UNIVERSITY OF CALIFORNIA, BERKELEY
LABORATORY FOR MANUFACTURING AND SUSTAINABILITY
COLLEGE OF ENGINEERING

Review of the Impacts of Crumb Rubber in Artificial Turf Applications

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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

<u>References for Table 2.1</u>

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

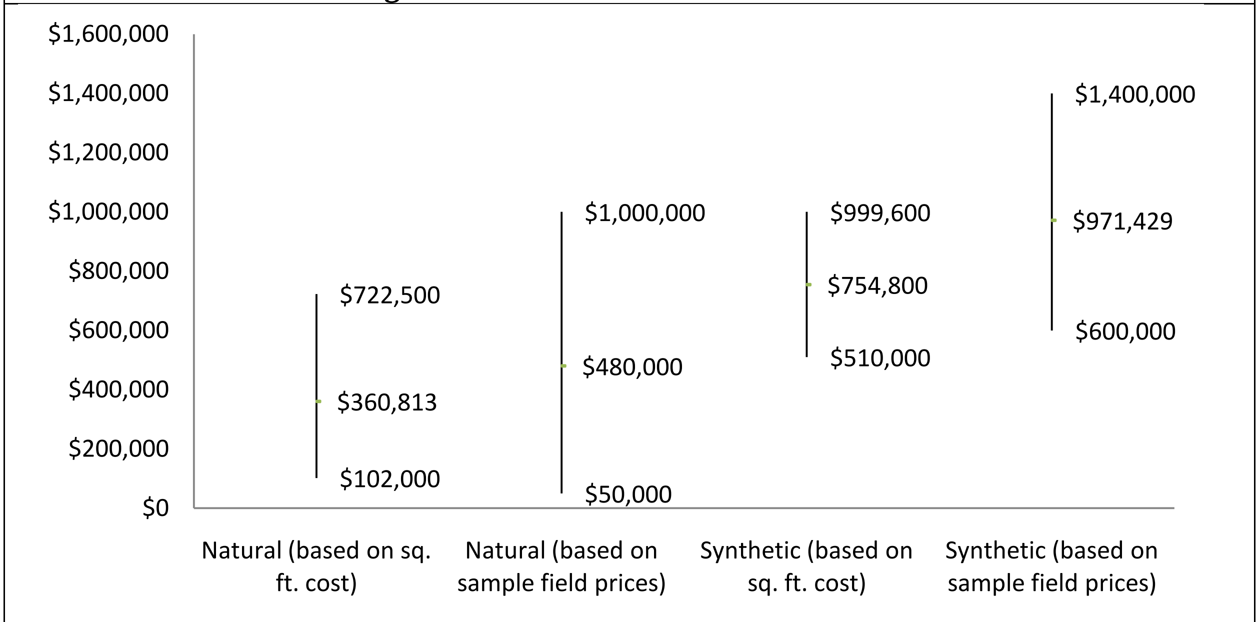
10,000 square foot "state-of-the-art fake grass" turf was installed in Shaw Park, GA for $30,000 (a price of $3 per square foot). Using these figures, the cost of an 85,000 square foot synthetic turf field ranges from $510,000 to $999,600. This figure is significantly higher than the range of $102,000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

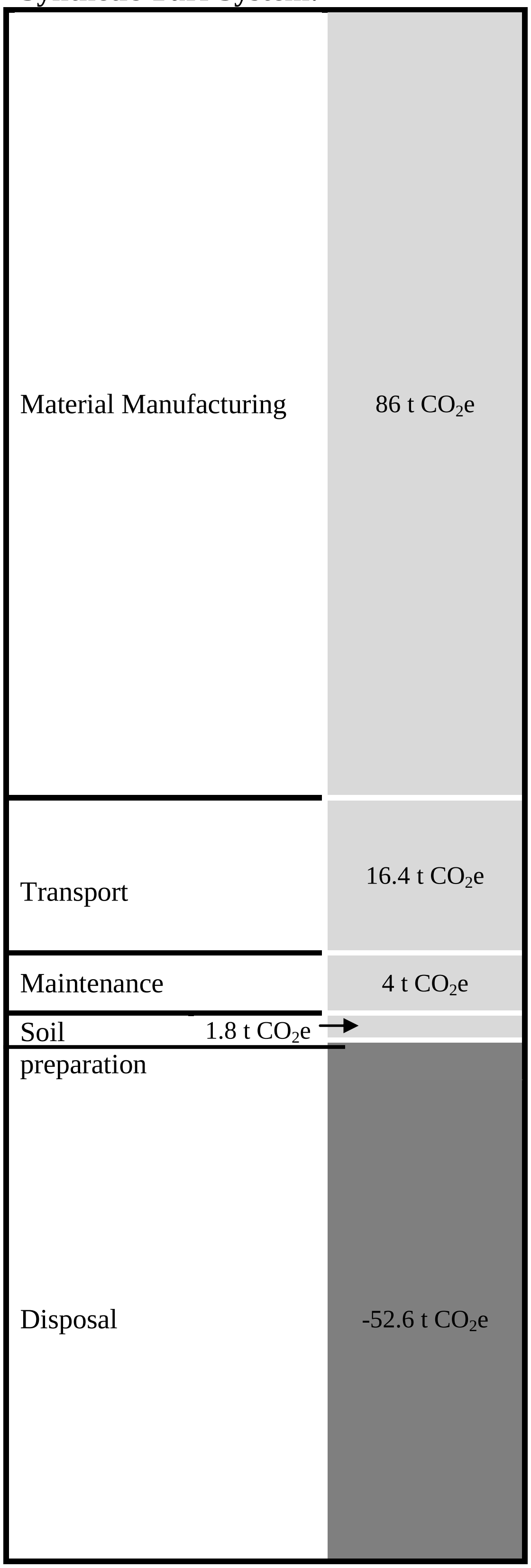
The Athena Institute (2007) study considers the entire scope of the product's life-cycle by means of SimaPro 7 LCA Software (2006). Assessments take into account various aspects of a playing field's life-cycle, including: the manufacturing of system components; transportation; surface preparation; maintenance; 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.

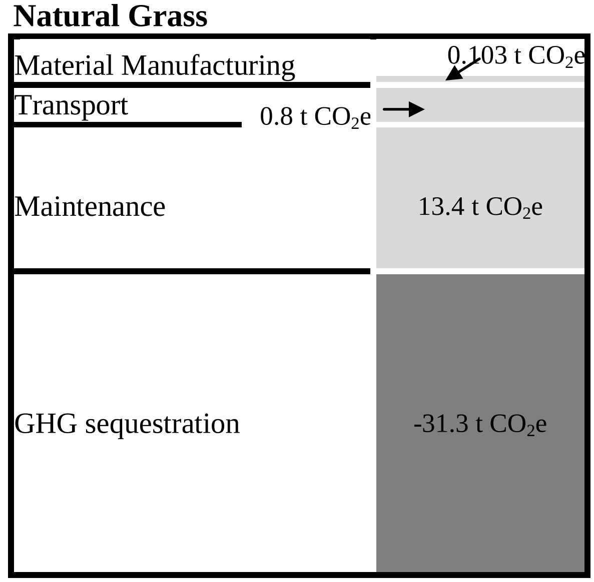
Figure 2.2 below shows a summary of the comparative impacts found by the Athena Institute. Following that is a discussion of their findings.

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

Synthetic Turf System:



Natural Grass



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 CO_2. 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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