose. For instance, ingesting 10 tablets may cause nausea while ingesting 100 tablets will cause death.

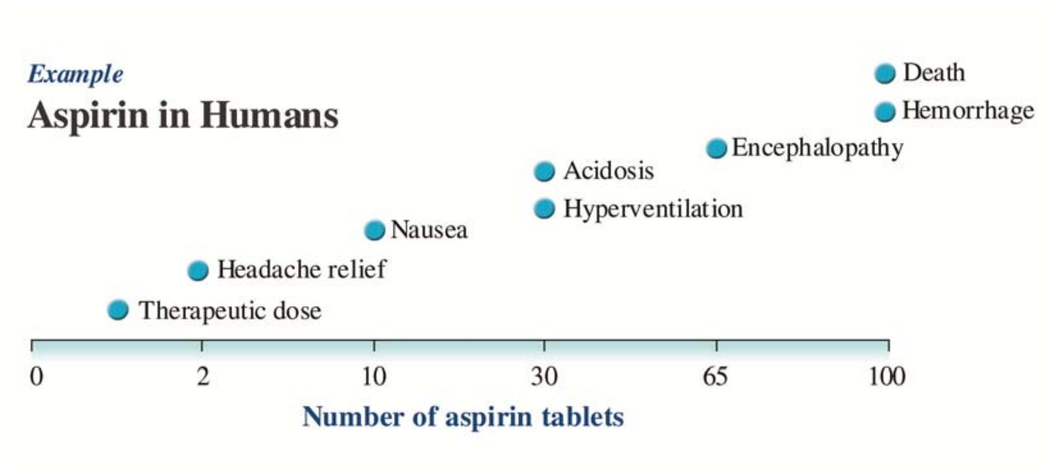

Figure 2. The Dose-Dependent Effects of Aspirin (based on information in Hardman *et al.*, 2001)

Exposure

- Chemicals need to first come into contact with the body before they can cause adverse effects (CCOHS, 2015). They then must reach the target site within the body (EC, 2003).
- There are two main factors that affect an individual's exposure to a substance: (1) the route of exposure; and (2) the frequency and duration of exposure (ATSDR, 2011, EC, 2003).
- Routes of exposure include oral (ingesting the substance), dermal (skin contact with the substance), or inhalation (breathing in the substance) (EC, 2003 215-4854).

Biological Characteristics

- Biological characteristics are factors specific to the individual exposed to the chemical. They include age, sex, diet, co-existence of infectious disease, and other genetic determinants (EC, 2003).
- These factors affect exposure and dose through modifying uptake, absorption, distribution and metabolism of the chemical, and in doing so, alter the response to the insult (EC, 2003). Susceptible populations may include babies, pregnant women, and the chronically ill, and the elderly.

Introduction to Risk Assessment

Risk assessment is the systematic evaluation of the likelihood of an adverse effect arising from exposure in a defined population. In the context of the risk assessment, risk is defined as the "probability of an adverse outcome based upon the exposure and potency of the hazardous agent(s)." (Faustman & Omenn, 2008). What this ultimately means is that without exposure and toxicity, there is no risk.

The risk assessment process contains both qualitative and quantitative components, as qualitative information (*i.e.,* the nature of the endpoints and hazards) is incorporated with a quantitative analysis (*i.e.*, assessment of the exposures, individual susceptibility factors, and the magnitude of the hazard) (Faustman & Omenn, 2008). The results of the risk assessment are used to facilitate risk management and guide the decision making process.

Standard Regulatory Risk Assessment

- The standard risk assessment framework has four key steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization (Faustman & Omenn, 2008).
    - Hazard identification involves assessing the toxicity of chemicals and examines whether a stressor has the potential to cause harm to humans systems, and if so, under what circumstances (US EPA, 2012a).
        - It ultimately answers the question: *Does the agent cause adverse health effects?*
    - Toxicity or dose-response assessment examines the numerical relationship between exposure and effects (US EPA, 2012a).
        - It answers the question: *What is the relationship between dose and response?*

- This step has two components: (1) an assessment of all of the available data and the selection of the critical adverse effect (*i.e.*, the significant adverse biological effect that occurs at the lowest exposure level, which depending on the data, is usually the LOAEL or the NOAEL) and (2) extrapolation to estimate the risk beyond the lower range of available observed data taking into account uncertainties in the data (such as variability, susceptibility, and quality of the data) (US EPA, 2012b).
  - The critical adverse effect is also known as the point of departure and the extrapolation to human-relevant doses is also known as calculating the reference dose (RfD). Mathematically:
    - RfD = point of departure / uncertainty factors
  - US EPA defines the RfD as, "An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime."

- Exposure assessment examines what is known about the frequency, timing, and levels of contact with a hazard (US EPA, 2012a).
  - It answers the question: *What types, levels, and duration of exposure are experienced or anticipated?*
  - This step involves determining the sources of exposure, route, and nature of the exposure followed by an estimation of exposure to the population of interest using standard calculations. For example, to determine if the artificial turf fields pose a health hazard, one would have to know the frequency, timing, and level of contact with the field. In addition, the concentration of potential contaminants in the field would have to be known, either *via* measured data or modeling estimations.
- Risk characterization evaluates how the data support the conclusions and the nature of the risk from the exposure at issue (US EPA, 2012a).
  - It answers the question: *What is the extra risk of health problems in the exposed population?*
  - The primary quantitative steps in the risk characterization are the calculation of the hazard index (HI) and cancer risk. These values are compared to "acceptable" risk levels published by regulatory agencies (in general, for non-carcinogens, an HI < 1 is acceptable, and for carcinogens a cancer risk less than 1 in a million is acceptable).
  - Depending on the results of the quantitative assessment, the risk characterization may provide additional detail on the toxicity of the chemicals involved, including comparison of exposure to health effects levels (as opposed to RfDs or guideline levels).
  - In addition, the risk characterization usually contains a discussion of uncertainty and the overall conclusions of the assessment.

Screening Risk Assessment

In some cases, a screening level risk assessment is conducted prior to a standard risk assessment as a means of determining whether a standard risk assessment is necessary. Screening risk assessments use a variety of conservative (*i.e.*, health protective) assumptions in an attempt to insure that health risks are not underestimated. In other words, risks calculated in screening risk assessment are most likely overestimated. The result of this practice is that if the calculated risks in a screening risk assessment are within acceptable parameters, the risk assessor can be fairly certain that exposure to the chemical in question does not pose a health risk.

- In a screening level risk assessment, hazard identification usually is already completed to some extent, and analytical data is available for the evaluation
- The toxicity assessment is simplified by using screening guideline values that have already been published by various governmental or regulatory agencies. These health effect guideline values are not in units of dose (as is typical for a standard risk assessment), but are in units of the exposure medium (*e.g.*, soil, water, air) to allow for simple comparisons to environmental sampling data.
- Instead of conducting a detailed exposure assessment, simplified assumptions are used in the calculation of the screening guideline values described in the toxicity assessment. For instance, US EPA uses a standard body weight of 70 kg (154 lbs) and a water consumption rate of 2 L (0.53 gallons) to convert a US EPA RfD into a screening level that can be compared to a chemical's concentration in water.
- The risk characterization portion of a screening risk assessment contains many of the similar components as a standard risk assessment. Concentrations that exceed health guideline values are discussed and evaluated, and sources of uncertainty and/or variability in the evaluation are detailed.
- Example: Screening Risk Assessment for Chlorine Gas At a Public Pool
  - Users of a local pool have been concerned about the chlorine odor at the pool, and wonder if their exposure might put them at risk for health effects.
  - A local environmental consulting company has been to the pool, and collected several air samples and sent them to a laboratory for analysis. The maximum air concentration reported by the laboratory was 0.003 $\mu g/m^3$.
  - The US EPA residential screening level (RSL) for chlorine gas is 0.015 $\mu g/m^3$.
  - As the maximum concentration at the pool is significantly less (5-fold) than the screening level, there is no expectation of risk to the pool users.
  - If the maximum concentration had instead been 0.018 $\mu g/m^3$ (above the RSL), that does not necessarily indicate there is a health risk due to the conservative nature of the RSL. In this situation, a risk assessor would evaluate how the RSL was derived, the uncertainty factors involved, the critical effect, the population exposed, and any number of other factors and determine if further investigation (*e.g.*, a standard risk assessment) was warranted.

Artificial Turf Risk Assessment

In order to evaluate the possible risk from exposure to chemicals in the two types of artificial turf products (as well as to artificial turf products in general), a screening risk assessment was conducted in addition to a review of the literature relevant to these products. This review was extensive, but should not be considered exhaustive due to the voluminous database and limited time available.

The exposure scenarios of interest include children, adolescents, or adults playing on the surface or watching from nearby. Thus several different screening guidelines that are protective of ingestion, inhalation, and dermal contact were selected for this evaluation. Chemical concentrations in samples of artificial turf products were compared to US EPA RSL residential soil guidelines (US EPA, 2015), concentrations of chemicals detected in ambient air above artificial turf products were compared to US EPA RSL residential air guidelines, and concentrations detected using product leaching protocols were compared to health based groundwater protection standards (NJDEP, 2013).

These guidelines should be considered to be conservative (*e.g.*, health protective) for assessment of a product such as artificial turf. For example, the soil and air RSL guidelines are intended to be protective of people (including sensitive subpopulations and children) exposed to chemicals 365 days per year for a lifetime. For soil, these guidelines assume dermal contact with the soil, inhalation of soil dust, and ingestion of soil particles.

Considerations

Screening level risk assessments are intended to be simplified exercises to determine if the possible risks related to an exposure are significant enough to warrant further investigation. In many cases, as mentioned above, exceeding a screening guideline does not necessarily indicate that a risk is likely. This is particularly true for a product based risk assessment, such as for artificial turf products. Several important considerations are detailed below.

- A significant volume of literature was evaluated to identify metal and organic chemical concentrations in artificial turf products, in the ambient air above those products, and in leachate from those products. The data collected can be found in Appendix A. However, the limited time frame for compilation of these data indicate that this literature search should be considered extensive, but not exhaustive.
- The data collected range in date from 2008 to 2014. There are many different types of products involved, from multiple manufacturers. As two of the products of considerable interest to the Verdant Health Commission were FieldTurf SBR and GeoTurf, we have limited our summary tables in this report to data from those two products. In addition, due to the reformulation of many products due to issues related to lead in 2008, we have focused on data that have been produced since 2010. The other data evaluated are in the appendices, and will be discussed qualitatively.
- As discussed briefly above, the soil and air RSL guidelines are intended for use at residential sites where exposure occurs from a variety of pathways over a lifetime. In addition, these guidelines assume that exposure is through the media of interest—namely, soil or air. The bioavailability[1] of these chemicals from artificial turf products appears to be substantially different than from soil and possibly air. Studies that have evaluated the bioavailability of chemicals from artificial turf have noted that there is likely to be limited availability from this substance (Pavilonis *et al.*, 2014; van Rooij and Jongeneelen, 2010; CalOEEHA 2007; US EPA, 2009).

[1] The bioavailability of a substance is a measure of how much is absorbed *via* a particular route of exposure. For instance, when arsenic is ingested in soil, only about 60% of the total ingested is absorbed.

Table 1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical	Residential Screening Level, HQ = 0.1 (mg/kg)	Washington State/ Seattle Area Background Levels (90th Percentile or Range)	Curtis & Tompkins (2011) for Limonta Sport USA[1]		Teter Engineering (2015) for Sprinturf[2]					
			Limonta Infill-Pro Geo (mg/kg)	Limonta Turf-Max-S (mg/kg)	FieldTurf Ambient Crumb Rubber (Curtis & Tompkins, 2013b) (mg/kg)	FieldTurf Cryogenic Crumb Rubber (Curtis & Tompkins, 2013b) (mg/kg)	FieldTurf Crumb Rubber (2 Years of Age) (Lioy and Weisel, 2011) (mg/kg)	FieldTurf Crumb Rubber (2 Years of Age) (Lioy and Weisel, 2012) (mg/kg)	FieldTurf SBR (TestAmerica, 2011a) (mg/kg)	FieldTurf SBR (TestAmerica, 2011b) (mg/kg)
Metals										
Antimony	3.1	NI	ND	ND	3.7	3.4	NA	NA		
Cobalt	2.3	NA	ND	ND	130	120	NA	NA		
Thallium	0.078	NA	0.9	ND	< 0.74	< 0.8	NA	NA		
Zinc	2,300	85	11	45	16,000	13,000	NA	NA		
SVOCs and VOCs										
Benzo(a)anthracene	0.15	0.0016-6.0							< 9.7	< 62
Benzo(a)pyrene	0.015	0.0017-6.7							< 9.7	< 62
Benzo(b)fluoranthene	0.15	0.0032-7.3							< 9.7	< 62
Benzo(k)fluoranthene	1.5	0.0013-2.0							< 9.7	< 62
Bis(2-ethylhexyl)phthalate	38								90	160

Notes:
HQ = Hazard Quotient; SBR = Styrene butadiene rubber; SVOC = Semivolatile Organic Compound; VOC = Volatile Organic Compound.
(1) Data from Curtis & Tompkins (2011, pp. 5-6).
(2) Data from Teter Engineering (2015, Appendix Table A-1, A-3). Note that the values from Table A-3 were converted to mg/kg for comparison across studies.
NA = Not Analyzed; ND = Not detected; NI = Not identified.
Highlighted cells are those with values above their respective Residential Screening Levels.
Data was not reported for blank cells.

Table 2 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Guideline Level (µg/L)	Curtis & Tompkins (2011) for Limonta Sport USA[1]		Teter Engineering (2015) for Sprinturf[2]				
		Limonta Infill-Pro Geo (µg/L)	Limonta Turf-Max-S (µg/L)	FieldTurf-SPLP Cryogenic Crumb Rubber (A-1007/T12) (Li *et al.*, 2010a) (µg/L)	FieldTurf-SPLP Ambient Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf-SPLP Cryogenic Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf-WET SBR (TestAmerica, 2011a) (µg/L)	FieldTurf-WET SBR (TestAmerica, 2011b) (µg/L)
Metals								
Aluminum	4,000							
Antimony	120	ND	ND	NA	< 1	< 1	< 200	< 200
Arsenic	3	ND	ND	< 3.0	< 1.2	< 1.2	< 200	< 200
Barium	120,000	430	ND	13	2.8	< 1	220	< 200
Beryllium	20	ND	ND	NA	< 4.3	< 4.3	< 80	< 80
Cadmium	80	ND	ND	< 1	< 1.3	< 1.3	< 100	< 100
Cobalt	2,000	ND	ND	NA	1.1	2.4	< 200	< 200
Copper	26,000	ND	ND	0.69	< 1	9.7	880	310
Lead	100	ND	ND	0.19	< 1	< 1	< 100	< 100
Manganese	1,000							
Mercury	40	ND	ND	NA	< 0.2	< 0.2	< 2	< 2
Nickel	2,000 (soluble salts)	ND	ND	0.65	< 3.0	< 3.0	< 200	< 200
Selenium	800	ND	ND	NA	< 1	< 1	< 200	< 200
Silver	800	ND	ND	NA	< 1	< 1	< 200	< 200
Thallium	10	ND	ND	NA	< 1	< 1	< 200	< 200
Vanadium	2	ND	ND	NA	< 1.1	< 1.1	< 200	< 200
Zinc	40,000	ND	ND	2,450	240	870	15,000	5,900

Notes:
NA = Not analyzed; ND = Not detected; SBR = Styrene butadiene rubber; SPLP = Synthetic precipitation leachate procedure.
(1) Data from Curtis & Tompkins (2011, pp. 13-14).
(2) Data from Table A-2 and A-4.
Data was not reported for blank cells.

Chemical Characteristics of SBR Infill

The substances that exceeded a screening guideline in at least one artificial turf product sample (using the selection criteria discussed above) are presented in Tables 1 and 2. In addition, the Washington State soil background concentrations of these substances are also presented. The implications of these exceedances are discussed below.

- Of the 55 chemicals tested in the soil analyses, 51 (93%) were below their respective screening guidelines.
- In every case except one, the exceedances are less than an order of magnitude (10-fold). Given the conservative nature of these RSL guidelines, it is unlikely that these exceedances are significant in terms of excess risk.
- In addition to the less than 10-fold exceedances, as mentioned above these chemicals are all embedded in a matrix that multiple studies (Pavilonis *et al.*, 2014; van Rooij and Jongeneelen, 2010; CalOEEHA, 2007; US EPA, 2009) have deemed renders them less bioavailable when ingested or exposed dermally.
- The one exceedance that is greater than an order of magnitude is for cobalt. As noted previously, the use of conservative screening guidelines as well as the lack of bioavailability of this metal from the SBR make any adverse health effects unlikely. In addition, the toxicity value used to derive the cobalt RSL is called a "Provisional Peer-Reviewed Toxicity Value" (PPRTV). These are secondary toxicity values used when US EPA has not derived a value using the standard process. The PPRTV for cobalt is based on a 2 week human study that saw decreased iodine uptake in the thyroid, which was then reduced by a factor of 3,000 to address limited data. The US EPA rates the confidence in this value as "low." Based on this evaluation, the likelihood of cobalt exposure from artificial turf products constituting a health threat is low.
- Data from the recent studies of FieldTurf SBR do not show detectable levels of PAHs (see Table 1); however, the limit of detection in these samples is higher than the RSL guidelines. Samples from older studies of FieldTurf SBR have detected PAHs in the product (see Appendix A). The levels detected are similar to those seen in normal Seattle residential area soils (see Table 1; WDOE, 2011).
- Leaching data (Table 2) from FieldTurf SBR indicate that no applicable screening guidelines were exceeded (60 of 60 passed).

Chemical Characteristics of GeoTurf Infill

As with the FieldTurf SBR results, the levels of compounds found in GeoTurf are presented in Tables 1 and 2. Several important considerations are detailed below.

- Of the 17 chemicals tested in the soil analyses, 16 (94%) were below their respective screening guidelines.
- Only one compound in GeoTurf exceeded a US EPA RSL—thallium. This compound exceeded its RSL by over an order of magnitude. As with cobalt, the toxicity value used to derive thallium's RSL is a PPRTV. The basis for the RSL is hair follicle atrophy observed in a rat study, which was considered to be similar to effects observed in humans. The observed dose was

adjusted by a 3,000 fold to address limited data. Based on this evaluation, the likelihood of thallium exposure from artificial turf products constituting a health threat is low.

- There is a significant uncertainty in the evaluation of GeoTurf infill due to the lack of analytical data comparable to SBR studies. No literature data were found that evaluated any organic compounds or pesticides which might be applied to natural products. Additional data related to this was requested from the manufacturer.
- Leaching data (Table 2) from GeoTurf indicate that no applicable screening guidelines were exceeded (18 of 18 passed).

Overall Evaluation of Two Types of Infills

Based on the data publically available for this analysis, the chemical levels found in FieldTurf SBR and GeoTurf infill do not present a risk to people playing on or using the fields with these products. In addition, for the PAH data available for SBR products, these products do not present a substantially different risk profile than playing in soil in the Seattle area.

Some concern has been expressed regarding the possible carcinogenicity of SBR, either from the PAH and metal content (which do not appear to be substantially elevated or bioavailable), or from other unknown chemicals. Several studies have evaluated the *in vitro* genotoxicity or mutagenicity[2] of actual SBR and have uniformly found that the substance tested negative or the results were comparable with urban sites in general (Birkholz *et al*., 2003; Schiliro *et al*., 2013).

Uncertainty Analysis

As with any scientific endeavor, there are a variety of sources of uncertainty in this analysis. Most of that uncertainty is related to the quality of the data that were identified for our screening risk assessment. Those issues are addressed specifically below.

Data Quality

- The air data available for this evaluation were inadequate to conduct an appropriate analysis of the risk from inhaling possible VOCs off-gassing from turf material or particulates associated with the FieldTurf SBR or GeoTurf infills. The studies of other SBR products that did conduct appropriate analyses found similar concentrations of chemicals upwind and downwind, however, which is supportive of minimal emissions from the turf surfaces. Thus, although a product specific analysis was not possible, a number of studies of other SBR surfaces indicate that chemical and particulate concentration above the fields are unlikely to pose a health risk.
- The available data support that over time and across brands there is variability in the chemical composition of SBR. Data were not available related to multiple batches of GeoTurf. As noted in previous reviews, this variability adds a source of uncertainty into the analysis. However, in general, even with this uncertainty the levels of chemicals found in SBR over the years have not been found to present an unacceptable risk by multiple regulatory agencies.
- There was a lack of data from GeoTurf for many of the chemicals evaluated for SBR. These include standard VOCs and SVOCs, as well as pesticides, which could be significant depending

[2] In toxicology, *in vitro* (test tube) tests are often used to screen chemicals to determine if they might have cancer-causing potential.

on where the coconut and cork components of the GeoTurf products are sourced. The impact of this uncertainty on the analysis cannot be determined without additional analytical data.

- For each of the products, much of the composition data available has been determined by standard analytical methods. In some cases, there may be chemicals inherent in the base materials that have not been disclosed, or of which manufacturers are unaware. The impact of this uncertainty on the analysis cannot be determined without additional data on the source and composition of the base materials. However, in general it appears that the analytical methods chosen in each study are reasonable considering the origin of the product (*i.e.*, it is reasonable to assume that recycled tires would contain metals, VOCs, SVOCs, *etc.*).

Carbon Nanotubes

- Carbon nanotubes are nanoparticles that may be used in tires, as well as many other products. There are many different types of nanotubes, with different physical and chemical characteristics. The toxicity of carbon nanotubes has been the subject of intense research over the last decade, with hundreds of studies being published on many different types of these materials (*e.g.*, Manke *et al*., 2013; Kuempel *et al*., 2012).
- Toxicity studies of carbon nanotubes have reported a wide range of toxicity depending on the structure of the nanotube, the nature of the test system (*e.g.*, *in vitro*, animal), and type of effect (for example, see Grosse *et al*., 2014; Manke *et al*., 2013; Kuempel *et al*., 2012). The International Agency for Research on Cancer (IARC) has reviewed the toxicity of three different types of nanotubes; they found possible evidence of carcinogenicity for one specific type, but the data were not sufficient to classify the other two types they evaluated (Grosse *et al*., 2014).
- Evaluating the risk from exposure to carbon nanotubes that may be present in artificial turf products is complicated by a number of factors. These include the lack of any information about concentration or type of nanotube in the source material, the lack of information on any transformation that may occur during manufacture of the tires, and the lack of information about the rate of release of the native nanotube *versus* an aggregated or agglomerated nanotube from the artificial turf product.
- Even if the nature of the native nanotubes used to manufacture the tires used for SBR was known, it is likely that these nanotubes would undergo agglomeration or aggregation during the manufacturing process. In addition, they are embedded or encapsulated within the tire rubber. Thus, it is uncertain if the material that would be released from an artificial turf product such as SBR would resemble the original material or not. Studies of nanoparticle release from composites (Nowack *et al*., 2013; Froggett *et al*., 2014) and other products generally have found that most of the material released from the product is larger particles, with any nanomaterials imbedded within a matrix which would presumably limit their bioreactivity.
- For the reasons discussed above, the impact of the uncertainties surrounding the possible addition of carbon nanotubes to tires on our analysis cannot be determined. However, based on the research conducted to date, it appears that nanotubes would not be released in their "original" chemical state, and would be weathered/eroded into chemically and/or physically different structures.

Carbon Black

- Carbon black is a powdered form of elemental carbon, which has a number of uses in consumer products. One of its most common uses is as reinforcing agent in rubber, including tires, but it is also used in pigments for inks, paints, plastics, and coatings. Depending on the manufacturing process, carbon black may have particle sizes ranging from nanometers to micrometers.
- As with carbon nanotubes, the chemical characteristics of carbon black particles that are used to manufacture tires may not be the same characteristics as particles that may be produced as tire particles wear. Carbon black particles are expected to agglomerate and aggregate, and are embedded in the rubber matrix of tire crumb until there are released by wear and abrasion.
- The toxicity of carbon black has primarily been informed by studies of carbon black workers, with high exposure levels unlikely to be relevant to artificial turf users. In relation to non-cancer effects, carbon black workers exposed to these high levels generally were subject to relatively minor respiratory tract symptoms such as cough, and bronchitis. These effects were similar to effects seen in workers exposed to other relatively inert dusts.
- Given that the levels of particulate matter (which would include levels of carbon black) detected above artificial turf fields has been found to be low and consistently below general particulate matter guideline levels, it is relatively certain that carbon black exposures at artificial turf fields would be substantially lower than in worker populations.
- The International Agency for Research on Cancer has labeled carbon black as a possible human carcinogen (Group 2B), based primarily on epidemiology data from the worker populations discussed above. While this is a source of some uncertainty in our analysis, it is unlikely that the type of carbon black released from artificial turf products is similar to that which workers were exposed to, and the exposure levels would be expected to be much lower.

Potential Allergic Reactions

- Most reviews of possible health effects from exposure to artificial turf projects focus on systemic or organ-specific effects of exposure to chemicals. However, there is also the possibility for allergic responses to the chemicals in these substances. These include possible sensitization to metals, as well possible reactions to organic chemicals or biological proteins. Two organizations (Norwegian Institute of Public Health, 2006, CalOEHHA, 2010) did evaluate exposure to components of SBR and found no evidence that exposure to SBR (either metals or latex) resulted in allergic reactions. In the case of GeoTurf, some portion of the population may have an allergic response to coconut and/or cork; cases of occupational sensitization to coconut fibers and occupational asthma from cork dust have also been documented (Deschamps *et al*., 2003; Stutius *et al*., 2010; Winck *et al*., 2002 ; Winck *et al*., 2004; Wittczak *et al*., 2005). As noted with carbon black, it is unlikely that the levels of coconut fibers and/or cork dust about GeoTurf fields would approach those found in occupational settings. However, there are no sampling data available to determine if this is actually the case (as opposed to data with FieldTurf infills). This is not likely a source of significant uncertainty in our evaluation, but as no rigorous allergy testing or environmental sampling of GeoTurf has been conducted it should be considered.

Review of Regulatory Agency (and Other) Evaluations of Artificial Turf

Over the last eight years, numerous US regulatory and other governmental agencies have evaluated the potential health risks involved with exposure to chemicals associated with artificial turf fields. The focus of almost all of these evaluations has been the potential toxicity of chemicals associated with SBR. Each of these reports have limitations based on the methodology used and data available for their analysis. However, in cases where these reports conducted quantitative risk assessments, they without exception concluded that the data support that use of these fields is safe. A summary of these analyses can be found in Appendix B.

Conclusions

Based on the data publically available for this analysis, the chemical levels found in FieldTurf SBR and GeoTurf infill do not present a risk to people playing on or using the fields with these products. These conclusions are consistent with those of multiple regulatory agencies that have evaluated the risk from artificial turf products in general (*e.g.*, CalOEHHA, 2007; New York City Department of Health and Mental Hygiene, 2009; US EPA, 2009; Connecticut Dept. of Public Health, 2010; CalOEHHA, 2010), including evaluations that are more complex than this screening level assessment. Although there are limitations with a screening level risk assessment such as this one, the consistent conclusion that the data do not indicate an increased risk of health effects from chemical exposure lends additional support to our conclusion.

We appreciate the opportunity to work with Verdant Health Commission on this project. If you have any questions or comments on our evaluation, please do not hesitate to contact us.

Sincerely,

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Appendix A

Data Tables

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical	Residential Screening Level (mg/kg)	Washington State/Seattle Area Background Levels (90th Percentile)	Curtis & Tompkins (2011 215-4632) for Limonta Sport USA[1]		Teter Engineering (2015 215-4633) for Sprinturf[2]		US EPA (2009 210-1256)[3]					
			Limonta Infill-Pro Geo (mg/kg)	Limonta Turf - Max-S (mg/kg)	Green Crumb Rubber (mg/kg)	Black Crumb Rubber (mg/kg)	Turf Field Infill Crumb Rubber - F1D1 (Range, mg/kg)	Turf Field Infill Crumb Rubber - F2, F3 (Range, mg/kg)	Turf Field Infill Crumb Rubber - F4, F5, F6 (Range, mg/kg)	Turf Field Blades- F1D1 (Range, mg/kg)	Turf Field Blades - F2, F3 (Range, mg/kg)	Turf Field Blades - F4, F5, F6 (Range, mg/kg)
Metals												
Antimony	3.1	NI	ND	ND	4.6	4.1						
Arsenic	0.67	7	0.48	ND	<0.24	<0.23						
Barium	1500	NI	10	0.48	4.5	5.8						
Beryllium	16	0.6	ND	ND	<0.097	<0.093						
Cadmium	7	1	ND	ND	0.54	0.53						
Chromium	12000	48	ND	ND	<0.41/2.7[1]	<0.41/1.7[1]	0.3-1.0	0.4-0.9	0.3-1.0	1.0-73.1	1.2-1.9	3.7-177
Cobalt	2.3	NI	ND	ND	120	120						
Copper	310	36	4.3	4.2	30	27						
Lead	400	24	ND	ND	21	26	13.1-34.7	20.6-61.2	10.7-47.7	2.8-389	2.4-2.8	2.1-701
Magnesium	NI	NI										
Mercury	2.3	0.07	ND	ND	<0.017	<0.015						
Molybdenum	39	NI	0.29	0.25	0.63	0.72						
Nickel	150	48	0.38	0.95	2.2	1.9						
Selenium	39	NI	ND	ND	<0.49	<0.46						
Silver	39	NI	ND	ND	<0.24	<0.23						
Thallium	0.078	NI	0.9	ND	<0.49	<0.46						
Titanium	14000	NI										
Vandium	NI	NI	0.77	ND	1.3	0.84						
Zinc	2300	85	11	45	14000	14000	5050-19200	3120-12300	2660-11400	316-730	199-255	131-206
SVOCs and VOCs												
1,2-Dichlorobenzene	180											
1,2,4-Trichlorobenzene	5.8											
1,3-Dichlorobenzene	NI											
1,4-Dichlorobenzene	2.6											
2-Chlorophenol	39											
2,4-Dichlorophenol	18											
2,4-Dimethylphenol	120											
2,4-Dinitrophenol	12											
2,4-Dinitrotoluene	1.7											
2,4,5-Trichlorophenol	620											
2,4,6-Trichlorophenol	6.2											
3,3'-Dichlorobenzidine	1.2											
Acenaphthene	350				<0.25	<0.49						
Acenapthylene	NI				<0.25	<0.49						
Aniline	43											
Anthracene	1700				<0.25	<0.49						
Azobenzene	5.6											
Benzo(a)anthracene	0.15				0.85	1.7						
Benzo(a)pyrene	0.015				0.95	2.1						
Benzo(b)fluoranthene	0.15				0.99	2						
Benzo(g, h, i)perylene	NI				3.6	10						
Benzo(k)fluoranthene	1.5				<0.25	0.54						
Benzoic acid	25000											
Bis(2-chloroethyl)ether	0.23											

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical	Residential Screening Level (mg/kg)	Washington State/Seattle Area Background Levels (90th Percentile)	Curtis & Tompkins (2011 215-4632) for Limonta Sport USA[1]		Teter Engineering (2015 215-4633) for Sprinturf[2]		US EPA (2009 210-1256)[3]					
			Limonta Infill-Pro Geo (mg/kg)	Limonta Turf - Max-S (mg/kg)	Green Crumb Rubber (mg/kg)	Black Crumb Rubber (mg/kg)	Turf Field Infill Crumb Rubber - F1D1 (Range, mg/kg)	Turf Field Infill Crumb Rubber - F2, F3 (Range, mg/kg)	Turf Field Infill Crumb Rubber - F4, F5, F6 (Range, mg/kg)	Turf Field Blades- F1D1 (Range, mg/kg)	Turf Field Blades - F2, F3 (Range, mg/kg)	Turf Field Blades - F4, F5, F6 (Range, mg/kg)
Bis(2-chloroisopropyl)ether	NI											
Bis(2-ethylhexyl)phthalate	38											
Butylbenzyl phthalate	280											
Carbazole	NI											
Chrysene	15				2.3	4.9						
Di-n-butylphthalate	620											
Di-n-octylphthalate	62											
Dibenz(a,h)anthracene	0.015				<0.25	0.52						
Diethyl phthalate	4900											
Dimethylphthalate	NI											
Diphenylamine	150											
Fluoranthene	230				3	60						
Fluorene	230				<0.25	<0.49						
Hexachlorobenzene	0.33											
Hexachlorobutadiene	6.2											
Indeno(1,2,3-cd)pyrene	0.15				0.47	1.3						
Isophorone	560											
N-Nitrosodiphenylamine	110											
Naphthalene	3.8				0.77	1.6						
Nitrobenzene	5.1											
Pentachlorophenol	0.99											
Phenanthrene	NI				1.2	2.5						
Phenol	1800											
Pyrene	170				9.3	19						

Notes:

NA = Not Analyzed; ND = Not Detected; NI = Not Identified; SVOC = Semivolatile Organic Compound; VOC = Volatile Organic Compound.

(1) Data from Curtis & Tompkins (2011, pp. 5-6).

(2) Data from Teter Engineering (2015, Tables 1 and 3).

(3) Data from US EPA (2009, Table 7, p .32). Note, more chemicals were analyzed but they were not reported in summary tables.

(4) Data from Zhang *et al.* (2008, Tables 4 and 5). Note that the values were converted to mg/kg for comparison across studies.

(5) Data from Pavilonis *et al.* (2013, Tables 2 and 3, pp. 5, 6).

(6) Data from Teter Engineering (2015, Appendix Tables A-1 and A-3). Note that the values from Table A-3 were converted to mg/kg for comparison across studies.

Highlighted cells are those with values above their respective Residential Screening Level.

Data was not reported for blank cells.

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical	Zhang *et al* . (2008 208-5919)[4]								
	Sample 1 A-Turf Rubber Crumb from Riverside Park (mg/kg)	**Sample 2 A-Turf Rubber Crumb from Riverside Park (mg/kg)**	**Sample 3 A-Turf Rubber Crumb from Riverside Park (mg/kg)**	**Sample 4 A-Turf Fibers from Riverside Park (mg/kg)**	**Sample 5 FieldTurf Rubber Crumb from Parade Grounds (mg/kg)**	**Sample 6 FieldTurf Rubber Crumb from Parade Grounds (mg/kg)**	**Sample7 FieldTurf Rubber Crumb from Sara Roosevelt Park (mg/kg)**	**Sample 8 Astroplay Rubber Crumb from E. Rochester HS (mg/kg)**	**New Crumb Infill - Sweat (Range, mg/kg)**
Metals									
Antimony									
Arsenic	3.55	1.57	ND	0.28				0.28	<0.50
Barium									
Beryllium									<0.20
Cadmium	0.21	0.41	0.37	ND				0.22	<0.090–0.11
Chromium	0.87	1.68	0.69	3.93				0.93	0.70–1.2
Cobalt									
Copper									<0.080–0.54
Lead	5.76	53.5	4.63	2.8				3.12	0.090–1.6
Magnesium									<7.0–980
Mercury									
Molybdenum									
Nickel									
Selenium									<1.9
Silver									<0.10
Thallium									
Titanium									0.60–1.3
Vandium									6.0–21
Zinc	5710	9988	NA	NA				NA	
SVOCs and VOCs									
1,2-Dichlorobenzene									
1,2,4-Trichlorobenzene									
1,3-Dichlorobenzene									
1,4-Dichlorobenzene									
2-Chlorophenol									
2,4-Dichlorophenol									
2,4-Dimethylphenol									
2,4-Dinitrophenol									
2,4-Dinitrotoluene									
2,4,5-Trichlorophenol									
2,4,6-Trichlorophenol									
3,3'-Dichlorobenzidine									
Acenaphthene	ND	0.03	ND	ND	0.16	0.09	ND	ND	
Acenapthylene									
Aniline									
Anthracene	0.03	0.17	ND	0.01	0.03	0.03	ND	ND	
Azobenzene									
Benzo(a)anthracene	1.23	1.26	0.31	ND	0.29	0.98	0.06	ND	
Benzo(a)pyrene	8.58	3.56	0.78	0.08	0.61	0.25	0.06	0.41	
Benzo(b)fluoranthene	3.39	2.19	ND	ND	1.08	0.58	0.2	0.43	
Benzo(g, h, i)perylene	7.75	2.61	2.73	0.11	0.85	0.46	2.03	ND	
Benzo(k)fluoranthene	7.29	1.78	0.17	ND	0.14	0.18	0.1	0.99	
Benzoic acid									
Bis(2-chloroethyl)ether									

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical	Zhang *et al*. (2008 208-5919)[4]								
	Sample 1 A-Turf Rubber Crumb from Riverside Park (mg/kg)	Sample 2 A-Turf Rubber Crumb from Riverside Park (mg/kg)	Sample 3 A-Turf Rubber Crumb from Riverside Park (mg/kg)	Sample 4 A-Turf Fibers from Riverside Park (mg/kg)	Sample 5 FieldTurf Rubber Crumb from Parade Grounds (mg/kg)	Sample 6 FieldTurf Rubber Crumb from Parade Grounds (mg/kg)	Sample7 FieldTurf Rubber Crumb from Sara Roosevelt Park (mg/kg)	Sample 8 Astroplay Rubber Crumb from E. Rochester HS (mg/kg)	New Crumb Infill - Sweat (Range, mg/kg)
Bis(2-chloroisopropyl)ether									
Bis(2-ethylhexyl)phthalate									
Butylbenzyl phthalate									
Carbazole									
Chrysene	1.32	7.55	ND	ND	1.96	1.34	0.06	4.9	
Di-n-butylphthalate									
Di-n-octylphthalate									
Dibenz(a,h)anthracene	3.52	1.55	ND	ND	0.71	0.52	1.43	ND	
Diethyl phthalate									
Dimethylphthalate									
Diphenylamine									
Fluoranthene	0.11	0.37	ND	ND	5.08	3.54	25.4	ND	
Fluorene	0.76	0.77	ND	ND	0.5	0.45	ND	ND	
Hexachlorobenzene									
Hexachlorobutadiene									
Indeno(1,2,3-cd)pyrene	0.4	0.37	ND	ND	ND	ND	ND	ND	
Isophorone									
N-Nitrosodiphenylamine									
Naphthalene	ND	0.1	0.4	0.2	0.03	0.03	ND	0.86	
Nitrobenzene									
Pentachlorophenol									
Phenanthrene	0.06	4.35	ND	ND	2.19	1.46	ND	ND	
Phenol									
Pyrene	3.73	8.76	ND	ND	6.24	9.61	2.45	13.5	

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical	Pavilonis *et al*. (2013 214-1253)[5]												
	New Turf Fiber - Sweat (Range, mg/kg)	Field Samples - Sweat (Range, mg/kg)	New Crumb Infill - Digestive (Range, mg/kg)	New Turf Fiber - Digestive (Range, mg/kg)	Field Samples - Digestive (Range, mg/kg)	New Crumb Infill - Lung (Range, mg/kg)	New Turf Fiber - Lung (Range, mg/kg)	Field Samples - Lung (Range, mg/kg)	New Crumb Infill - Nitric Acid (Range, mg/kg)	New Turf Fiber - Nitric Acid (Range, mg/kg)	Field Samples - Nitric Acid (Range, mg/kg)	All Samples - Sweat (Maximum, mg/kg)	All Samples - Lung (Maximum, mg/kg)
Metals													
Antimony													
Arsenic	<0.10	1.4–1.7	<0.10–0.48	<0.040	<3.0	<0.50	<0.20	<0.050	<0.70–0.80	<0.040–4.0	<0.70		
Barium													
Beryllium	<0.20	<0.20	<0.40	<0.40	<0.40	<0.50	<0.20	<0.030	<0.70	<0.040–0.51	<0.70		
Cadmium	<0.030	<0.20	<4.0	<0.30	2.5–11	<0.20	<0.090	<0.090	<0.70–1.1	<0.50	<0.70		
Chromium	0.10–1.3	2.1–2.7	<7.0	<0.60–0.74	<6.0	<0.20–0.66	<0.090–0.12	<0.050	<0.70–16	0.34–820	<0.70–0.92		
Cobalt													
Copper	0.030–1.6	1.8–2.2	<20–32	<1.0–1.6	<20	<0.40–0.58	<0.2–2.0	<0.20	<0.70–36	0.69–110	8.8–59		
Lead	0.030–12	<0.20–1.5	5.3–66	<0.30–4.7	2.5–260	<0.20–0.26	<0.02–0.61	<0.020–0.023	<0.010–17	0.53–4400	4.1–140		
Magnesium	3.3–18	<10	<1000–4600	<90	<900	650–970	77–300	<100	<7.0–7800	<30–12000	<70–160		
Mercury													
Molybdenum													
Nickel													
Selenium	<0.60	<0.70	<0.90–1.5	<0.10	<2.0	<2.0	<0.90	<0.10	<1.0	<0.10–2.9	<0.60–1.3		
Silver	<0.060	<0.70	<0.20–0.23	<0.20	<0.40–0.90	<0.50	<0.20	<0.10	<10	<8.0	<10		
Thallium													
Titanium	0.10–1.1	3.2–4.0	<10	<0.10	<10	1.5–6.7	0.20–0.96	<0.40	<0.70–18	0.81–820	1.9–9.6		
Vandium	0.50–1.6	15–18	<1.0	<0.10–0.12	<1.0	0.65-3.0	0.39–1.5	<0.70	<0.10–2.1	<40	<0.80–0.74		
Zinc													
SVOCs and VOCs													
1,2-Dichlorobenzene													
1,2,4-Trichlorobenzene													
1,3-Dichlorobenzene													
1,4-Dichlorobenzene													
2-Chlorophenol													
2,4-Dichlorophenol													
2,4-Dimethylphenol													
2,4-Dinitrophenol													
2,4-Dinitrotoluene													
2,4,5-Trichlorophenol													
2,4,6-Trichlorophenol													
3,3'-Dichlorobenzidine													
Acenaphthene												<0.11	<0.05
Acenapthylene												<0.17	<0.09
Aniline													
Anthracene												<0.08	<0.04
Azobenzene												<0.49	<0.24
Benzo(a)anthracene												<0.31	<0.16
Benzo(a)pyrene												<1.4	<0.74
Benzo(b)fluoranthene												<1.2	<0.56
Benzo(g, h, i)perylene													
Benzo(k)fluoranthene												<1.9	<0.69
Benzoic acid													
Bis(2-chloroethyl)ether													

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical	Pavilonis *et al*. (2013 214-1253)[5]												
	New Turf Fiber - Sweat (Range, mg/kg)	Field Samples - Sweat (Range, mg/kg)	New Crumb Infill - Digestive (Range, mg/kg)	New Turf Fiber - Digestive (Range, mg/kg)	Field Samples - Digestive (Range, mg/kg)	New Crumb Infill - Lung (Range, mg/kg)	New Turf Fiber - Lung (Range, mg/kg)	Field Samples - Lung (Range, mg/kg)	New Crumb Infill - Nitric Acid (Range, mg/kg)	New Turf Fiber - Nitric Acid (Range, mg/kg)	Field Samples - Nitric Acid (Range, mg/kg)	All Samples - Sweat (Maximum, mg/kg)	All Samples - Lung (Maximum, mg/kg)
Bis(2-chloroisopropyl)ether													
Bis(2-ethylhexyl)phthalate													
Butylbenzyl phthalate													
Carbazole												<0.35	<0.18
Chrysene												<1.1	<0.54
Di-n-butylphthalate													
Di-n-octylphthalate													
Dibenz(a,h)anthracene												<2.0	<0.98
Diethyl phthalate													
Dimethylphthalate													
Diphenylamine													
Fluoranthene												<0.11	<0.06
Fluorene												<.07	<0.03
Hexachlorobenzene													
Hexachlorobutadiene													
Indeno(1,2,3-cd)pyrene													
Isophorone													
N-Nitrosodiphenylamine													
Naphthalene												<0.03	<0.02
Nitrobenzene													
Pentachlorophenol													
Phenanthrene												<0.10	<0.05
Phenol													
Pyrene												<0.10	<0.05

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical			Teter Engineering (2015 215-4633) for Sprinturf[6]					
	All Samples - Digestive (Maximum, mg/kg)	All Samples - Total Extract (Maximum, mg/kg)	FieldTurf 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (mg/kg)	FieldTurf Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (mg/kg)	FieldTurf Ambient Crumb Rubber (Curtis & Tompkins, 2013b) (mg/kg)	FieldTurf Cryogenic Crumb Rubber (Curtis & Tompkins, 2013b) (mg/kg)	FieldTurf Crumb Rubber (2 Years of Age) (Lioy and Weisel, 2011) (mg/kg)	FieldTurf Crumb Rubber (2 Years of Age) (Lioy and Weisel, 2012) (mg/kg)
Metals								
Antimony			0.18	0.24	3.7	3.4	NA	NA
Arsenic			0.39	<1	<0.37	<0.4	<0.7	<0.7
Barium			2.2	0.41	2.7	6.4	NA	NA
Beryllium			<0.4	<0.4	<0.15	<0.16	<0.7	<0.7
Cadmium			1.5	<0.5	<0.37	<0.4	<0.7	<0.7
Chromium			0.72	1.9	1.2	1.9	<0.7	<0.7
Cobalt			<5	<5	130	120	NA	NA
Copper			11	0.4	54	26	15	59
Lead			<0.3	<0.3	15	8.4	40	8
Magnesium								
Mercury			0.011	<0.033	<0.15	<0.16	NA	NA
Molybdenum			NA	NA	0.57	0.64	NA	NA
Nickel			1.6	0.52	2	2.9	NA	NA
Selenium			0.37	<0.5	<0.74	<0.8	<1.2	1.3
Silver			0.14	<0.5	<0.37	<0.4	NA	NA
Thallium			1	<1	<0.74	<0.8	NA	NA
Titanium								
Vandium			0.52	0.55	1.2	2.2	0.71	0.74
Zinc			9,990	2.8	16,000	13,000	NA	NA
SVOCs and VOCs								
1,2-Dichlorobenzene								
1,2,4-Trichlorobenzene								
1,3-Dichlorobenzene								
1,4-Dichlorobenzene								
2-Chlorophenol								
2,4-Dichlorophenol								
2,4-Dimethylphenol								
2,4-Dinitrophenol								
2,4-Dinitrotoluene								
2,4,5-Trichlorophenol								
2,4,6-Trichlorophenol								
3,3'-Dichlorobenzidine								
Acenaphthene	<0.56	<0.03						
Acenapthylene	<0.68	2.48						
Aniline								
Anthracene	<0.42	<0.02						
Azobenzene	<2.5	<0.12						
Benzo(a)anthracene	<1.7	<0.08						
Benzo(a)pyrene	<7.6	<0.37						
Benzo(b)fluoranthene	<6.4	<0.31						
Benzo(g, h, i)perylene								
Benzo(k)fluoranthene	<7.2	<0.34						
Benzoic acid								
Bis(2-chloroethyl)ether								

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical			Teter Engineering (2015 215-4633) for Sprinturf[6]					
	All Samples - Digestive (Maximum, mg/kg)	All Samples - Total Extract (Maximum, mg/kg)	FieldTurf 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (mg/kg)	FieldTurf Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (mg/kg)	FieldTurf Ambient Crumb Rubber (Curtis & Tompkins, 2013b) (mg/kg)	FieldTurf Cryogenic Crumb Rubber (Curtis & Tompkins, 2013b) (mg/kg)	FieldTurf Crumb Rubber (2 Years of Age) (Lioy and Weisel, 2011) (mg/kg)	FieldTurf Crumb Rubber (2 Years of Age) (Lioy and Weisel, 2012) (mg/kg)
Bis(2-chloroisopropyl)ether								
Bis(2-ethylhexyl)phthalate								
Butylbenzyl phthalate								
Carbazole	<1.9	<0.09						
Chrysene	<5.5	<0.27						
Di-n-butylphthalate								
Di-n-octylphthalate								
Dibenz(a,h)anthracene	<10	<0.49						
Diethyl phthalate								
Dimethylphthalate								
Diphenylamine								
Fluoranthene	<0.62	<0.03						
Fluorene	<0.35	<0.02						
Hexachlorobenzene								
Hexachlorobutadiene								
Indeno(1,2,3-cd)pyrene								
Isophorone								
N-Nitrosodiphenylamine								
Naphthalene	<0.12	0.27						
Nitrobenzene								
Pentachlorophenol								
Phenanthrene	<0.52	<0.02						
Phenol								
Pyrene	<0.52	<0.02						

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical				Teter Engineering (2015 215-4633) for Sprinturf[6]			
	FieldTurf Crumb Rubber (6 Years of Age) (Lioy and Weisel, 2013) (mg/kg)	FieldTurf Rubber (SBR?) (Maxxam, 2009) (mg/kg)	FieldTurf Crumb Rubber (TestAmerica, 2009) (mg/kg)	FieldTurf 10-14 CRYO SBR (Conestoga-Rovers, 2008) (mg/kg)	FieldTurf SBR (TestAmerica, 2011a) (mg/kg)	FieldTurf SBR (TestAmerica, 2011b) (mg/kg)	FieldTurf SBR - Wellesley (Conestoga-Rovers, 2008) (mg/kg)
Metals							
Antimony	NA	NA	<1				
Arsenic	<0.7	<6	<1				
Barium	NA	<5	3.9				
Beryllium	<0.7	NA	<0.4				
Cadmium	<0.7	<0.5	0.36				
Chromium	<0.7	<2.0	1.3				
Cobalt	NA	10	81				
Copper	20	20	19				
Lead	37	<5	36				
Magnesium							
Mercury	NA	NA	0.018				
Molybdenum	NA	4	5.6				
Nickel	NA	<1	3.1				
Selenium	<1.2	NA	1.4				
Silver	NA	<2	<0.5				
Thallium	NA	NA	0.34				
Titanium							
Vandium	0.73	NA	1.3				
Zinc	NA	940	12,000				
SVOCs and VOCs							
1,2-Dichlorobenzene				NA	<9.7	<62	NA
1,2,4-Trichlorobenzene				NA	<9.7	<62	NA
1,3-Dichlorobenzene				NA	<9.7	<62	NA
1,4-Dichlorobenzene				0.025	<9.7	<62	0.021
2-Chlorophenol				NA	<9.7	<62	NA
2,4-Dichlorophenol				NA	<9.7	<62	NA
2,4-Dimethylphenol				<0.990	<9.7	<62	<0.990
2,4-Dinitrophenol				NA	<19	<120	NA
2,4-Dinitrotoluene				NA	<9.7	<62	NA
2,4,5-Trichlorophenol				NA	<9.7	<62	NA
2,4,6-Trichlorophenol				NA	<9.7	<62	NA
3,3'-Dichlorobenzidine				NA	<24	<160	NA
Acenaphthene				0.13	<9.7	<62	<0.2
Acenapthylene							
Aniline				NA	NA	NA	NA
Anthracene				<0.2	<9.7	<62	<0.2
Azobenzene							
Benzo(a)anthracene				<0.2	<9.7	<62	<0.2
Benzo(a)pyrene				<0.2	<9.7	<62	<0.2
Benzo(b)fluoranthene				1.9	<9.7	<62	<0.2
Benzo(g, h, i)perylene							
Benzo(k)fluoranthene				<0.2	<9.7	<62	<0.2
Benzoic acid				NA	NA	NA	NA
Bis(2-chloroethyl)ether				4	<48	<31	<0.2

Table A-1 Comparison of Turf Chemical Content to Residential Soil Screening Levels

Chemical				Teter Engineering (2015 215-4633) for Sprinturf[6]			
	FieldTurf Crumb Rubber (6 Years of Age) (Lioy and Weisel, 2013) (mg/kg)	FieldTurf Rubber (SBR?) (Maxxam, 2009) (mg/kg)	FieldTurf Crumb Rubber (TestAmerica, 2009) (mg/kg)	FieldTurf 10-14 CRYO SBR (Conestoga-Rovers, 2008) (mg/kg)	FieldTurf SBR (TestAmerica, 2011a) (mg/kg)	FieldTurf SBR (TestAmerica, 2011b) (mg/kg)	FieldTurf SBR - Wellesley (Conestoga-Rovers, 2008) (mg/kg)
Bis(2-chloroisopropyl)ether				NA	<9.7	<62	NA
Bis(2-ethylhexyl)phthalate				170	90	160	<0.990
Butylbenzyl phthalate				NA	NA	NA	NA
Carbazole							
Chrysene				<0.2	<9.7	<62	<0.2
Di-n-butylphthalate				4.8	<9.7	<62	<0.990
Di-n-octylphthalate				<0.990	<9.7	<62	<0.990
Dibenz(a,h)anthracene				<0.2	<12	<78	<0.2
Diethyl phthalate				0.25	<9.7	<62	<0.990
Dimethylphthalate				<0.990	<9.7	<62	<0.990
Diphenylamine				NA	NA	NA	NA
Fluoranthene				7.4	<9.7	<62	<0.2
Fluorene				0.2	<9.7	<62	<0.2
Hexachlorobenzene				NA	<9.7	<62	NA
Hexachlorobutadiene				NA	<9.7	<62	NA
Indeno(1,2,3-cd)pyrene				<0.2	<9.7	<62	<0.2
Isophorone				NA	NA	NA	NA
N-Nitrosodiphenylamine				NA	NA	NA	NA
Naphthalene				1.5	<9.7	<62	<0.2
Nitrobenzene				NA	<9.7	<62	NA
Pentachlorophenol				NA	<24	<160	NA
Phenanthrene				3.6	<9.7	<62	<0.2
Phenol				1.9	<9.7	<62	<0.2
Pyrene				16	<9.7	<62	<0.2

Table A-2 Comparison of Airborne Concentrations of Turf Constituents to Residential Air Screening Levels

		Milone & MacBroom (2008 215-3891) (FieldTurf - Crumb Rubber)[1]										NYC DHMH (2009 212-7391)[2]		DPH (2010 212-739	A DRRR (2010 212-7602	ES (2007 215-460	
Chemical	Residential Screening Level (µg/m3)	Field F SF-1 (µg/m³)	Field F SF-2 (µg/m³)	Field F SF-3 (µg/m³)	Field F SF-4 (µg/m³)	Field F SF-5 (µg/m³)	Field G SF-1 (µg/m³)	Field G SF-2 (µg/m³)	Field G SF-3 (µg/m³)	Field G SF-4 (µg/m³)	Field G SF-5 (µg/m³)	Synthetic Turf Fields (Range, µg/m³)	Background - Grass/Upwind (Range, µg/m³)	Max. Detect at 4 Crumb Rubber Fields (µg/m³)	Max. Detect in 4 Towns with Crumb Rubber Fields (µg/m³)	Crumb Rubber (ng/mL air)	Thomas Jefferson Field Max. On-field (µg/m³)
Metals																	
Cadmium	0.001											ND	ND				
Chromium	NI											0.87-1.4	ND-1.8				
Copper	NI											ND	ND				
Iron	NI											ND	ND				
Lead	0.15											ND	ND				
Manganese	0.0052											ND	ND				
Nickel	0.0094											ND	ND				
Silver	NI											ND	ND				
Tin	NI											ND	ND				
Zinc	NI											ND	ND-83				
Particulate Matter																	
PM 2.5	1.2											0.003-0.048	0.003-0.05				
PM 10	150																
PM 10 (Cr)	NI																
PM 10 (Pb)	0.15																
PM 10 (Zn)	NI																
SVOCs and VOCs																	
1,2,4-Trimethylbenzene	0.73														10.7		
1,3-Butadiene, 2-methyl	NI																
1,3-Pentadiene	NI																0.46
1,3-Pentadiene, (E-)	NI																NR
1,4-Dichlorobenzene	0.26																0.12
1,4-Pentadiene	NI																NR
1-Methylnapthalene	NI													9.3x10-3			
2-Butanone (MEK)	520											ND-3	ND	2.94			
2-Propanol	21														1.9		
4-(tert-octyl)phenol	NI	<0.19	<0.20	<0.19	<0.19	<0.20	<0.21	<0.21	<0.21	<0.21	<0.21					5.64	
4-Ethyltoluene	NI														6.3		
4-Methyl-2-pentanone	310													3.39			ND
Acenaphthene	NI											ND	ND				
Acenapthylene	NI											ND	ND	6.6x10-3			
Acetone	3200											9.3-51	ND-11	52.2			
Anthracene	NI											ND	ND				
Benzaldehyde, ethyl-	NI																
Benzene	0.36													1.56			0.4
Benzene, 1-ethyl-4-methyl	NI																0.41
Benzo(a)anthracene	0.0092											ND	ND	1.1x10-4			
Benzo(a)pyrene	0.00092											ND	ND	1.9x10-4			
Benzo(b)fluoranthene	0.0092											ND	ND	2.1x10-4			
Benzo(e)pyrene	NI													2.6x10-4			
Benzo(g, h, i)perylene	NI											ND	ND	1.4x10-4			
Benzo(k)fluoranthene	0.0092											ND	ND	8x10-5			
Benzothiazole	NI	<0.19	<0.20	<0.19	<0.19	<0.20	0.39	<0.21	<0.21	<0.21	<0.21	ND	ND	1.2		225.87	
Butane	NI																NR
Butylated hydroxyanisole (BHT alteration product)	49															13.89	

Table A-2 Comparison of Airborne Concentrations of Turf Constituents to Residential Air Screening Levels

Chemical	Residential Screening Level (µg/m3)	Milone & MacBroom (2008 215-3891) (FieldTurf - Crumb Rubber)[1]										NYC DHMH (2009 212-7391)[2]		DPH (2010 212-739	A DRRR (2010 212-7602	ES (2007 215-460	
		Field F SF-1 ($\mu g/m^3$)	Field F SF-2 ($\mu g/m^3$)	Field F SF-3 ($\mu g/m^3$)	Field F SF-4 ($\mu g/m^3$)	Field F SF-5 ($\mu g/m^3$)	Field G SF-1 ($\mu g/m^3$)	Field G SF-2 ($\mu g/m^3$)	Field G SF-3 ($\mu g/m^3$)	Field G SF-4 ($\mu g/m^3$)	Field G SF-5 ($\mu g/m^3$)	Synthetic Turf Fields (Range, $\mu g/m^3$)	Background - Grass/Upwind (Range, $\mu g/m^3$)	Max. Detect at 4 Crumb Rubber Fields ($\mu g/m^3$)	Max. Detect in 4 Towns with Crumb Rubber Fields ($\mu g/m^3$)	Crumb Rubber (ng/mL air)	Thomas Jefferson Field Max. On-field ($\mu g/m^3$)
Carbon Disulfide	73													0.47			
Carbon tetrachloride	0.47																
Chloroform	0.12											ND-2.9	ND				ND
Chromethane	9.4											ND-1.1	ND-1.1	1.7			
Chrysene	0.092											ND	ND	3.4x10-4			
Cyclohexane	630													17.5	1.2		
Cyclohexane, 1,1,3-trimethyl	NI																
Cyclohexane, 1,4-dimethyl	NI																
Decanal	NI																NR
Dibenz(a,h)anthracene	0.00084											ND	ND				
Dichlorodifluoromethane	10																
Ethanol	NI											6.2-22	5.1-8.9				
Ethyl benzene	1.1													4.29			
Fluoranthene	NI											ND	ND	6.8x10-3			
Fluorene	NI											ND	ND				
Freon 11	NI																0.34
Freon 113	NI																0.085
Freon 12	NI																
Heptane	NI													5.72			0.31
Hexadecane	NI															1.58	
Indeno(1,2,3-cd)pyrene	0.0092											ND	ND				
Isopropylbenzene	42 (cumene)														11.6		
Methylchloride	9.4 (chloromethane)																
Methylene Chloride	63											ND-9	ND-6.9	14.1			0.11
Naphthalene	0.083											ND	ND				
n-Hexane	73											ND-2.1	ND	31.3			
Nitrosodibutylamine (n-)	0.0018	<1.1	<1.1	<1.4	<1.1	<1	<1.3	<1.4	<1.4	<1.4	<1.4						
Nitrosodiethylamine (n-)	0.000024	<1.1	<1.1	<1.4	<1.1	<1	<1.3	<1.4	<1.4	<1.4	<1.4						
Nitrosodimethylamine (n-)	0.000072	<1.1	<1.1	<1.4	<1.1	<1	<1.3	<1.4	<1.4	<1.4	<1.4						
Nitrosodipropylamine (n-)	0.0014	<1.1	<1.1	<1.4	<1.1	<1	<1.3	<1.4	<1.4	<1.4	<1.4						
Nitrosomorpholine (n-)	0.0015	<1.1	<1.1	<1.4	<1.1	<1	<1.3	<1.4	<1.4	<1.4	<1.4						
Nitrosopiperidine (n-)	0.001	<1.1	<1.1	<1.4	<1.1	<1	<1.3	<1.4	<1.4	<1.4	<1.4						
Nitrosopyrrolidine (n-)	0.0046	<1.1	<1.1	<1.4	<1.1	<1	<1.3	<1.4	<1.4	<1.4	<1.4						
Nonane	2.1																1.1
Pentane	100																
Pentane, 2-methyl	NI																
Phenanthrene	NI											ND	ND				
Pyrene	NI											ND	ND	6.9x10-3			
Styrene	100													1.96			
Toluene	520											ND-2.7	ND-2	52.7	6.4		
Trichloro-fluoromethane	73																
Trichloro-trifluoromethane	NI																
Xylenes	10													14.7	44.3		

Notes:

ND = Not Detected; NI = Not Identified; NR = Not Reported; SVOC = Semivolatile Organic Compound; VOC = Volatile Organic Compound.

(1) Data from Milone & MacBroom (2008, Section 2, Tables 2, 3, 5, and 6, pp. 10-11, 15).

(2) Data from NYC DHMH (2009, Table B-1, p.). Note, more chemicals were analyzed but they were ND.

(3) Data from CT DPH (2010, Table 2, p. 35). Note, more chemicals were analyzed but they were ND.

(4) Data from CA DRRR (2010, Table 11, p. 25). Note, more chemicals were analyzed but were left out because they were ND or considered contamination and not further evaluated.

(5) Data from CAES (2007, Table 2, p. 5). Out-gassing experiment. Note that the values were converted to $\mu g/m^3$ for comparison across studies.

(6) Data from NY DH (2009, Tables 8.4 and 8.5). Note, more chemicals were analyzed but they were not selected for health risk evaluation.

(7) Data from US EPA (2009, Table 6, p .31). Note, more chemicals were analyzed but they were not reported in summary tables. Note that the values were converted to $\mu g/m^3$ when necessary for comparison across studies.

Highlighted cells are those with values above their respective Residential Screening Level.

Data was not reported for blank cells.

Table A-2 Comparison of Airborne Concentrations of Turf Constituents to Residential Air Screening Levels

Chemical	NY DH (2009 215-4606)[6]					US EPA (2009 210-1256)[7]							
	Thomas Jefferson Field Upwind (μg/m³)	Thomas Jefferson Field Max. Downwind (μg/m³)	John Mullaly Field Max On-field (μg/m³)	John Mullaly Field Upwind (μg/m³)	John Mullaly Field Max. Downwind (μg/m³)	Synthetic Turf Field F1D1 - On-field (μg/m³)	Synthetic Turf Field F1D1 - Background (μg/m³)	Synthetic Turf Field F1D2 - On-field (μg/m³)	Synthetic Turf Field F1D2 - Background (μg/m³)	Synthetic Turf Field F2 - On-field (μg/m³)	Synthetic Turf Field F2 - Background (μg/m³)	Synthetic Turf Field F4 - On Field (μg/m³)	Synthetic Turf Field F4 - Background (μg/m³)
Metals													
Cadmium													
Chromium													
Copper													
Iron													
Lead													
Manganese													
Nickel													
Silver													
Tin													
Zinc													
Particulate Matter													
PM 2.5													
PM 10						27.8	29.5	29.8	29.5	NR	NR	31.8	28.6
PM 10 (Cr)						0.0029	0.002	0.0036	0.0033	NR	NR	ND	ND
PM 10 (Pb)						ND	ND	0.0077	0.0063	NR	NR	ND	ND
PM 10 (Zn)						0.0108	0.0238	0.0118	0.0116	NR	NR	0.0314	0.0217
SVOCs and VOCs													
1,2,4-Trimethylbenzene													
1,3-Butadiene, 2-methyl			NR	0.23	NR								
1,3-Pentadiene	1.1	0.58	NR	0.52	0.53								
1,3-Pentadiene, (E-)	NR	0.62											
1,4-Dichlorobenzene	0.18	0.13											
1,4-Pentadiene	NR	0.52											
1-Methylnapthalene													
2-Butanone (MEK)						1.39	1.30	1.12	1.06	1.21	1.09	1.27	1.30
2-Propanol													
4-(tert-octyl)phenol													
4-Ethyltoluene													
4-Methyl-2-pentanone	1.2	ND	ND	0.78	ND	0.53	ND	0.49	ND	ND	ND	ND	ND
Acenaphthene													
Acenapthylene													
Acetone			ND	0.56	ND								
Anthracene													
Benzaldehyde, ethyl-			NR	9.6	NR								
Benzene	0.54	0.41				0.29	0.22	0.26	0.29	0.35	0.38	0.64	0.38
Benzene, 1-ethyl-4-methyl	0.67	0.55											
Benzo(a)anthracene													
Benzo(a)pyrene													
Benzo(b)fluoranthene													
Benzo(e)pyrene													
Benzo(g, h, i)perylene													
Benzo(k)fluoranthene													
Benzothiazole			ND	6.5	ND								
Butane	0.48	0.34											
Butylated hydroxyanisole (BHT alteration product)													

Table A-2 Comparison of Airborne Concentrations of Turf Constituents to Residential Air Screening Levels

Chemical	NY DH (2009 215-4606)[6]					US EPA (2009 210-1256)[7]							
	Thomas Jefferson Field Upwind (μg/m^3)	Thomas Jefferson Field Max. Downwind (μg/m^3)	John Mullaly Field Max On-field (μg/m^3)	John Mullaly Field Upwind (μg/m^3)	John Mullaly Field Max. Downwind (μg/m^3)	Synthetic Turf Field F1D1 - On-field (μg/m^3)	Synthetic Turf Field F1D1 - Background (μg/m^3)	Synthetic Turf Field F1D2 - On-field (μg/m^3)	Synthetic Turf Field F1D2 - Background (μg/m^3)	Synthetic Turf Field F2 - On-field (μg/m^3)	Synthetic Turf Field F2 - Background (μg/m^3)	Synthetic Turf Field F4 - On Field (μg/m^3)	Synthetic Turf Field F4 - Background (μg/m^3)
Carbon Disulfide													
Carbon tetrachloride						0.57	0.63	0.63	0.63	0.57	0.50	0.57	0.63
Chloroform	0.15	0.084	ND	0.96	0.15								
Chromethane			ND	0.1	0.1								
Chrysene													
Cyclohexane													
Cyclohexane, 1,1,3-trimethyl			NR	0.6	NR								
Cyclohexane, 1,4-dimethyl			NR	1.1	NR								
Decanal	0.46	NR											
Dibenz(a,h)anthracene													
Dichlorodifluoromethane						2.57	2.72	2.47	2.77	2.77	2.52	2.37	2.67
Ethanol													
Ethyl benzene													
Fluoranthene													
Fluorene													
Freon 11	0.69	0.4	0.4	0.69	0.7								
Freon 113	0.13	0.1	0.092	0.22	0.16								
Freon 12			0.74	1	1.1								
Heptane	0.43	0.3											
Hexadecane													
Indeno(1,2,3-cd)pyrene													
Isopropylbenzene													
Methylchloride						0.97	0.99	0.97	0.95	0.93	0.93	0.99	1.07
Methylene Chloride	0.17	0.29	0.19	2.3	3	0.24	0.21	ND	ND	0.21	0.21	0.21	0.21
Naphthalene													
n-Hexane						0.74	0.21	0.28	0.28	0.28	0.18	0.49	0.18
Nitrosodibutylamine (n-)													
Nitrosodiethylamine (n-)													
Nitrosodimethylamine (n-)													
Nitrosodipropylamine (n-)													
Nitrosomorpholine (n-)													
Nitrosopiperidine (n-)													
Nitrosopyrrolidine (n-)													
Nonane	2.5	2.3											
Pentane			NR	0.46	NR								
Pentane, 2-methyl			NR	NR	0.35								
Phenanthrene													
Pyrene													
Styrene													
Toluene						1.58	0.57	0.41	0.45	0.68	0.72	1.05	0.72
Trichloro-fluoromethane						1.46	1.57	1.46	1.52	1.52	1.40	1.35	1.68
Trichloro-trifluoromethane						0.08 (ppbV)	0.08 (ppbV)	0.08 (ppbV)	0.08 (ppbV)	0.08 (ppbV)	0.07 (ppbV)	0.07(ppbV)	0.15 (ppbV)
Xylenes						0.74	0.35	0.43	ND	0.30	0.35	0.61	ND

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Guideline Level (µg/L)	Curtis & Tompkins (2011 215-4632)		Milone & MacBroom (2008 215-3891) (FieldTurf - Crumb Rubber)[2]						Teter Engineering (2015 215-4633) for Sprinturf[3]			
		Limonta Infill-Pro Geo (µg/L)	Limonta Turf-Max-S (µg/L)	Raw Crumb Rubber (µg/L)	Field F (4 months) (µg/L)	Field F (6 months) (µg/L)	Field G (6 months) (µg/L)	Field F (1 year) (µg/L)	Field E (4 months) (µg/L)	Green Crumb Rubber - SPLP 1 (µg/L)	Green Crumb Rubber - SPLP 2 (µg/L)	Black Crumb Rubber - SPLP 1 (µg/L)	Black Crumb Rubber - SPLP 2 (µg/L)
Metals													
Aluminum	4,000												
Antimony	120	ND	ND										
Arsenic	3	ND	ND	<4	<4	<4	<4	<4	<4				
Barium	120,000	430	ND	<50	<50	<50	<50	<50	<50				
Beryllium	20	ND	ND										
Bromide	NI	ND	ND										
Cadmium	80	ND	ND	<5	<5	<1	<1	<5	<5				
Calcium	NI												
Chromium	NI	ND	ND	<50	<50	<50	<50	<50	<50				
Cobalt	2,000	ND	ND										
Copper	26,000	ND	ND	<40	<40	<40	<40	NA	NA				
Iron	NI												
Lead	100	ND	ND	<13	<13	6	4	<13	<13				
Magnesium	NI												
Manganese	1,000												
Mercury	40	ND	ND	<2	<2	<2	<2	<2	<2				
Molybdenum	NI	ND	ND										
Nickel	2000 (soluble salts)	ND	ND	<50	<50	<50	<50	NA	NA				
Potassium	NI												
Selenium	800	ND	ND	<10	<10	<2	<2	<10	<10				
Silver	800	ND	ND	<20	<20	<20	<20	<20	<20				
Sodium	NI												
Thallium	10	ND	ND										
Vanadium	2	ND	ND										
Zinc	40,000	ND	ND	1600	910	1900	1100	2400	4700	8.4	110	38	69
SVOCs and VOCs													
1H-isoindole-1,3(2H)-dione	NI												
1,2-Dichlorobenzene	12,000												
1,2,4-Trichlorobenzene	180												
1,3-Dichlorobenzene	12,000												
1,4-Dichlorobenzene	1,500												
2-Chlorophenol	800												
2(3H)-benzothiazolone	NI												
2,4-Dichlorophenol	400												
2,4-Dimethylphenol	2,000												
2,4-Dinitrophenol	200												
2,4-Dinitrotoluene	NI												
2-Mercaptobenzothiazole	NI												
2-Methylphenol	NI												
2,4,5-Trichlorophenol	14,000												
2,4,6-Trichlorophenol	20												
4-Methylphenol	NI												
3,3'-Dichlorobenzidine	30												

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Guideline Level (µg/L)	Curtis & Tompkins (2011 215-4632)		Milone & MacBroom (2008 215-3891) (FieldTurf - Crumb Rubber)[2]						Teter Engineering (2015 215-4633) for Sprinturf[3]			
		Limonta Infill-Pro Geo (µg/L)	Limonta Turf-Max-S (µg/L)	Raw Crumb Rubber (µg/L)	Field F (4 months) (µg/L)	Field F (6 months) (µg/L)	Field G (6 months) (µg/L)	Field F (1 year) (µg/L)	Field E (4 months) (µg/L)	Green Crumb Rubber - SPLP 1 (µg/L)	Green Crumb Rubber - SPLP 2 (µg/L)	Black Crumb Rubber - SPLP 1 (µg/L)	Black Crumb Rubber - SPLP 2 (µg/L)
Acenaphthene	4,200												
Acetophenone	14,000												
Aniline	NI									<9.6	<9.4	<9.6	<9.4
Anthracene	43												
Benzaldehyde, 3-hydroxyl-4-methoxy	NI												
Benzo(a)anthracene	1												
Benzo(a)pyrene	0.1												
Benzo(b)fluoranthene	1												
Benzo(k)fluoranthene	0.8												
Benzoic Acid	NI												
Benzothiazole	NI												
Benzyl alcohol	NI												
Bis(2-chloroethyl)ether	7												
Bis(2-chloroisopropyl)ether	6,000												
Bis(2-ethylhexyl) phthalate	40												
Butylbenzyl phthalate	2,000												
Carbazole	NI												
Chrysene	2												
Cyclohexane, isothiocyanato-	NI												
Cyclohexaneamine, N-cyclohexyl	NI												
Cyclohexanone	NI												
Dibenz(a,h)anthracene	0.3												
Diethyl phthalate	120,000												
Dimethylphthalate	NI												
Di-n-butyl phthalate	11,000												
Di-n-octylphthalate	20												
Diphenylamine	NI												
Fluoranthene	210												
Fluorene	2000												
Formamide, N-cyclohexyl-	NI												
Hexachlorobenzene	0.4												
Hexachlorobutadiene	8 (Hexachloro-1,3-butadiene)												
Hexanedioic acid, bis(2-ethylhexyl)	NI												
Indeno(1,2,3-cd)pyrene	0.2												
Isophorone	800												
Methane, diethoxy-cyclohexane	NI												
Methyl isobutyl ketone	NI												
Napthalene	6,000												
Nitrobenzene	80												
n-Nitrosodiphenylamine	140												
o-cyanobenzoic acid	NI												
Pentachlorophenol	6												

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Guideline Level (μg/L)	Curtis & Tompkins (2011 215-4632)		Milone & MacBroom (2008 215-3891) (FieldTurf - Crumb Rubber)[2]						Teter Engineering (2015 215-4633) for Sprinturf[3]			
		Limonta Infill-Pro Geo (μg/L)	Limonta Turf-Max-S (μg/L)	Raw Crumb Rubber (μg/L)	Field F (4 months) (μg/L)	Field F (6 months) (μg/L)	Field G (6 months) (μg/L)	Field F (1 year) (μg/L)	Field E (4 months) (μg/L)	Green Crumb Rubber - SPLP 1 (μg/L)	Green Crumb Rubber - SPLP 2 (μg/L)	Black Crumb Rubber - SPLP 1 (μg/L)	Black Crumb Rubber - SPLP 2 (μg/L)
Phenanthrene	NI												
Phenol	40,000									37	15	37	15
Phthalimide	NI												

Notes:

NA = Not Analyzed; ND = Not Detected; NI = Not Identified; SBR = Styrene Butadiene Rubber; SPLP = Synthetic Precipitation Leachate Procedure; SVOC = Semivolatile Organic Compound; TCLP = Toxicity Characteristic Leaching Procedure;

(1) Data from Curtis & Tompkins (2011, pp. 13-14).

(2) Data from Milone & MacBroom (2008, Section 3, Table 4, p. 7). Note that the values were converted to μg/L for comparison across studies.

(3) Data from Teter Engineering (2015, Table 2).

(4) Data from Baumann (2014, Table 1, p. 5).

(5) Data from CAES (2007, Table 3, p. 6).

(6) Data from NY DH (2009, Tables 2.2, 2.3, and 2.4). Note, more chemicals were analyzed but they were ND.

(7) Data from OEEHA (2007, Table 14, p. 54). Note, more chemicals were analyzed but they were not reported in summary table.

(8) Data from Teter Engineering (2015, Tables A-2 and A-4).

Highlighted cells are those with values above their respective Residential Screening Level.

Data was not reported for blank cells.

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Baumann (2014 215-4638)[4]	CAES (2007 215-4603)[5]		NY DH (2009 215-4606)[6]	OEEHA (2007 215-4614)[7]					
	Synthetic Turf (µg/L)	Crumb Rubber - Amount in Water (µg/kg tire)	Crumb Rubber - Amount in Acidified Water (µg/kg tire)	Crumb Rubber (31 samples, average µg/L)	Tire Sample "G" (µg/L)	Tire Sample "S" (µg/L)	Tire Sample "C" (µg/L)	FieldTurf - SPLP 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - SPLP Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (µg/L)	FieldTurf- SPLP Cryogenic Crumb Rubber (A-1007/T12) (Li *et al*., 2010a) (µg/L)
Metals										
Aluminum				ND						
Antimony				ND	110	42	1.7	<10	<10	NA
Arsenic	<50			ND	6.1	5.4	4.7	<10	<10	<3.0
Barium				30.4	130	110	870	6.3	0.74	13
Beryllium				ND				<4	<4	NA
Bromide										
Cadmium	<4	0.07	0.26	ND	2.2	2.8	1.1	<5	<5	<1
Calcium				2443.5						
Chromium	<5			ND	41	57	35	<5	1.7	<1
Cobalt				ND	45	50	33	1.4	<50	NA
Copper				9.8	1500	960	1600	0.93	5	0.69
Iron				1704.8						
Lead	<40	1.85	3.26	12.8	140	120	48	<100	<100	0.19
Magnesium				ND						
Manganese				20.7						
Mercury	<0.5			ND				<0.2	<0.2	NA
Molybdenum				ND	11	18	8.5	NA	NA	NA
Nickel				ND	27	27	22	<40	<40	0.65
Potassium				ND						
Selenium		246	260	ND	18	10	7.1	NA	NA	NA
Silver				ND				<5	<5	NA
Sodium				ND						
Thallium				ND				<10	<10	NA
Vanadium				ND	9	9.5	5.8	<50	1.1	NA
Zinc	95	20957	55010	1947.4	17000	26000	13000	342	4.3	2,450
SVOCs and VOCs										
1H-isoindole-1,3(2H)-dione					ND	490	ND			
1,2-Dichlorobenzene								NA	NA	NA
1,2,4-Trichlorobenzene								NA	NA	NA
1,3-Dichlorobenzene								NA	NA	NA
1,4-Dichlorobenzene								<5.0	<5.0	NA
2-Chlorophenol								NA	NA	NA
2(3H)-benzothiazolone				261.9	640	450	480			
2,4-Dichlorophenol								NA	NA	NA
2,4-Dimethylphenol				2.6				2.7	<10	NA
2,4-Dinitrophenol								NA	NA	NA
2,4-Dinitrotoluene								NA	NA	NA
2-Mercaptobenzothiazole				52.4						
2-Methylphenol				1.4						
2,4,5-Trichlorophenol								NA	NA	NA
2,4,6-Trichlorophenol								NA	NA	NA
4-Methylphenol				3.2						
3,3'-Dichlorobenzidine								NA	NA	NA

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Baumann (2014 215-4638)[4]	CAES (2007 215-4603)[5]		NY DH (2009 215-4606)[6]	OEEHA (2007 215-4614)[7]					
	Synthetic Turf (µg/L)	Crumb Rubber - Amount in Water (µg/kg tire)	Crumb Rubber - Amount in Acidified Water (µg/kg tire)	Crumb Rubber (31 samples, average µg/L)	Tire Sample "G" (µg/L)	Tire Sample "S" (µg/L)	Tire Sample "C" (µg/L)	FieldTurf - SPLP 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - SPLP Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (µg/L)	FieldTurf- SPLP Cryogenic Crumb Rubber (A-1007/T12) (Li *et al*., 2010a) (µg/L)
Acenaphthene								<2.0	<2.1	NA
Acetophenone				2.3						
Aniline				103.4	2800	3000	6700	<2.0	<2.1	NA
Anthracene								<2.0	<2.1	NA
Benzaldehyde, 3-hydroxyl-4-methoxy					ND	ND	ND			
Benzo(a)anthracene								<2.0	<2.1	NA
Benzo(a)pyrene								<2.0	<2.1	NA
Benzo(b)fluoranthene								<2.0	3.9	NA
Benzo(k)fluoranthene								<2.0	<2.1	NA
Benzoic Acid				19.8				NA	NA	NA
Benzothiazole				526.3	320	450	390			
Benzyl alcohol				2.8						
Bis(2-chloroethyl)ether								<2.0	<2.1	NA
Bis(2-chloroisopropyl)ether								NA	NA	NA
Bis(2-ethylhexyl) phthalate				1.6				<10	<10	NA
Butylbenzyl phthalate								<10	<10	NA
Carbazole				1.4						
Chrysene								<2.0	<2.1	NA
Cyclohexane, isothiocyanato-				129.6						
Cyclohexaneamine, N-cyclohexyl				208.1	190	410	ND			
Cyclohexanone					ND	ND	48			
Dibenz(a,h)anthracene								<2.0	<2.1	NA
Diethyl phthalate				1.7				3	<10	NA
Dimethylphthalate								<10	<10	NA
Di-n-butyl phthalate				1.2				<10	<10	NA
Di-n-octylphthalate								4.1	<10	NA
Diphenylamine										
Fluoranthene								<2.0	<2.1	NA
Fluorene								<2.0	<2.1	NA
Formamide, N-cyclohexyl-					ND	ND	110			
Hexachlorobenzene								NA	NA	NA
Hexachlorobutadiene								NA	NA	NA
Hexanedioic acid, bis(2-ethylhexyl)					ND	ND	ND			
Indeno(1,2,3-cd)pyrene								<2.0	<2.1	NA
Isophorone				3.6				NA	NA	NA
Methane, diethoxy-cyclohexane				330						
Methyl isobutyl ketone				173.5						
Napthalene				1.4				0.93	<2.1	NA
Nitrobenzene								NA	NA	NA
n-Nitrosodiphenylamine				3.6				NA	NA	NA
o-cyanobenzoic acid					990	ND	910			
Pentachlorophenol								NA	NA	NA

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Baumann (2014 215-4638)[4]	CAES (2007 215-4603)[5]		NY DH (2009 215-4606)[6]	OEEHA (2007 215-4614)[7]					
	Synthetic Turf (µg/L)	Crumb Rubber - Amount in Water (µg/kg tire)	Crumb Rubber - Amount in Acidified Water (µg/kg tire)	Crumb Rubber (31 samples, average µg/L)	Tire Sample "G" (µg/L)	Tire Sample "S" (µg/L)	Tire Sample "C" (µg/L)	FieldTurf - SPLP 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - SPLP Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (µg/L)	FieldTurf- SPLP Cryogenic Crumb Rubber (A-1007/T12) (Li *et al*., 2010a) (µg/L)
Phenanthrene								<2.0	0.76	NA
Phenol				12.8	190	ND	ND	35	0.86	NA
Phthalimide				108.6						

: VOC = Volatile Organic Compound.

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Teter Engineering (2015 215-4633) for Sprinturf[8]					
	FieldTurf- SPLP Ambient Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf- SPLP Cryogenic Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf - TCLP 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - TCLP Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - WET SBR (TestAmerica, 2011a) (µg/L)	FieldTurf - WET SBR (TestAmerica, 2011b) (µg/L)
Metals						
Aluminum						
Antimony	<1	<1	NA	NA	<200	<200
Arsenic	<1.2	<1.2	130	140	<200	<200
Barium	2.8	<1	29	2.5	220	<200
Beryllium	<4.3	<4.3	NA	NA	<80	<80
Bromide						
Cadmium	<1.3	<1.3	<100	<100	<100	<100
Calcium						
Chromium	<1	<1	3	3.5	100	<100
Cobalt	1.1	2.4	NA	NA	<200	<200
Copper	<1	9.7	NA	NA	880	310
Iron						
Lead	<1	<1	3.3	<500	<100	<100
Magnesium						
Manganese						
Mercury	<0.2	<0.2	<2	<2	<2	<2
Molybdenum	<3.2	<3.2	NA	NA	<400	<400
Nickel	<3.0	<3.0	NA	NA	<200	<200
Potassium						
Selenium	<1	<1	<250	<250	<200	<200
Silver	<1	<1	<500	<500	<200	<200
Sodium						
Thallium	<1	<1	NA	NA	<200	<200
Vanadium	<1.1	<1.1	NA	NA	<200	<200
Zinc	240	870	NA	NA	15,000	5,900
SVOCs and VOCs						
1H-isoindole-1,3(2H)-dione						
1,2-Dichlorobenzene	<10	<10	NA	NA		
1,2,4-Trichlorobenzene	<10	<10	NA	NA		
1,3-Dichlorobenzene	<10	<10	NA	NA		
1,4-Dichlorobenzene	<10	<10	<50	<50		
2-Chlorophenol	<10	<10	NA	NA		
2(3H)-benzothiazolone						
2,4-Dichlorophenol	<10	<10	NA	NA		
2,4-Dimethylphenol	<10	<10	NA	NA		
2,4-Dinitrophenol	<50	<51	NA	NA		
2,4-Dinitrotoluene	<10	<10	<50	<50		
2-Mercaptobenzothiazole						
2-Methylphenol						
2,4,5-Trichlorophenol	<10	<10	<50	<50		
2,4,6-Trichlorophenol	<10	<10	<50	<50		
4-Methylphenol						
3,3'-Dichlorobenzidine	<20	<20	NA	NA		

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Teter Engineering (2015 215-4633) for Sprinturf[8]					
	FieldTurf- SPLP Ambient Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf- SPLP Cryogenic Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf - TCLP 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - TCLP Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - WET SBR (TestAmerica, 2011a) (µg/L)	FieldTurf - WET SBR (TestAmerica, 2011b) (µg/L)
Acenaphthene	<10	<10	NA	NA		
Acetophenone						
Aniline	<10	<10	NA	NA		
Anthracene	<10	<10	NA	NA		
Benzaldehyde, 3-hydroxyl-4-methoxy						
Benzo(a)anthracene	<10	<10	NA	NA		
Benzo(a)pyrene	<10	<10	NA	NA		
Benzo(b)fluoranthene	<10	<10	NA	NA		
Benzo(k)fluoranthene	<10	<10	NA	NA		
Benzoic Acid	<50	<51	NA	NA		
Benzothiazole						
Benzyl alcohol						
Bis(2-chloroethyl)ether	<10	<10	NA	NA		
Bis(2-chloroisopropyl)ether	<10	<10	NA	NA		
Bis(2-ethylhexyl) phthalate	<10	11	NA	NA		
Butylbenzyl phthalate	<10	<10	NA	NA		
Carbazole						
Chrysene	<10	<10	NA	NA		
Cyclohexane, isothiocyanato-						
Cyclohexaneamine, N-cyclohexyl						
Cyclohexanone						
Dibenz(a,h)anthracene	<10	<10	NA	NA		
Diethyl phthalate	<10	<10	NA	NA		
Dimethylphthalate	<10	<10	NA	NA		
Di-n-butyl phthalate	<10	<10	NA	NA		
Di-n-octylphthalate	<10	<10	NA	NA		
Diphenylamine						
Fluoranthene	<10	<10	NA	NA		
Fluorene	<10	<10	NA	NA		
Formamide, N-cyclohexyl-						
Hexachlorobenzene	<10	<10	<50	<50		
Hexachlorobutadiene	<10	<10	<50	<50		
Hexanedioic acid, bis(2-ethylhexyl)						
Indeno(1,2,3-cd)pyrene	<10	<10	NA	NA		
Isophorone	<10	<10	NA	NA		
Methane, diethoxy-cyclohexane						
Methyl isobutyl ketone						
Napthalene	<10	<10	NA	NA		
Nitrobenzene	<10	<10	<50	<50		
n-Nitrosodiphenylamine	<10	<10	NA	NA		
o-cyanobenzoic acid						
Pentachlorophenol	<20	<20	<250	<250		

Table A-3 Comparison of Turf Leaching Results to Regulatory Guideline Levels

Chemical	Teter Engineering (2015 215-4633) for Sprinturf[8]					
	FieldTurf- SPLP Ambient Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf- SPLP Cryogenic Crumb Rubber (Curtis & Tompkins, 2013b) (µg/L)	FieldTurf - TCLP 10-14 Cryogenic Crumb Rubber (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - TCLP Crumb Rubber (Wellesley Field) (Conestoga-Rovers, 2008) (µg/L)	FieldTurf - WET SBR (TestAmerica, 2011a) (µg/L)	FieldTurf - WET SBR (TestAmerica, 2011b) (µg/L)
Phenanthrene	<10	<10	NA	NA		
Phenol	<10	<10	NA	NA		
Phthalimide						

Appendix B

Conclusions From Regulatory and Other Agencies

Appendix B: Conclusions From Regulatory and Other Agencies

California Office of Environmental Health Hazard Assessment (2007)

- In 2007, CalOEHHA performed an extensive evaluation of possible exposure to and effects from chemicals in SBR. They evaluated ingestion, gastric bioavailability, and chronic hand-to-mouth activity. The performed a detailed risk assessment that involved calculating hazard indices and cancer risks for these scenarios. They found that none of the scenarios evaluated were associated with unacceptable risks.
- CalOEHHA acknowledges limitations of its study, including uncertainties that might increase or decrease risk estimates, as well as uncertainty in the data evaluated. They also did not perform an evaluation of possible risks related to inhalation exposure.

Connecticut Agricultural Experiment Station (2007)

- This is a "very modest study" of artificial turf infill conducted to determine if compounds volatilized from infill and whether chemicals could leach from the infill. The authors concluded that chemicals did volatilize (including benzothiazole) and leach (zinc, selenium, lead, and cadmium) from the materials under laboratory conditions. They further state that additional data should be collected, in particular from field studies. No statements related to the health implications of the volatilization or leaching are provided.

Connecticut Department of Public Health (2007)

- This "Technical Fact Sheet" was produced in response to concerns related to exposures from artificial turf. It is a general review of the literature available at the time. The authors note that people are exposed to the chemical of concern (metals, PAHs, particulate matter) during everyday activity, and also note that in some urban areas approximately 1-2% of the ambient particulate matter is composed of tire material.
- The evaluation concludes, "Based upon the current evidence, a public health risk appears unlikely. DPH does not believe there is a unique or significant exposure from chemicals that can be inhaled or ingested at these fields. However, there is still uncertainty and additional investigation is warranted."

New Jersey Dept. of Environmental Protection (2007)

- This document is a literature review and evaluation of possible toxicity from ingestion, dermal, and inhalation of component of artificial turf. In general, the authors states that there is not enough information to complete a standard risk assessment. However, the evaluation concludes, "…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."

CDC (2008)

- This document is a CDC health advisory that is related to lead samples taken on artificial turf fields. The advisory notes that nylon/polyethylene blend turf fibers may have levels of lead that are a public health concern. Fields with polyethylene fibers only had low levels of lead.
- As noted previously, after 2008 the lead content of artificial turf fields has decreased substantially.

Consumer Product Safety Commission (2008a)

- This is a limited study that evaluated potential risks from exposure to lead at artificial turf fields. The evaluation concluded that young children are not at risk from exposure to lead in these fields. The limitations of the study are explicitly addressed, including sample uniformity, sample method quality, and the uncertain bioavailability of lead from fields.

TRC/New York City Department of Health and Mental Hygiene (2008)

- This document is a literature review and compilation of the other risk assessments conducted up until 2008. They note that, "Eleven different risk assessments applied various available concentrations of COPCs [Chemicals of Potential Concern] and none identified an increased risk for human health effects as a result of ingestion, dermal or inhalation exposure to crumb rubber."

New York City Department of Health and Mental Hygiene (2009)

- Based upon possible data gaps from an earlier review of the literature, an air monitoring study was conducted to determine concentrations of SVOCs, VOCs, metals, and particulate matter above artificial turf fields.
- The only chemicals detected were considered to be either a) at similar levels to background samples, or b) at levels below those associated with possible health effects. None of the PAHs were detected, and a marker for synthetic rubber (benzothiazole) was also not detected.
- Based on the lack of detected and/or elevated concentrations, a risk assessment was not deemed to be necessary. The report did note that one bulk sample contained elevated levels of lead. However, since this time period the levels of lead used in artificial turf products has decreased significantly.

New York State Department of Environmental Conservation (2009)

- This study evaluated the potential toxicity associated with SBR using a number of different experiments.
- The leaching investigation (using the SPLP protocol) found that "Zinc (solely from truck tires), aniline, and phenol have the potential to be released above groundwater standards or guidance

values." However, when the New York dilution-attenuation factor was applied to the results, it indicated that there was unlikely to be an impact on groundwater.

- An evaluation of SBR digested in acid revealed that the levels of lead did not exceed federal standards.
- Ambient air sampling at artificial turf fields did not reveal concentrations that were above normal urban levels or above health guideline levels. Particulate matter samples were not elevated, which the authors indicate is likely because most of the particulate in SBR is not the respirable size range. They conclude, "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."
- Limitations of this study are discussed by the authors, "This report is not intended to broadly address all synthetic turf issues, including the potential public health implications associated with the presence of lead-based pigments in synthetic turf fibers."

US EPA (2009)

- The US EPA conducted a limited scale air monitoring study for VOCs and particulate matter at several artificial turf fields in 2008. In addition, they analyzed multiple artificial turf and wipe samples.
- The air monitoring results did not find that particulate matter or VOCs were elevated above background at the fields, with the exception of one detection of methyl isobutyl ketone. Concentrations of lead in the extraction tests were below levels of concern. The authors note that the aggressive nature of the extraction tests likely overestimates the availability of metals from SBR.
- The report concludes, "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 [sic], 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."

Connecticut Dept. of Public Health (2010)

- This evaluation involved air sampling at four outdoor fields and one indoor field in Connecticut, as well as laboratory off-gas studies. A human health risk assessment was prepared using the analytical results.
- The study reported that 27 chemicals were evaluated in the risk assessment due to their detection above the indoor or outdoor fields, and the fact that they were potentially associated with the artificial surface. The authors indicate that conservative, health protection assumptions were used in their assessment.
- The authors report that despite the conservative nature of the assessment, only the indoor scenario showed a risk (slightly) above *de minimis* levels. Non-cancer hazards were not elevated in any scenario. The evaluation concludes, "Based upon these findings, the use of outdoor and indoor artificial turf fields is not associated with elevated health risks."

- The results of this Connecticut study have been published in three peer-reviewed articles (Ginsberg *et al*., 2011a,b; Simcox *et al*., 2011).

Mount Sinai Children's Environmental Health Center (Undated)

- This document is a fact sheet that presents a brief review of the literature. Potential exposure routes, chemical of concern, and exposure levels are discussed. The fact sheet notes that exposure where health effects have been observed from chemicals associated with artificial turf infills are much higher than exposures at artificial turf fields. Several recommendations for minimizing exposure (washing, wearing shoes, *etc.*) are presented.

New Jersey Dept. of Environmental Protection (2011)

- This document presents the results of a limited study of airborne lead concentrations associated with several artificial turf fields in New Jersey. The study observed higher levels of lead were detected during sampling with either a robotic sampler or a soccer player. They also found that where significant amounts of lead were found *via* wipe samples at a field that there was the potential for inhalation exposure. The author concluded, "While it is not possible to draw broad conclusions from this limited sample of fields 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."
- The levels found in ambient air at fields where high lead levels were observed were approximately half of the US EPA guideline level for lead.

CalOEHHA (2010)

- CalOEHHA undertook a second evaluation of artificial turf in 2010 under contract to the California Department of Resources Recycling and Recovery. The primary focus of their evaluation was VOC and PM2.5 (including metals) concentrations above playing fields using SBR.
- The PM2.5 (and associated metals) samples did not show elevations above the detection limit or normal background. Most VOCs were also below the limit of detection. For those VOCs that were detected, they were generally not consistent across the fields evaluated. Regardless, seven VOCs were evaluated in a screening risk assessment and all were found to be below health based screening levels.
- Interestingly, the report notes that increasing temperatures were not correlated with increasing VOC levels from the fields.

Consumer Product Safety Commission (2013)

- This document is a letter response to an appeal from Public Employees for Environmental Responsibility (PEER). PEER appealed for the removal of CPSC's conclusions regarding artificial turf from 2008, specifically the conclusion in the 2008 press release, "OK to install, OK to play on." PEER believed that headline was misleading given the limited scope of the study. They specifically requested the removal of all materials related to artificial turf from the CPSC's website, the dissemination of a warning regarding exposure to contaminants in artificial turf, and the commissioning of an ambient air study of artificial turf fields.
- The letter denies the appeal request, except for adding an explanatory note about the limitations of the study to the previously posted press release.
- There have been subsequent news stories (*e.g.*, Stockman, 2015) indicating that CPSC has withdrawn its determination that artificial turf is safe. However, we were unable to find any documentation of that on their website, and the 2008 press release (with the added note) is still posted. It is uncertain what these news reports are referring to, but it is possible that the addition of the note on limitations was misinterpreted as a retraction.

Connecticut Dept. of Public Health (2015)

- This document is a letter in response to concerns expressed by a university soccer coach regarding possible cancer clusters related to artificial turf fields. The Connecticut Department of Public Health reiterated its opinion that "…outdoor artificial turf fields do not represent an elevated health risk…"
- The document also states that the cancer cluster reports are anecdotal in nature, and the current news reports of cancer "…does not constitute a correlation or causality and thus raises a concern that currently lacks scientific support."
- Subsequent investigations of this proposed cancer cluster have raised doubts about its validity (Green, 2015), however, as Dr. Green notes in her review there has been no systematic collection of data for these cases so a cluster investigation is not possible currently.

Massachusetts Dept. of Public Health (2015)

- This document is a letter reviewing more recent literature and risk assessment related to artificial turf components. In addition, the author discussed the possible cancer cluster discussed above.
- The review indicates that the recent literature continues to "…suggest that exposure opportunities to artificial turf fields are not generally expected to result in health effects." In addition, the author discusses several issues related to the proposed cluster, including the wide variety of cancers reported.

TECHNICAL REPORT

Toxicological Analysis of performance infill for synthetic turf fields according to *EN 71-3* standard – Safety of toys Part 3: Migration of certain elements. Lower Canada College.

Report Number **R14525CAN-B1**

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SUMMARY

Toxicology test according to **EN 71-3 - *Safety of toys Part 3: Migration of certain elements (Material of Category III)*** has been carried out on rubber sample collected at Lower Canada College synthetic turf field.

<u>Abstract:</u>

The EN 71-3 standard specifies maximum migration limits for three categories of (toy) materials. The limits for the migration of certain elements are expressed in milligrams per kilogram material and are detailed in the report. The purpose of the limits is to minimise children's exposure to certain potentially toxic elements. The EN 71-3 concerns all toys and materials that might be ingested.

Soluble elements are extracted from materials using conditions which simulate the material remaining in contact with gastric juices for a period of time after swallowing. The concentrations of the soluble elements are determined quantitatively by two different methods:

1. Method for determining general elements: Aluminium, Antimony, Arsenic, Barium, Boron, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Mercury, Nickel, Selenium, Strontium, Tin and Zinc;
2. Method for determining Chromium (III) and Chromium (VI);

DESCRIPTION OF THE PRODUCT

Description of the product tested	PERFORMANCE INFILL FOR SYNTHETIC TURF FIELDS
Name of the product	SBR RUBBER – AMBIENT GROUND
Manufacturer	NOT SUBMITTED
Site	LOWER CANADA COLLEGE, MONTREAL, QC
Sample number	CAN0001465
Date of the tests	NOVEMBER 2014

REPORTED BY:

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IDENTIFICATION OF RUBBER SAMPLE CAN0001465

Parameter	Test method	Results	Product Declaration	Variation	Requirements	Pass/Fail
Size (mm)	EN933	0.8 – 2.5	0.5 – 2.0	-1 %	**≤±20%**	**Pass**
Shape	prEN14955	Angular	Angular	Similar shape	Similar shape	**Pass**
Density (g/cm^3)	EN 1097	0.49	0.47	4 %	**≤±15%**	**Pass**
TGA %org.	TGA	64.8	63.2	3 %	**≤±15%**	**Pass**
TGA %inorg.	TGA	35.2	36.8	-4 %	**≤±15%**	**Pass**

TOXICOLOGICAL ANALYSIS CAN0001465

Element	Units	Test method	Results	Requirements Category III	Pass/Fail
Aluminium	mg/kg MS	*NF EN ISO 11885*	**45.3**	70 000	**Pass**
Antimony	mg/kg MS	*NF EN ISO 11885*	**n.d.***	560	**Pass**
Arsenic	mg/kg MS	*NF EN ISO 11885*	**n.d.***	47	**Pass**
Barium	mg/kg MS	*NF EN ISO 11885*	**3.43**	18 750	**Pass**
Boron	mg/kg MS	*NF EN ISO 17294-1 et 2*	**2.30**	15 000	**Pass**
Cadmium	mg/kg MS	*NF EN ISO 17294-1 et 2*	**n.d.***	17	**Pass**
Cobalt	mg/kg MS	*NF EN ISO 11885*	**1.06**	130	**Pass**
Copper	mg/kg MS	*NF EN ISO 11885*	**4.73**	7 700	**Pass**
Lead	mg/kg MS	*NF EN ISO 11885*	**n.d.***	160	**Pass**
Manganese	mg/kg MS	*NF EN ISO 11885*	**7.66**	15 000	**Pass**
Mercury	mg/kg MS	*NF EN ISO 17294-1 et 2*	**n.d.***	94	**Pass**
Nickel	mg/kg MS	*NF EN ISO 11885*	**2.11**	930	**Pass**
Selenium	mg/kg MS	*NF EN ISO 11885*	**n.d.***	460	**Pass**
Strontium	mg/kg MS	*NF EN ISO 17294-1 et 2*	**1.23**	56 000	**Pass**
Tin	mg/kg MS	*NF EN ISO 11885*	**n.d.***	180 000	**Pass**
Zinc	mg/kg MS	*NF EN ISO 11885*	**532**	46 000	**Pass**
Chromium III	mg/kg MS	*NF T 90-043*	**n.d.***	460	**Pass**
Chromium VI	mg/kg MS	*NF T 90-043*	**n.d.****	0.2	**Pass**

**Not detectable – substance could not be detected, the detection limit for the used test method is <0.5mg/kg MS*

*** Not detectable – substance could not be detected, the detection limit for the used test method is <0.2mg/kg MS*