Submission on Hosken Reserve Refresh and synthetic turf by Climate Action Moreland

Abstract:
The Hosken Reserve issue is about a failure in transparency and consultation with the local community, and poorly framed triple bottom line decision making by Moreland Council. There are questions about the integrity of the triple bottom line decision making embracing the social, environmental and economic impacts, costs and benefits, that was used in the process in the past decade for this site. And there are questions how triple bottom line decision making and weighting of factors will be applied for the current process. This submission provides numerous reasons why conversion of a natural grass oval and open space to a fenced synthetic soccer pitch should not take place. It finds that there are two primary reasons against synthetic turf at Hosken Reserve, and that either reason is significant in itself for the primary project not to go ahead. These two essential reasons are - synthetic turf carbon footprint (up to 1500 CO2e tonnes) in total life cycle greenhouse gas emissions, and synthetic turf increasing waste to landfill contributing to toxic leachates pollution and microplastics pollution. On both these grounds conversion of a shared use natural grass oval to synthetic turf would appear to conflict with existing Council policy and frameworks related to climate change and the climate emergency, and Council's zero waste to landfill by 2030 target. On the triple bottom line factors we found the social factors weighed up with some positive and some negative, the environmental factors were mostly against, and the economics didn't stack up, even after factoring in 2 to 1 equivalence usage factor for synthetic turf. This submission investigated peer reviewed science, grey literature and relevant policy documents to ascertain the following issues with synthetic turf:

1. Derived from fossil fuel petrochemical industry
2. Produces greenhouse gas emissions during manufacturing and as it degrades
3. Increases landfill at end of life
4. Produces micro-plastic pollution as synthetic turf breaks down
5. Increases urban heat island effect on local residents.
6. Replaces natural grass which allows soil organic carbon sequestration, provides oxygen
7. Reduces soil biota, grass seeds and insects with a trophic impact on local biodiversity primarily birdlife.
8. Compacts the soil increasing stormwater runoff
9. Toxic Chemical leachates from rubber infill pollute waterways
10. Results in increased lower extremity injuries in elite players
11. Long term human health impacts uncertain, but vertebrate model confirms toxicity to human health of rubber infill leachates
12. Enhances infection transmission risk. Encourages a microbial community structure primarily defined by anthropic contamination.
13. Appears to improve water conservation, but the situation is far more complex when life-cycle assessment and irrigation to reduce heat for playability is taken into account
14. Other issues: increased fire risk, increase in traffic, parking on quiet residential streets

A full annotated bibliography of all referenced documents was also prepared to accompany this submission.

This document was researched and prepared by John Englart, Convenor of Climate Action Moreland and was subject to peer review by other group members and other active members in the Moreland climate community. 27 March 2021

Council implementing the Tragedy of the Commons

The decision taken to upgrade grass to synthetic at Hosken Reserve went through several iterations and locations. While Football Federation Victoria and Pascoe Vale Football Club have advocated and been consulted over an 11 year period, the community was never informed of the decision making and the masterplan. The changes over time, and the Reserve Masterplan, remained a hidden document until very recently.

I'd like to consider Hosken Reserve as an example of the Tragedy of the Commons: where one group of users sees a way to maximise their benefit in using the commons area, but to long term detriment to sustainability and liveability of local residents and the municipality overall.

Advocacy by Football Federation Victoria

We note that Football Federation Victoria advocates and articulates very well the narrow social benefits of more football pitches, including artificial pitches, but fails to include any sustainability criteria in its Football Facilities Strategy. (Football Federation Victoria, 2018).

Football Federation Victoria have as a priority a new synthetic turf pitch in Moreland and also advocate for increasing pitches from 10 to 16 within the municipality by 2026. This is being done in a medium to high density population growth area already suffering from an absence of open space for informal active recreation activity.

We note that the global Football Federation, FIFA, commissioned in 2017 a detailed report into the sustainability and environmental impact of synthetic turf soccer pitches. This is not mentioned or cited in FFV's strategic facilities document, and appears to be totally ignored as part of their advocacy to Local Government for more facilities.(Eunomia Research & Consulting Ltd for FIFA, March 2017)

The Sports Environment Alliance have also done work into making sport more aligned with long term sustainability outcomes. This includes being aware of built environment impacts of sport, including minimisation of energy use and of greenhouse gas emissions; minimisation of adverse impacts on land, water, noise and air quality; use of long-lasting environmentally and socially responsible materials; minimisation of waste and maximising reuse and recycling of materials. FFV do not appear to be heeding Sports best practice in this time of climate emergency. (Sports Environment Alliance 2020)

Council as independent arbiter and perceptions of conflict of interest

Council needs to be the independent arbiter here ensuring the triple bottom line is adequately considered in all its forms and not heavily skewed to one group of users.

There is a certain perception in the community that some Councillors and some within the Council bureaucracy have been captured by narrow sports interests associated with Football Federation Victoria and have a perceived conflict of interest in impartial governance over the future of Hosken Reserve and the issue of conversion of several sports fields within Moreland to synthetic surfaces.

The whole planning process appeared (from the outside) to have come from a silo approach within Council driven by Sports and Recreation and certain Councillors, with little public evidence of other sections of council feeding into planning or decision making for this open space for a more even consideration of the issues.

A relevant comment from author Douglas Adams to the situation with Hosken Reserve:

> "But the plans were on display…"
> "On display? I eventually had to go down to the cellar to find them."
> "That's the display department."
> "With a flashlight."
> "Ah, well, the lights had probably gone."
> "So had the stairs."
> "But look, you found the notice, didn't you?"
> "Yes," said Arthur, "yes I did. It was on display in the bottom of a locked filing cabinet stuck in a disused lavatory with a sign on the door saying 'Beware of the Leopard."
>
> — Douglas Adams, The Hitchhiker's Guide to the Galaxy

Local residents and informal active recreation users have, until recently, been treated as insignificant. There has been for many years a sharing of the grass playing fields between the community and sporting clubs at Hosken Reserve.The oval has been Commons space.

Conversion to synthetic and fencing the field is tantamount to a land grab being facilitated by Council. The fence might be kept low, but the community will face a host of restrictions in use, with more time being allocated for use by the sports club.

This is in effect alienation of public lands and open space, the tragedy of the commons and repetition of the British land enclosures on a micro scale. The South Hosken oval is already fenced for the exclusive use of Pascoe Vale Football Club.

The Tragedy of the Commons by Garrett Hardin is a classic science article that articulates that we all to often focus on the benefits accruing to individuals or small groups in exploiting a common resource in the short term, rather than regulating commons usage to ensure impacts and damages are limited and the resource can continue to deliver shared benefits over the long term. We need to factor in externalities and costs and regulate the usage of individuals or specific groups. Failure to do this results in the Tragedy of the Commons.(Hardin 1968)

This philosophically applies to the situation at Hosken Reserve with the oval and east pitch being unfenced and shared by the community for active recreation and experiencing nature, and sharing the space with the Sports Club for training and the school for use for sports and for lunchtime activity.

Triple Bottom Line Decision Making

Triple Bottom Line decision Making is all about adequate consideration and weighting of social, environmental and economic factors. Weighing up all the benefits, and all the impacts and the costs. Triple Bottom line decision making has been enshrined in the Local Government Act 2020 under section 9 Overarching governance principles and supporting principles, Point (2) The following are the overarching governance principles—

> (b) priority is to be given to achieving the best outcomes for the municipal community, including future generations;
> (c) the economic, social and environmental sustainability of the municipal district, including mitigation and planning for climate change risks, is to be promoted;

To this point in time the narrow social benefits of organised sport have been the overwhelming driving force for the decision to convert a natural grass sporting field to a synthetic field at Hosken Reserve. The social benefits/impacts of this course of action to local residents and the municipality have been reduced to footnotes. Football Federation Victoria has provided strong advocacy for the social benefits for organised sport and in particular soccer. (Football Federation Victoria, 2018)

There has not been, to date, an equal champion for the retention of natural grass and the long term sustainability and liveability benefits this provides. In the absence of anyone else, Council should have been that champion, but failed to do so.

This submission seeks to highlight especially the environmental impacts and economic costs of synthetic turf and the benefits of retaining the natural grass as open space, which we think were not appropriately weighted in past decisions on Hosken Reserve.

We appreciate the benefits of people being active outside, whether in informal active recreational activity or organised sport, delivers substantial population health benefits. Sporting Clubs like Pascoe Vale Football club are important social institutions that bring people together. But they provide a narrow focussed view and governance decisions need to be made from a far broader perspective.

Areas like Hosken Reserve currently fill important roles as both sporting spaces and open space for surrounding residents. Due to our growing urban population density sporting fields and open spaces are under more intense use. With more infill urban development nearby in Merlynston the importance of having this as a natural grass surface open space is going to only increase.

The social, environmental and economic impacts and costs must be weighed carefully and each given appropriate consideration.

Sports Surface Needs Analysis (2018)

While sustainability and environmental impacts were considered as per the Sports surface Needs Analysis (2018), they were very much on a secondary level, to be adapted and worked around, rather than considered as a primary issue with equal weight as the social benefits to the sporting clubs and school.

This bias of environmental integrity being subservient to social benefit as part of the triple bottom line can clearly be seen in the Sports Surface Needs Analysis (2018). The Consultants Needs Analysis Sports Surfaces Draft Report 2.04 February 2018 by Smart Connection Consultancy, is quite detailed and reasonably thorough but focussed on formal sports capacity and was driven by the social side of triple bottom line decision making. Effectively, the decision had already been made to recommend proceeding with conversion of the sporting fields to synthetic, it was just a matter of working out which fields and presenting some relevant justification with a nod to some sustainability criteria to give it a greenwash.

The Sports Surface Needs Analysis study aimed to:

* Identify current and future community and sporting needs,
* Examine all sportsgrounds and open spaces within Moreland identifying:
  - the most suitable locations for synthetic and hybrid surfaces;
  - the circumstances when hybrid /synthetic surfaces should be considered (ie principles or trigger points of usage to apply into future; and
  - Identify potential opportunities where the installation of synthetic surfaces could be embraced."

Under point 8d -

> “Develop fields that are environmentally friendly and aligns with Council ESD policy.
> i. When procuring synthetic turf where possible request virgin rubber that will negate the negative perceptions around recycled SBR tyres.
> ii. Ensure that the infill has been tested against the "toy Ingestion standard EN71-03 Table 2 Category III
> iii. Ensure heat reduction technology is part of the scoping strategy for the procurement of a synthetic system."

The consultants report did mention greenhouse emissions of a synthetic turf field referencing the Athena Institute (2006) Total Life Cycle Assessment and comparison, but this was buried in the detail in the report (pp 354 of Council Agenda 11 April 2018) and not brought to the attention in either the consultant report executive summary, nor in the Council Officers report that fronted the Consultants report.

The more recent peer reviewed Swedish total life cycle assessment of greenhouse gas emissions (Magnusson et al 14 April 2017) should have been available, but wasn’t used or referenced by the Consultants. This showed a synthetic field would produce 527 ton of CO2 equivalent emissions over a 10 year field lifetime.

Also the consultants failed to consider the Urban Heat Island Effect (UHIE) Action Plan 2016-2026 in the listed strategic and policy plans as part of their review for the Consultants study, even though it was relatively recent Council policy passed at Council 8 June 2016. This appears to be an important oversight.

Reconciling Synthetic Turf with Moreland’s Zero Waste to Landfill by 2030

The Sports surface Needs Analysis (2018) really didn’t reconcile the issue of end of life disposal. Certainly there wasn’t a Waste Policy included as part of the strategic review by the Consultants.

It is clear that Synthetic Turf in Australia results in end of life landfill disposal.

In May 2018 Council voted 9/2 for NOM15/18 - Zero Waste to Landfill by 2030 (D18/151809) which "Seeks to refocus the new Waste and Litter Strategy with goal of zero waste to landfill across the municipality by 2030. The strategy as a minimum shall:
a) Establish a 2030 Zero Waste to Landfill framework.
b) Seek to embed and give weight to the '5R's - Refuse, Reduce, Reuse, Repurpose, Recycle' as core values in all future contracts and procurement"

This became part of the Moreland Council Waste and Litter Strategy adopted at 12 December 2018 Council meeting.

Any decision by Moreland Council to convert a natural grassed sporting oval to synthetic turf needs to reconcile how at end of life this turf product will be disposed of and not producing landfill waste, or greenhouse gases and other toxic gases from incineration.

The change in General social context with a climate and biodiversity emergency

We should note that over the last 6 years since the Paris Climate Agreement was signed in 2015 and especially the last 3 years, there has been a substantial contextual social change regarding multiple global crises that also manifests at the local level: climate change, biodiversity loss, plastics pollution. These need to be given weighting as accords their rise in social importance in triple bottom line decision making.

In April 2018 when the Sports Surface Needs Analysis (Moreland Council April 2018) was presented and adopted by Moreland Council there was not widespread concern that we had a climate emergency, a biodiversity extinction emergency, a plastic pollution crisis within the chambers and offices of Council. These issues were all there, but hadn't made it to the top priority. I raised a hastily prepared public question on urban heat impact of synthetic turf when that report was presented. I received a response that this would be considered as part of any specific project.

The last 3 years has seen a substantial change in the general context. There are far more scientific and policy papers warning of the triple crises confronting us.

In September 2018 Moreland Council voted to declare a climate emergency. This was a significant turning point in Council that addressing the climate challenge needed to be front and centre in all decision making by Council. In October 2018 the Intergovernmental Panel on Climate Change (IPCC) published its Special Report on 1.5C of Global Warming (IPCC 2018) which delineated the need for strong and rapid action at all levels of Government and business decision making to avoid catastrophic climate outcomes.

In 2019 the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published The global assessment report on Biodiversity and Ecosystem Services. (IPBES 2019) Climate Action Moreland highlighted this report in our submission to the Draft Moreland Nature Plan to be included as part of the international context regarding threats to biodiversity loss in Moreland. This report highlights that nature and ecosystems have deteriorated worldwide, with the process accelerating in the last 50 years.

We need to make transformative changes across economic, social, political and technological factors for conserving and sustainably using nature and achieving sustainability.(Díaz, S. et al. December 2019)

The United Nations Environment Program report published February 2021 (UNEP 2021) outlines the extent of the climate, biodiversity and plastics pollution problems and the solutions to tackle them.

For many years we have been aware of the problem with plastics. Many of them are marketed as recyclable, when in fact only a small proportion of plastics do have a recycling process established, according to a PBS documentary on Plastic Wars broadcast on Four Corners (PBS Frontline production, August 2020).

The plastics that aren't recycled end up in landfill where they slowly degrade into smaller and smaller pieces until they become microplastics. Plastic and microplastics is now a considerable problem for ocean ecosystems and comparable to the climate crisis in many ways argues Joshi (2021). Moreland Council got on board with a single use Plastic wise policy in April 2019 (Moreland Council 2019).

This change in general social context should require better weighting of environmental factors in triple bottom line decision making about synthetic turf at Hosken Reserve.

Here are detailed reasons why synthetic turf should not proceed at Hosken Reserve.

The rest of this submission outlines the environmental and health impacts and risks of conversion of a natural grass sporting field presently shared by the community and local organised sport.

Environmental, Health and Biodiversity impact of synthetic turf

Synthetic turf is:

1. Derived from fossil fuel petrochemical industry
2. Produces greenhouse gas emissions during manufacturing and as it degrades
3. Increases landfill at end of life
4. Produces micro-plastic pollution as synthetic turf breaks down
5. Increases urban heat island effect on local residents.
6. Replaces natural grass which allows soil organic carbon sequestration, provides oxygen
7. Reduces soil biota, grass seeds and insects with a trophic impact on local biodiversity primarily birdlife.
8. Compacts the soil increasing stormwater runoff
9. Toxic Chemical leachates from rubber infill pollute waterways
10. Results in increased lower extremity injuries in elite players
11. Long term human health impacts uncertain, but vertebrate model confirms toxicity to human health of rubber infill leachates
12. Enhances infection transmission risk. Encourages a microbial community structure primarily defined by anthropic contamination.
13. Appears to improve water conservation, but the situation is far more complex when life-cycle assessment and irrigation to reduce heat for playability is taken into account
14. Other issues: fire risk, alternative infills, traffic, parking and cycling impacts

Synthetic turf a child of the fossil fuel based plastics and petrochemical industry

The report prepared for FIFA highlights that synthetic turf is mostly fossil based materials. (Eunomia Research & Consulting Ltd 2017). The environmental context is that we need to transition off using fossil fuel manufactured products due to the embedded carbon emissions as rapidly as possible. The plastics and petrochemical industry are a derivative of fossil fuels - oil and gas.

Plastics are estimated “to make up around 9% of oil demand measured in mbpd (less if measured in tonnes), but are the largest component of oil demand growth.” They are seen widely in the oil sector as a growth area. (Carbon Tracker 2020)

Professor Alice Mah articulates that the oil and petrochemical companies seek to pivot their business models to encompass the ‘circular economy’ and ‘sustainability’ criteria and the problem that poses in regard to increased resource use and growth model. (Mah 2020)

The plastics crisis is compared to the climate crisis by Ketan Joshi highlighting the problem we have with plastics and microplastics pollution, especially in waterways and oceans. (Joshi 2021)

While synthetic turf products, including synthetic grass, are marketed as "recycleable", like many plastics they are not recycled but instead disposed of mostly to landfill due to the exorbitant costs and energy in setting up a recycling stream process. PBS Frontline video documentary, rebroadcast on Four Corners, investigates the hype and marketing spin behind plastics and its marketing as products that are recycled. Nothing seems different with synthetic turf… (PBS Frontline 2020)

Produces greenhouse gas emissions during manufacturing and as it degrades

Lifetime CO_2 is estimated at an average of 5 tonnes of CO_2 per tonne of plastics. It also imposes a massive "untaxed externality upon society of at least $1,000 per tonne ($350bn a year) from carbon dioxide, health costs, collection costs, and ocean pollution….plastic is responsible for roughly twice as much carbon dioxide per tonne as oil." (Carbon Tracker 2020)

For Moreland Council a decision to avoid conversion of natural grass to synthetic turf is a substantial carbon and externality cost saving.

I have found two full Life Cycle Assessment (LCA) analysis that include a life cycle greenhouse gas emissions estimate: a Canadian study from 2006 (Meil and Bushi 2006) and a Swedish study from 2017 (Magnusson and Macsik April 2017). There is also a comparative assessment of total life cycle emissions in the 2017 report to FIFA, but this lacks information on data and methodology with no references as to source.(Eunomia Research & Consulting Ltd for FIFA, March 2017)

The Canadian study estimated greenhouse gas emissions for a single field for a 10 year lifetime at 55 ton CO_2e, but assumed full recycling. Without the recycling this would likely be > 100 tonne CO_2e. I could not find any peer review process for this study, so classified it as Grey literature.

The Swedish study was peer reviewed and gave a lifetime greenhouse gas estimate of 527 ton CO_2 equivalents for an average soccer pitch. This study concluded total energy use was 5.9GJ and the GHG emissions was 527 ton CO_2 equivalents. The authors point out that these totals can vary with a factor of 1.5 and 2.2 respectively depending upon the infill type chosen, and method of disposal whether incineration or landfill (both are problematic for a closed loop circular economy which Moreland is aiming for). The study also raised some concern over leachates.(Magnusson and Macsik 14 April 2017)

In the 2017 report prepared for FIFA - Environmental Impact Study on Artificial Football Turf - there is a comparative chart showing the CO_2e total life cycle emissions for various infills, but no source or methodology is given for this data.(Eunomia Research & Consulting Ltd for FIFA, March 2017) Note that very limited recycling takes place globally, even in Europe according to multiple reports. (See Zembla September 2018, Lundstrom and Wolfe December 2019).

According to this report a FIFA standard pitch is 7526 square metres. The graph shows the SBR crumbed rubber infill synthetic turf pitch produces 200 kg CO2e total life cycle emissions per square metre. Cork infill pitch would be similar. This equates as 1505.2 tonnes CO2e for a full pitch. This is the best case scenario for a synthetic pitch for either landfill or incinerator disposal. This is three times the 2017 Swedish study greenhouse gas assessment. (Magnusson and Macsik 14 April 2017)

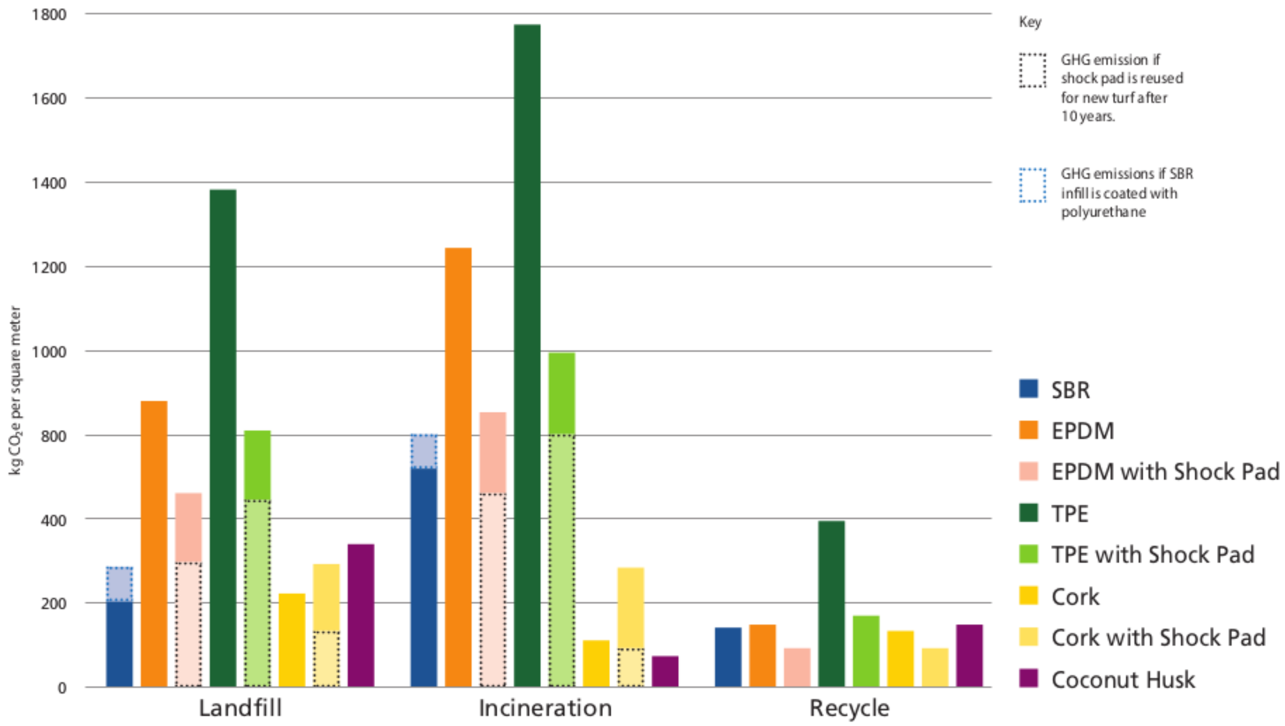


Figure 8: Climate Change Comparison between Turf Containing Different Infill Materials

Source: ENVIRONMENTAL IMPACT STUDY ON ARTIFICIAL FOOTBALL TURF by Eunomia Research & Consulting Ltd for FIFA March 2017

Image from Eunomia Research & Consulting Ltd for FIFA, (March 2017): "Figure 8 shows the results of a comparison between different formulations of turf, each containing one of the five main infill types, for each of the potential disposal routes. It displays the greenhouse gas (or 'carbon') emissions over the life of each product per square meter installed. Although there are many ways to indicate and compare the environmental impact, carbon emissions are given as an example that is broadly representative of many of the other environmental impacts such as air pollution or toxicity in humans or ecosystems. This life cycle includes the raw materials, manufacture, transport, installation, maintenance and disposal options at the end of life." Note: very limited recycling takes place, even in Europe.

Greenhouse gas emissions alone is reason enough for Moreland not to proceed with the conversion of the natural grass oval at Hosken Reserve to synthetic turf. Moreland has declared a climate emergency which highlights that reduction of emissions is a priority. The natural grass oval is likely minimal emissions, depending on the level of the maintenance regime. There is a great deal of research on urban lawns and grasslands sequestering Soil Organic Carbon, although grass sporting fields due to regular restoration work are unlikely to act as a carbon sink. This doesn't negate their role in producing oxygen and other environmental services. Now is not the time to be increasing Council emissions from a new synthetic sports field.

If Moreland does proceed with synthetic field installation, it then needs to publicly explain how these emissions will be properly and entirely mitigated in its Moreland Zero Carbon Framework.

Climate Action Moreland believes on the Greenhouse gas emissions issue alone Hosken Reserve conversion to synthetic turf should not proceed.

Increases landfill at end of life

A report done for the global soccer federation - FIFA, highlights lack of recycling and reuse, usually landfill used for disposal. All synthetic turf in Australia currently ends up in landfill. The report also noted that the "majority of the manufacturers interviewed for this study claimed their products are 'recyclable', but none are taking significant steps to make sure this happens in practice." (Eunomia Research & Consulting Ltd for FIFA, March 2017)

PBS Frontline production (August 2020) highlights the extent of the 'recycling' spin used by plastics manufacturers as part of their marketing when recycling of most plastics is simply not cost effective at scale, hence landfill being the cheapest form of disposal.

A standard pitch containing SBR infill could weight around 274 tonnes for disposal at end of life. This consists of the polyethylene fibres, the plastic matting, the SBR rubber infill, sand all of which would need separation into different streams to make recycling of some of the materials possible.

If we look overseas, Marjie Lundstrom and Eli Wolfe did an investigative journalism article published at Fair Warning highlighting the lack of any recycling of synthetic turf in North America and the growing problem of used synthetic grass as landfill along with associated rubber infill. (Lundstrom and Wolfe December 19, 2019)

In Europe Investigative Journalism team Zembla probed the end of life disposal of synthetic turf, highlighting the extent of the problems. This highlights that even in Europe where there is some recycling of artificial turf, much of it is stockpiled as landfill left to cause pollution by companies contracted to recycle. (Zembla September 2018)

Sport and Recreation Victoria (Feb 2011) ignores the problem of synthetic turf in landfill and the emissions and microplastics this creates

If Moreland does proceed with synthetic field installation, it then needs to publicly explain how the synthetic turf will be recycled or kept out of landfill as per the current Moreland Council Waste and Litter Strategy which includes a zero waste to landfill target by 2030. This product responsibility for disposal should not be passed onto a contractor.

Climate Action Moreland believes that on end of life disposal of synthetic turf and its conflict with existing Council Waste and Litter Strategy and 2030 zero waste to landfill target, is the second complete reason not to proceed with a conversion of a natural grass field to synthetic pitch.

Produces micro-plastic pollution as synthetic turf breaks down

The report prepared for FIFA in 2017 outlined the microplastic problem as “More recently plastic infill (including SBR, TPE and EPDM) has been identified as a possible source for microplastic marine pollution. Infill can get washed away during rain or stick to clothing and boots before being put in a washing machine. ... It is estimated that 1–4% of plastic infill is lost and replaced every year.” (Eunomia Research & Consulting Ltd for FIFA, March 2017)

Synthetic turf at landfill will slowly degrade and breakdown into smaller plastic particles and microplastics. This will generate the powerful greenhouse gas emissions of methane and ethylene as the plastic degrades. (Royer et al August 2018).

There is another problem. As the plastic breaks down it forms a ‘hacky structure’ which provides a vector for organic contaminants and heavy metals. The microplastics then transport these contaminants or enrich them in biota, “thus imposing major impacts on human health and ecosystems (Bouwmeester et al, 2015)....”. This could enhance the environmental risk of leachate discharged to the environment. (Su et al 2019)

A recent news report from Sydney highlights the extent of plastic fibres and rubber infill pollution: “New research by the Australian Microplastic Assessment Project (AUSMAP) with Northern Beaches Council, funded by NSW’s Environment Protection Authority, has found 80 per cent of the waste entering stormwater drains was black crumb (recycled tyres used for the base of these fields) and microplastics from astroturf – compared to 5 per cent in areas without these playing fields…. USMAP director of research Dr Scott Wilson said they were “definitely finding a proliferation of the crumb and some grass” particularly when many games had been played and after wet or windy weather.” (Power 14 March 2021)

Moreland Council is aware of the problem of plastics and microplastics pollution adopting a Plastic Wise policy for all Council organised events and festivals, including Sporting Clubs using Moreland Council Facilities (Moreland Council, 10 April 2019) It provides a sharp contrast to the Sport and Recreation Department drive to convert natural grass sporting fields to plastics based synthetic surfaces.

Increases urban heat island effect on local residents.

We know that “Global warming exacerbates the urban heat island effect in cities and their surroundings, especially during heatwaves, increasing people’s exposure to heat stress.” (UNEP February 2021)

A new report published March 2021 highlights the increasing temperatures in Australian cities, including Melbourne, and the growing impact of the urban heat island effect on liveability..
It does not mention the role of synthetic surfaces that add to urban heat, but advises that putting in place green infrastructure to address growing urban heat takes time, early action is essential. Extreme and average maximum temperatures are projected to increase, the number of days over 35C will increase. This will reduce useability of synthetic surfaces unless water is used for temporary cooling, which then reduces the justification for synthetic turf providing a water saving. Natural grass sporting oval as open space is importance for limiting urban heat island impacts at Hosken Reserve. (Monash Climate change Communication Research Hub March 2021)

For background on how climate change and heatwaves are amplifying the urban heat island effect and the social, environmental impacts for Melbourne the 2015 literature review and annotated bibliography: Climate change and heatwaves in Melbourne - a Review, is an excellent resource to investigate further. (Englart 2015)

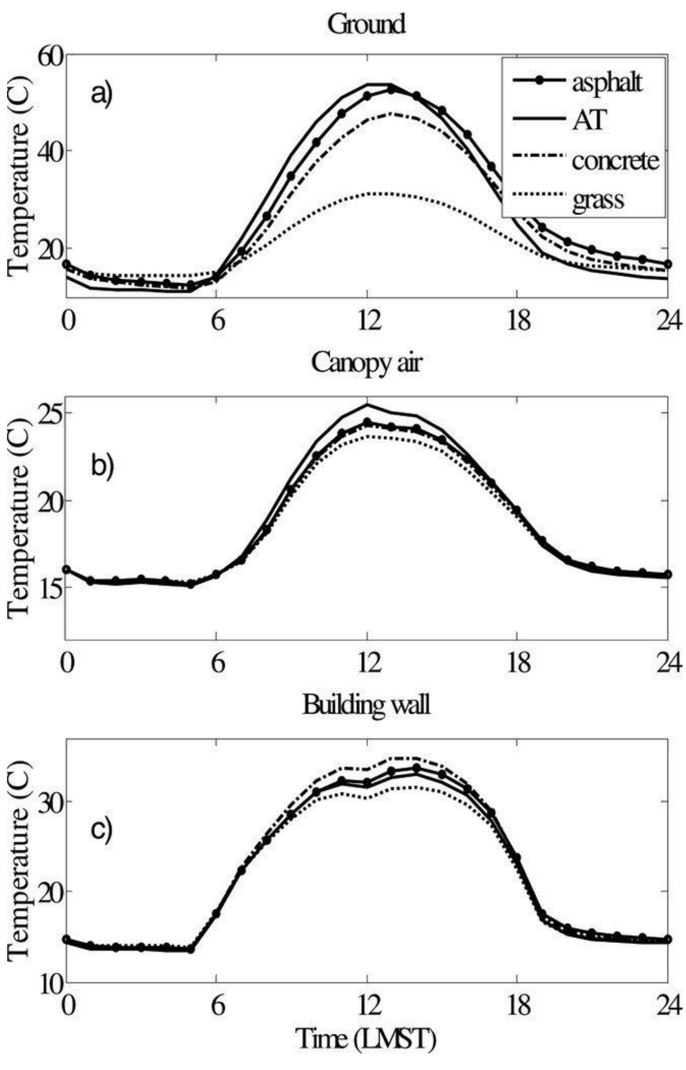
The Victorian Centre for Climate Change Adaptation Research (VCCCAR) which was funded to 2014 stated in a policy paper on responding to the urban heat island regarding synthetic turf:

“Not all Green Infrastructure is ‘Green’
A concern raised during this study was the suggestion by a number of interviewees that there is increasing use of artificial turf or grass on private and council-owned lands, because it is perceived to be ‘environmentally friendly’. One industry representative stated that they don’t call artificial turf ‘green’ infrastructure “because you can paint a wall green, but that doesn’t make it sustainable”.

Several interviewees argued that artificial turf is therefore not GI, even when coupled with underlying water retention tanks or other mechanisms. Although often portrayed as a solution to limited water availability, the literature suggests that artificial turf is not as green or eco-friendly as may have been claimed. McNitt et al (2008) state that “surface temperatures of synthetic turf are significantly higher than natural turfgrass surfaces when exposed to sunlight, with traditional synthetic turf being as much as 35-60°F higher than natural turfgrass surface temperatures”. Additionally, Claudio (2008) refers to work by Stuart Gaffin of the Center for Climate Systems Research at Columbia University, stating that “synthetic turf fields can get up to 60°F hotter than grass, with surface temperatures reaching 160°F on summer days” and concludes that the fields rival black roofs in their elevated surface temperatures.” (Bosomworth et al 2013)

The McNitt study, one of several from Pennsylvania State University, on the heat retention of synthetic turf, concluded that synthetic turf was found to have substantially higher surface temperatures than natural turfgrass. It suggests there are benefits in cooling synthetic surfaces with irrigation to reduce heat retention when needed, although that comes with the cost of installing irrigation. Water cooling would reduce the water savings benefit of synthetic turf that is often used as a justification for synthetic turf installation. (McNitt et al 2008).

A related study from Penn State assessing whether different fibre colours would make a difference to surface temperatures concluded that “No product in this test substantially reduced surface temperature compared to the traditional system of green fibers filled with black rubber in both the indoor and outdoor test. Reductions of five or even ten degrees [Fahrenheit. This equates to 2.77°C - 5.55°C] offer little advantage when temperatures still exceed 150° F [65.55° C]. Until temperatures can be reduced by at least twenty or thirty degrees [Fahrenheit. This equates to 11.11°C - 16.66°C] for an extended period of time, surface temperature will remain a major issue on synthetic turf fields.” (Pennsylvania State University Center for Sports Surface Research 2012)



Detailed Thermal modelling of artificial turf in an urban environment in southern California found “Using a simple offline convection model, replacing grass ground cover with artificial turf was found to add 2.3 kW h m -2 day -1 of heat to the atmosphere, which could result in urban air temperature increases of up to 4C.” (Yaghoobian et al 2010)

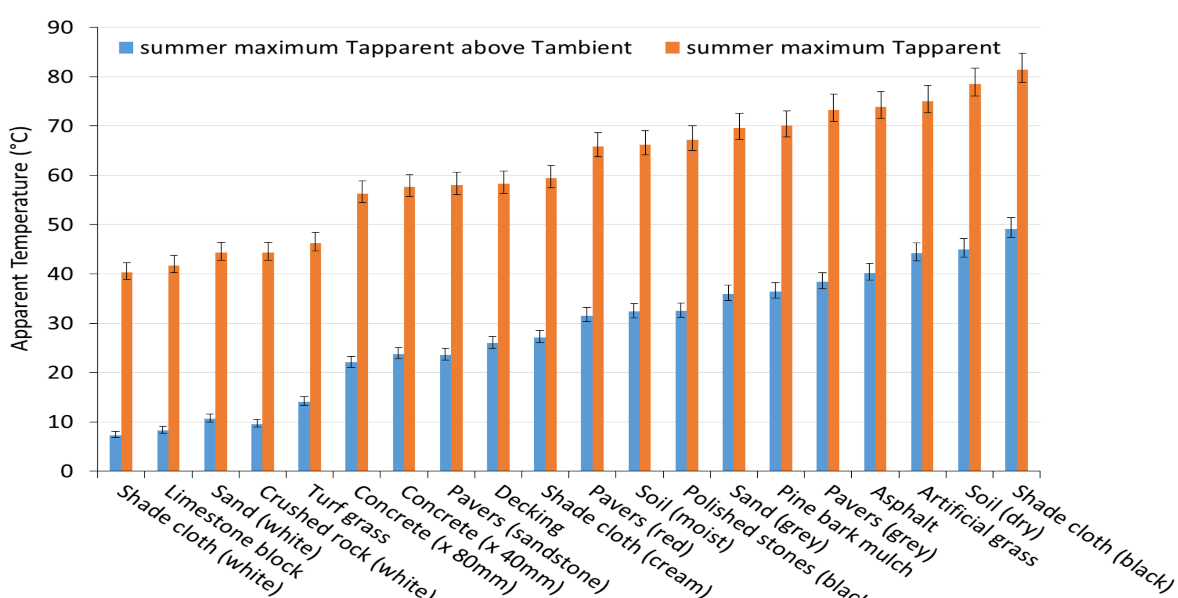
“The largest sensible heat flux from ground to canopy occurs over AT (Fig. 9). The reasons are high surface temperature (Fig. 5a), lack of water availability (unlike grass), and higher surface roughness (than asphalt and concrete; Table 1). Hence AT increases the canopy air temperature (Fig. 5b). (Left: Fig 5 shown)

The associated decrease in building wall-to-canopy sensible heat fluxes increases building wall temperatures and wall conductive heat fluxes.” reports Yaghoobian et al. This study has implications for surface heating of adjacent buildings, but that is a small impact for Hosken Reserve.

This study did not investigate the increase in Canopy air temperature on urban heat island temperatures which is most prominently an enhanced night time effect. As canopy air temperatures are heated during the day with less atmospheric mixing at night to conduct the ambient heat away it is likely night time temperatures in the local vicinity will be elevated due to the synthetic turf.

Research in Hong Kong highlighted that high air and surface temperature of artificial turf raises concerns on player health. Artificial turf with low specific heat and moisture incurs fast heating and cooling. The study identified cooler periods fit for matches on sunny, cloudy and overcast days. The study highlighted that Synthetic turf surface on a sunny day heated to 72.4 °C compared with natural grass at 36.6 °C. The synthetic turf dissipates heat by conduction and convection to near-ground air and by strong ground-thermal emission. The study found that the artificial surface exceeded the heat-stress threshold most of the time, but it cooled quickly from late afternoon for heat-safe use soon after sunset. (Jim 2017)

A Perth based study on the urban heat island effect of various surfaces, including turfgrass and synthetic turf, included a focus on change in evening surface and air temperatures. The study correctly notes that the urban heat island effect is most prominent as a night time impact, although it also is seen during the daytime. The research also highlights this is an issue beyond summer season and may include Spring and Autumn days when temperatures are elevated. This trend will only continue with rising temperatures associated with climate change. Perth average temperatures give a glimpse of Melbourne's future. For evening temperature change artificial turf surface temperatures will cool through convection of the heat to the atmosphere (lowering surface temperatures) but thus keeping the ambient air temperature high. This accentuates the night time impact of the urban heat island effect. This will especially impact local residents around a synthetic field, but is also be relevant to potential player heat stress from elevated ambient air temperatures (Loveday et al 2019)



Source: (2019) Seasonal and Diurnal Surface Temperatures of Urban Landscape Element

Melbourne climate researchers identified issues with urban heat island effect hotspots for Melbourne, and that the UHIE is predominantly a night time effect, measuring this night time temperature difference. The authors used an urban climate model, The Air Pollution Model (TAPM), to simulate the UHI intensity of 3–4 °C at 2 a.m. in January. Results for summer showed increased housing density results in increased intensity of night time UHI with growth areas and activity centres particularly affected. The model was calibrated against observational data from medium density Preston, a residential neighborhood in Melbourne's north. This was used to assess where urban planning should best be applied to mitigate UHI to improve local climates and identified in particular activity centres and growth areas. The research doesn't specifically cite what role synthetic turf has in adding to night time ambient air canopy temperatures. (Coutts et al 2008)

Researchers from the University of Western Sydney have been actively researching in recent years urban heat impacts especially for playgrounds and schools. While no artificial sporting fields are considered so far, the research on playground and school artificial surfaces is still highly relevant. "Assessment of surface temperature of different materials in full sunshine revealed that artificial grass and bare soil were the hottest surfaces, regardless of ambient temperatures (Table 8). Sunlit artificial grass reached a mean temperature of 52°C during the normal summer day despite the air temperature being below 30°C. The surface temperature of artificial grass increased when ambient air temperatures rose and a maximum value of close to 70°C was measured for this material." says the report. One of the recommendations of the report is that "Use of artificial grass should be avoided or restricted to areas with zero exposure to direct sunshine." (Pfautsch S., et al Sept 2020) This study built upon the work of an earlier report on Cool Schools (Madden et al 2018). It also is part of a collection of studies on impact of various surfaces and tree canopy on air temperature in Western Sydney (Pfautsch et al Oct 2020)

A recent news article in Sydney raised urban heat and plastics pollution issue of synthetic fields, with the NSW Planning Minister Rob Stokes asking his department to investigate sustainable alternatives to synthetic grass. One of the climate researchers specialising in heat in urban environments commented: "I absolutely loathe synthetic grass," said Dr Pfautsch, "It is possibly the worst materials for heat and it is made from completely unsustainable, non-recyclable plastic that goes straight to landfill." (Power March 2021)

Temperatures of sites around Moreland, including the synthetic pitch at Clifton Park, were measured on a 30C day in November 2020. The synthetic turf spot temperature ranged up to double the temperature of natural grass. (Englart, 2020)

The present grassed oval at Hosken Reserve would contribute to a park cooling effect for the local area, moderating urban heat island temperatures. A study on the cooling impact of parks (or park cooling effect) in moderating the Urban Heat Island Effect conducted in the Canadian city of Toronto concluded that "parks were cooler than the surrounding urban environment by up to 7°C" and that "park cooling was variable but could extend almost 100m downwind into the neighborhood" (Slater 2010)

The Victorian 'Artificial Grass for Sport Guide' fails to assess synthetic sports surface urban heat island effect (UHIE) for the local neighborhood, although it does minimally highlight there is a problem with high surface temperatures and heat stress health impact for users of the surface. (Sport and Recreation Victoria Feb 2011) In contrast, The WA State Government Department of Sport prepared a detailed Natural Grass vs Synthetic Turf report and Decision Making Guide. The guide devotes a section to Heat issues – natural grass and synthetic surfaces which contains temperature comparisons between natural grass and artificial turf from studies carried out in the US, Japan and elsewhere, focusing on third generation artificial turf. (WA State Government Department of Sport 2011)

The consultants report for the Sports Surface Needs Analysis only offered limited measures to ameliorate the extra urban heat of these fields, with perhaps some extra tree vegetation on the margins and recommendation to use Coolgrass technology synthetic turf which only offers a marginal reduction (10-15 percent) in surface temperatures. (Moreland Council April 2018) This is far from sufficient for player safety and in moderating surface heat and contribution to the urban heat island effect impact on local residents

There is some good news for reducing synthetic turf heat by using organic infill which has a high moisture retention capacity. Through regular irrigation twice a week for a field, this can limit the temperature to slightly above grass temperatures.(Greenplay Organics, July 2012) But this has a major tradeoff regarding water use and conservation (refer to water conservation argument) It also does not negate the greenhouse gas emissions, waste to landfill, biodiversity impacts and health risks.

Replaces natural grass which allows soil organic carbon sequestration, provides oxygen

One of the benefits of natural grass oval is its potential to sequester carbon both in grass leaves and in the soil, and produce oxygen. It is a living ecosystem that provides a host of environmental services that is simply not matched by synthetic turf.

There are many studies that argue that urban lawns, even golf courses, can potentially be carbon negative if managed conservatively. Two of the largest sources for greenhouse gas emissions are the use of fertiliser and use of fuel in maintenance. Fertiliser is emissions intensive in manufacturing, and can increase nitrous oxide emissions from grasslands if not applied carefully. Some of these studies argue that fuel use as part of the hidden carbon costs could perhaps be eliminated or greatly reduced through transition to battery electric maintenance vehicles and tools. See (Braun et al 21 March 2019, Kong et al 2013, Law et al 2017, Meil et al 2006, Poeplau et al 2016, Qian et al 2012, Tidåker et al 2017)

A 2010 study argued that due to regular restoration work due to sports wear, sporting ovals are unlikely to provide carbon sink capability as Soil Organic Carbon. These natural grass sporting ovals are also subject sometimes to high maintenance regimes with irrigation and fertiliser which can cause excess Nitrous Oxide emissions, a very powerful greenhouse gas. Originally the authors concluded most urban lawns would not be carbon sinks but a correction issued 2 months later adjusted their conclusions that while sporting field grass could not effectively store soil organic carbon, the situation was more nuanced generally for urban lawns and grasslands depending upon the maintenance regime hidden carbon costs and conservative fertiliser management. (Townsend-Small, A. and Czimczik, C. (2010a,b).

Irrespective of whether the Hosken Reserve grass is actually carbon neutral and operates as a carbon sink, the lifecycle emissions associated with grass is far less than synthetic turf. (See Greenhouse gas emissions section)

Reduces soil biota, grass seeds and insects with a trophic impact on local biodiversity primarily birdlife.

One usually doesn't associate biodiversity with a grass sporting oval, yet the grasses support a whole host of small creatures: insects, bacteria, and fungi in the soil. The insects and grass seeds are part of a food chain for higher species like local birdlife. Replace this grass with synthetic turf and you impact all this soil biota with a trophic impact on local birdlife.

This is far from supposition. An academic study published in 2020 that looked at replacement of natural grass parks and surfaces to hard surfaces in an urban setting caused a decline of house sparrows. The authors thought this is likely symptomatic of other birdlife decline. Birds that visit the present oval will try to go elsewhere but will likely be subjected to competitive pressures. The result is less birdlife. (Bernat-Ponce et al 2020). This study references a Melbourne study: that "replacing natural lawn with artificial grass is seen as a way to save water (Moore 2009) and to reduce management requirements in Mediterranean climates."

It draws a conclusion that "These changes could lead to a significant reduction of the diversity and number of available invertebrates which could have an important effect limiting the reproductive success and survival of urban bird species (Chamberlain et al. 2009; Peach et al. 2015)."

There may be a knock on effect of reduced birdlife on mental health of people who live in the area. There is some evidence that birdsong assists in general mental health. Converting Hosken Reserve oval to a synthetic oval will have a trophic impact reducing local birdlife which will be another stressor reducing human mental health of local residents. (Begum, Tammana, 8 October 2020)

Insects often get short shrift when biodiversity is talked about, and yet we are facing a major decline in insect populations globally which has a trophic impact on biodiversity up the food chain and also reduces insect pollination services argues the academic study Scientists' warning to humanity on insect extinctions.(Cardoso et al 2020)

While replacing a grass oval with synthetic turf at Hosken Reserve may be quite a marginal impact on insect numbers in the global scheme of things, it is part of a cumulative impact in urban areas of increasing hard built-up surfaces reducing insect numbers.

Conversion of a natural grass sports oval that supports some biodiversity and provides environmental services, as well as recreation and organised sport use, to a synthetic pitch epitomises at the micro level what is happening to varying degrees at the landscape and global level. Scientists are clear: Pervasive human-driven decline of life on Earth points to the need for transformative change**.** (Díaz et al. December 2019) (see also UNEP February 2021)

Compacts the soil increasing stormwater runoff

As well as killing the soil biota a synthetic pitch will compact the soil increasing soil stormwater runoff.

One of the impacts of rising temperatures due to climate change is that for every degree Celsius of global warming the atmosphere can increase its moisture carrying capacity by about 7 per cent. We are already at 1.1 degrees C of warming so more water can be carried in the atmosphere to come down in more intense rainfall events. A natural grass sporting oval would have a certain capacity to soak up the water while a synthetic turf oval needs to be engineered to capture and store this water to prevent local flash flooding.

Natural grass provides erosion control, Groundwater Recharge and Surface Water Quality, and assists in organic chemical decomposition preventing pollution and heavy metals from flowing into local stormwater and creek waterways affecting water ecosystems. (Beard et al 1994)

Toxic Chemical leachates from rubber infill pollute waterways

Most synthetic turf fields use a recycled tyre rubber infill. After rain chemicals from the synthetic turf wash out as leachates into stormwater and local waterways. These leachates pose toxic health risk for humans and aquatic ecosystems according to a recent study that looked at leachates from 50 synthetic fields around Portugal. (Celeiro et al 2021)

Magnusson and Macsik (14 April 2017) in their Swedish study also raised some concern over leachates: “Substances which are known to be harmful for the aquatic environment and/or humans was detected in all infill leachates. Eight harmful substances were detected from RT with a total of 46 □g/l in the leachate….The results show that all infills tested produced leachates containing substances harmful to aquatic life. For the leachates from TPE, EPDM and R-EPDM, information about potential toxicity could not be found for a large share of the total S-VOCs identified and seems to be missing.” (Magnusson et al April 2017)

See also: A review of potentially harmful chemicals in crumb rubber used in synthetic football pitches. Gomes et al. (May 2021), Xu et al (2019) in their study of toxicity from leachates using a vertebrate model highlighted environmental impacts of Crumb rubber leachates on aquatic life and potential health risk on humans. (Xu et al 2019)

Results in increased lower extremity injuries in elite players

There has been various studies on whether there is an increase in sports injuries from Synthetic turf, some being inconclusive. These are two different surfaces with different sports dynamics.

A recent epidemiological study conducted with 5 years of data concluded that synthetic turf produces more sports injuries associated with lower extremities than on grass fields. The researchers attempted to eliminate other factors by relying on 5 years of data from the USA National Football league. The study concluded that “These results support the biomechanical mechanism hypothesized and add confidence to the conclusion that synthetic turf surfaces have a causal impact on lower extremity injury.” (Mack et al Jan 2019)

Long term human health impacts uncertain, but vertebrate model confirms toxicity to human health of rubber infill leachates

A widely cited authoritative literature review from 2014 advised that there appeared to be low health risks from synthetic turf with crumb rubber infill. This was based on several studies. “Overall, studies evaluating end points in both children and adults consistently found that the tire rubber crumb in playgrounds and artificial turf fields poses low risk to human health through oral exposure.” But the review authors also called for more research: “It is also important to assess more systematically the risk posed by the tire rubber crumb on the environment and human health.” (Cheng et al 2014)

A letter in the International Journal of Hyperthermia in April 2019 identified a lack of epidemiological studies on the prevalence of heat stress episodes associated with synthetic turf compared to natural turf. “Such a study could help answer the questions posed here, regarding dangers associated with elevated surface temperatures. These values should give pause to the use of synthetic turf in warm and sunny situations. Reliance upon regional weather reporting or the wet bulb temperature does not provide a full picture of the threat of heat on synthetic athletic fields.” (Abraham April 2019)

A more recent Dutch study appears to confirm the conclusions of Cheng (2014):
“on the current evidence available, it is considered safe to play sports on STP with the rubber infill in place in the Netherlands. No immediate action was thus required. It was recommended though to review the conclusions when the results of the ongoing, large-scale studies in the US become available. Further, it was recognised that, should the rubber granulate have contained concentrations of PAHs as high as the European concentration limits for mixtures, safe use might not be guaranteed. To ensure therefore the supply of rubber granulate with only very low concentrations of hazardous substances (PAHs in particular) and thus the safety for people

playing sports, it was recommended to set regulatory limit values specifically for (substances in) rubber granulate.” (Pronk et al 2020)

However Xu et al (2019) examined the toxicity from leachates using a vertebrate model and the threat it poses to human health. The paper argues:

“Existing risk assessments of artificial athletic turf or CR have suggested low or negligible environmental and human health risks (2–5). However, none of these studies used a vertebrate model. Human health assessments often focused on youth or adult professional players, but the potential risk to younger children could be higher due to their earlier stage of development and frequent hand and facial ground contact. Moreover, the risk to human embryos via maternal exposure to CR is unknown. Environmental risk assessments are usually based on acute toxicity tests with invertebrate species on limited simple toxicological endpoints such as mortality. Chronic tests of CR on vertebrate species are lacking but critically needed because the release of toxic chemicals from CR is continuous and the leaching of contaminants from aging CR can be significant over the field’s functional lifetime.”

It is clear from Xu et al (2019) and others that the health risks of synthetic turf are far from being scientifically settled.

See also further scientific references on toxicity and health risk in the Leachates section.

Enhances infection transmission risk. Encourages a microbial community structure primarily defined by anthropic contamination.

A 2019 study looking at the bacterial and microbiotic differences between natural turf and synthetic grass sporting pitches. There are more incidents of abrasions and turf burns from artificial grass which may provide a pathway for bacterial and microbial infections. A major factor driving microbial diversity on synthetic surfaces is contamination with human sweat or saliva as well as from the natural microflora in the surrounding area. This highlights the importance of regular disinfecting maintenance required. There is an increased infection health risk from synthetic turf. “Infill materials can represent a potential source for bacterial grow posing putatively higher infection risks respect to natural fields.” (Valeriani et al 2019)

On the other hand, natural grass and soil on the oval at Hosken Reserve may have a positive health effect. There is evidence that contact with natural grass and soil has a positive effect on human health for allergies and auto-immune response. Converting natural grass sporting fields to synthetic surfaces reduces this positive effect. This 2012 study highlights that environmental biodiversity, human microbiota, and allergy are interrelated. As Moreland population density grows, natural spaces, including grass sporting ovals, will provide an important point in boosting children’s immune systems. The study concludes: “Interactions with natural environmental features not only may increase general human well being in urban areas (45), but also may enrich the commensal microbiota and enhance its interaction with the immune system, with far-reaching consequences for public health.” (Hanski et al April 2012)

Appears to improve water conservation, but the situation is far more complex when life-cycle assessment and irrigation to reduce heat for playability is taken into account

Water conservation is seen as an important justification for the transition from natural grass to synthetic. While it appears synthetic turf saves more water, this is not straight forward with far more complexity.

The Millennial drought highlighted the changing climate we face here in Melbourne, with rising temperatures and reducing winter and spring rainfall. Our sporting fields suffered, some of our park trees died and many had to be put on drip feed water rations to keep them alive through the drought. Out of this period also came a concerted push by sporting organisations for synthetic turf to ensure they could train and play, rather than the rationed use of grass sporting fields, due to water restrictions preventing irrigation.

The Melbourne University researcher Greg Moore published an academic paper in 2010 which highlighted water conservation. Dr Greg Moore was Principal of Burnley College of the Institute of Land Food Resources at Melbourne University with expertise in Plant Science and Arboriculture. He was also Head of the School of Resource Management at the University from 2002 to 2007. In the abstract he highlighted the problem; “At a time of climate change, it is worrying that both private and public open spaces are threatened by urban renewal and development that puts at risk long term sustainability.”

“Despite the current, popular view that turf and lawns are profligate water users and are unsustainable in the Australian environment, natural turf is usually a more sustainable option than sealed surfaces or artificial turf if you consider the latter’s fossil fuel chemical base and imbedded energy. Turf is quite a complex ecosystem that has a significant effect on temperature and the heat island effect, and if properly managed also sequesters a considerable amount of carbon. Perhaps it is not the villain that many think it is when they consider only the water component of a more complex equation.” (Moore 2009)

Dr Moore goes on to provide a scenario in the drought of a local Council replacing a naturf turf oval with synthetic turf due to local water authority water restrictions not allowing them to irrigate. It is part of their water policy to be more water efficient.. But the decision ignores the fossil fuel nature of the imported product they are installing with high embedded energy, carbon and water use in the manufacture of the product. Neither has the Council considered capyuring the water that runs off or passes through the new artificial turf surface. He argues that an efficient irrigation and water recycling and a water efficient native grass would be a far more sustainable option.

Does this scenario sound familiar to Hosken Reserve? Since that time many Councils, including Moreland have invested in stormwater harvesting and storage to supplement mains water supply for irrigation of sporting fields. This included the Stormwater harvesting and wetlands project at Hosken Reserve, which involved and engaged and was supported by the community, all while the Hosken Masterplan remained hidden from view.

Yaghoobian et al (2010) pointed out in their academic study that there is also embodied energy in water used in maintaining manicured lawns. When this energy in transport, delivery and use of water is accounted for there, they found a total energy use saving resulting in water and energy conservation in artificial lawns, although these results are particular to Southern California location and climate. Drought tolerant plants which require significantly less water than lawn may have a similar effect as artificial turf conjecture the researchers.

Abigail Alm in her undergraduate thesis highlighted the extent of embedded water use in synthetic turf manufacture and compared it with water used for irrigating a natural turf sporting field. She found evidence that synthetic turf uses about 4 years worth of water in the manufacturing process as one year of natural turf irrigation. Synthetic turf will also use water for cooling and cleaning. So the proffered water savings of synthetic turf during maintenance needs to be balanced with the embedded water during manufacturing once total life-cycle assessment analysis is taken into account.

“...producing synthetic turf, a product that raves about its ability to “save” water, requires a significant amount of water to be produced.” says Ms Alm

“A natural grass athletic field, under the assumption a standard field is 1.32 acres and must be watered once a week with a volume comparable to an acre/inch, requires 1,290 kGal to maintain the field per year (Sports Turf Managers Association and SAFE: The Foundation for Safer Athletic Fields). Whereas, synthetic fibers used to produce turf, according to Table 2, requires 6880 kGal per one million dollars spent on production.

“According to FieldTurf, one synthetic field costs 720,000 dollars to produce (Sports Turf Managers Association and SAFE: The Foundation for Safer Athletic Fields). When taken into consideration, it costs 4,985 kGal of water to produce one synthetic field. This amount is 4 times the amount required to adequately maintain a natural grass field over the course of one year (Table 4). Granted, synthetic turf will outlast a 4 year period, but may in some environments require small inputs of water to be properly maintained (cleaning and cooling) throughout the many years of use in addition to the manufacturing demands. Overall, synthetic turf may not be “saving” as much water as the companies claim when production demands are accounted for. The negative externalities featured in Table 1, 2, and 3 make artificial turf a product that should be more thoroughly evaluated before installation continues in areas across the country not featured in Figure 4.”

Another life cycle analysis by Adachi et al (2016) compared lifetime water use between a synthetic field and a natural grass field. It found that “our lifecycle water consumption for artificial turf (1926.26 gal/m 2) was much lower than that of natural grass (7926.08 gal/m 2). Turf requires roughly 24.3% of the water that natural grass does.”

“For artificial turf, by far the two highest contributors to this water consumption were water used to create energy used in manufacturing artificial turf (50.12% of life cycle water consumption), and water used to clean the turf (48.65% of life cycle water consumption). The remaining 1.23% came from backing production, water used directly in production (stage one), and blade manufacturing. For natural grass, the largest component is by far the water used to irrigate the grass once it is installed. This represents 82.77% of the total water input. If you add in the water used to produce the sod, which is essentially just watering the lawn before it’s rolled up and delivered to a home, then that figure rises to 87.90% of all water consumed.”

Clearly there is a discrepancy here on total life cycle assessment of water in these two studies, although synthetic turf comes out ahead in both assessments on total water use.

Natural turf is also becoming more drought tolerant with higher water efficiency, with different varieties and future possibilities as described by Hatfield, J. (2017).

But the issue gets more complicated.

A study by Kanaan et al (August 2020) called Water Requirements for Cooling Artificial Turf confirms a water usage for cooling model that Synthetic Turf and Natural turf water usage may be comparable during the maintenance part of the total life cycle assessment.

“This model indicates that the amount of water required to maintain AT temperatures at levels comparable to irrigated NT over a 24-h period exceed the water requirements of bermudagrass NT in the same environment. Thus, the argument for using AT- instead of bermudagrass-based NT in arid climate zones for water conservation is nuanced and depends on the presence of an irrigation system, desired playing conditions, and the length of time irrigation will be used to maintain the target temperature during daylight hours.”

Development of organic infills has occurred due to heightened community perceptions over the health risk of crumb rubber infill used in synthetic turf, and the elevated surface temperatures that can cause heat stress.

At least one synthetic turf manufacturer has developed a product with an organic infill material that ameliorates the high surface temperatures. It does this by having a moisture carrying capacity which acts similar to plant transpiration in cooling the artificial surface. But it comes with a tradeoff: increased water use.

The ISA Sports test results on comparing the Limonta Sports synthetic turf with organic Infill with a synthetic field with rubber infill and Natural grass has implications for water use of synthetic fields. "Even under the most intense heat and with no naturally occurring precipitation we feel that the field will require no more than 12,000 gallons of water applied twice a week for the field to perform optimally."(Greenplay Organics, July 2012)

That translates as 1,200 kgals per year. A Natural grass field will use about 1,290 kgals per year, according to Alm (2016). So this is pretty similar to Kanaan et al (2020) position that synthetic field water use for managing field temperatures is comparable to the water requirements of a natural grass field.

If Organic infill is used for a new sporting field, increased water use needs to be also part of the equation. The original source of the infill fibres also need consideration to ensure this isn't causing emissions associated with land clearing and biodiversity impacts at source.

Organic infill synthetic turf still has a waste problem. "There are no reports of organic infill pitches being recycled at present." reported Eunomia Research & Consulting Ltd for FIFA, (March 2017).

It is clear that water conservation is a complex issue regarding natural turf vs synthetic turf, and needs to be considered with care.

Economic Costs

The Western Australia Department of Sport in their 2011 analysis of Synthetic vs natural sporting fields contained the following total life cycle cost comparison for a soccer pitch with construction and annual maintenance costs and Total life costs for 25 year and 50 year life periods. Costs are in 2011 dollar values. (WA State Government Department of Sport, 2011)

Construction Costs	Natural Grass	Synthetic Turf
Soccer (Community pitch)	$212,000	$705,000

Operating Costs (Annual)	Natural Grass	Synthetic Turf
Soccer (Community pitch)	$27,250	$25,000

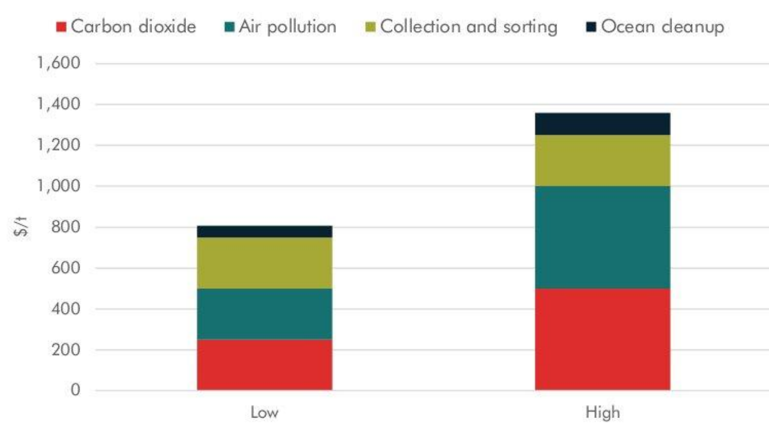
Total life cost	Natural Grass 25 years	Natural Grass 50 years	Synthetic Turf 25 years	Synthetic Turf 50 years
Soccer (community pitch)	$1,004,917	$1,797,833	$2,517,500	$4,330,000

Synthetic turf total life cycle assessment economic costs are more than double that of natural grass.

FFV recommends a 2:1 equivalence value for synthetic turf to Natural grass pitch usage.(Football Federation Victoria, 2018) On a usage basis, halving the total life cycle economic costs for synthetic turf still does not quite match the total life cycle economic costs of Natural grass for a 25 year or 50 year period.

Carbon Tracker estimates plastics contribute an untaxed externality upon society of at least $1,000 per tonne from carbon dioxide, health costs, collection costs, and ocean pollution. This may be a conservative estimate as the researchers say it does not include the cost of litter on land, the cost of microplastics, and the health costs to workers in petrochemical plants.(Carbon Tracker 2020).

FIGURE 7. PLASTIC EXTERNALITIES PER TONNE $



Source: EPA, CREA, WHO, UNEP, CT estimates, Breaking the Plastic Wave

In the Moreland City Council - 'Detailed Capital Works Expenditure Program for 2020/21' 18623 Hosken Reserve - Synthetic Soccer $1,000,000 allocated being $300,000 grant funding and $700,000 from Council.

The Moreland Sport and Recreation Strategy 2020 listed 4 expenditure items for Hosken Reserve:

Hosken Reserve	Moreland Pavilion Redevelopment Strategy	Refurbish facilities at Reserve	2021/22	$222K
Hosken Reserve (south)	Moreland Sportsfields Review	Reconstruct playing field	2020-22	$600K
Hosken Reserve (north)	Moreland Sportsfields Review	Develop synthetic field (including lights)	2021/22	$1.2M
Hosken Reserve	Hosken Reserve Masterplan	Complete implementation of masterplan	6-10 years	$800K

So we are looking at Moreland Council expenditure of at least One million dollars to convert an existing grass oval to a new synthetic surface. This includes ripping up the current irrigation system on the oval. A large amount of expense would need to be renewed at end of life in replacing the synthetic turf mat and infill, generally considered as 10 years.

And we get over 500 tonnes CO2 equivalent emissions (Magnusson and Macsik 14 April 2017) and all the problems of generating approximately 274 tonnes of landfill waste (turf mat and infill) every ten years.(Eunomia Research & Consulting Ltd for FIFA, March 2017)

The Sports and Recreation Strategy, written at the time when Council were proceeding with grass to synthetic conversion without any local engagement or public availability of the Reserve masterplan, also recommended installation of an athletics track when the synthetic field is constructed at Hosken Reserve.

Other issues: Fire risk, alternative infills, Traffic, Car Parking, cycling impacts

One of the issues discovered during research was the increased flammability of a synthetic turf pitch. If synthetic turf was to go ahead Fire risk plans would need to be put into place. There is a risk of sporting fans causing fire, a risk of vandals trying to start a fire on the field. Currently the oval is occasionally used by people to set off fireworks as this is the only local space to do so for nearby residents. This would no longer be acceptable from a fire risk point of view, but I wonder if New Years Eve revellers would accept this restriction? Accompanying the fire risk is the toxicity and health risk of smoke from any fire for local residents.(Kukfisz, B., 2018)

The Sports Surface Needs Analysis (2018) proposed that organic infills be used to counter public perceptions of a health risk from using SBR crumbed rubber infills and other plastics based infill products. While recent studies confirm that there appears to be minimal toxicity health risk to player safety from crumbed rubber infills, this is a far from settled issue according to several reports, including the vertebrate model confirming toxicity of crumbed rubber infill, and the lack of any long term epidemiological studies which may show higher cancer risk.

The Delaware River Keepers report on alternative infills raises several concerns. “Very few toxicological and risk assessment studies regarding the health and environmental impacts of emerging alternative infill options have been completed but from the data that is available there are many concerns to be had. While there is insufficient data on the chemical composition, off-gassing, leaching, and associated health and environmental effects that may result, the data that is available demonstrates many reasons for concern. For these reasons, the precautionary principle should be used to avoid the unnecessary and potentially devastating harms to those who would come in direct contact with the infills and the environment surrounding them. All alternative infill options are significantly more expensive than traditional crumb rubber; with all artificial turf systems (including those with crumb rubber infill) costing more than natural turf grass.There is no proven record of the durability, performance, and lifespan of these infills to warrant the cost.”(Delaware Riverkeeper Network, October 2016)

A synthetic turf pitch with double the usage will likely generate more traffic in surrounding streets, particularly Shorts Road and Pallett street. Traffic levels may increase on these quiet streets. This will likely increase competition for on street parking, and add to residents perceptions of safety for children, reduce local residential amenity.

Both Shorts Road and Pallett street are presently fairly quiet traffic routes, and sometimes used by cyclists for this reason. Shorts Road is an east-west route from Merri Creek to Sussex street and further west, Pallett street as a north-south route to Richards Reserve and the velodrome and points further south.

Discussion

Let us go back to examine the triple bottom line criteria of the benefits and impacts for the social, environmental and economic factors for conversion of a natural grass sporting oval to a synthetic sports pitch.

There is social benefit gained by increased organised sport usage enabled by a synthetic turf pitch. This benefit predominantly accrues to those people participating in the sporting clubs that use this space and it also contributes to a general population health benefit. There are also social and mental health benefits accruing to these people from also being part of a sporting club. But there are also social impacts which largely accrue to local residents who presently use this open space. Restrictions on use of artificial turf, and less availability of this space due to increased use by the Sporting Club, less open space for informal active recreation, more traffic in local streets, less birds to enjoy their birdsong, increased urban heat island effect which will manifest as a higher night time impact on local residents liveability and comfort.

The environmental factors are mostly negative: increased greenhouse gas emissions, a product that adds to landfill and pollution from leachates, increases microplastics, reduces biodiversity, urban heat island effect, increases infection risk and reduces opportunity for boosting immune systems. Both the carbon footprint of synthetic turf and disposal of synthetic turf contradict existing Moreland Council policies.

On the Economic side the total life cycle cost of synthetic turf is more than double the total life cycle cost of natural grass. Even if you factor in a 2 to 1 Usage factor for artificial surface as per Football Federation Victoria, the economic total life cycle cost is still marginally greater for synthetic turf. And this ignores the present situation with Hosken Reserve with an established grass surface with an irrigation system connected to existing stormwater harvesting already installed. This infrastructure is slated to be ripped up as part of installation of any synthetic pitch.

Water conservation has been widely used as a justification for installing synthetic turf, but this issue too is complicated. Synthetic turf has water embedded in its production, although less water is used during maintenance but resulting in substantial surface temperatures during sunny weather. It is the water content in the soil, grass and trees that through evapotranspiration provides essential cooling which adds to human comfort and liveability. These benefits largely apply to local residents. To maximise usage of synthetic turf in spring, summer and autumn to keep surface temperatures low and avoid heat stress health risk, irrigation would be required to cool the artificial surface on a regular basis thus cancelling out any water saving. There are organic infill products now available that may help limit synthetic surface temperatures by having a moisture carrying capacity, but these require regular irrigation thus also cancelling out any purported water conservation.

Conclusion

It is the considered opinion of Climate Action Moreland that based on triple bottom line decision making factors synthetic turf justification is marginal at best for the social factors with some positive and some negative, strongly against based on the environmental factors, with the economics still not stacking up for synthetic turf even once you factor in the 2 to 1 equivalence usage factor as used by Football Federation Victoria..

Climate Action Moreland argues that there are two grounds on which synthetic turf should not even be contemplated based upon conflict with existing Council policies. Either reason should be singly sufficient for natural grass conversion to synthetic turf to not proceed at Hosken Reserve. These reasons are: total life cycle assessment analysis of greenhouse gas emissions at a time when we need to be reducing high carbon footprint infrastructure, and the end of life disposal as landfill and its associated problems of leachate pollution and microplastics.

The reasons enumerated are also strong grounds for Moreland Council to reconsider the standing recommendations for the nine sporting fields recommended to be converted to either hybrid or full synthetic surfaces. This reconsideration should be done as it is a requirement of the Local Government Act 2020 overarching governance principles (section 9 Point (2)

> “(b) priority is to be given to achieving the best outcomes for the municipal community, including future generations;
> (c) the economic, social and environmental sustainability of the municipal district, including mitigation and planning for climate change risks, is to be promoted;”

Climate, health, biodiversity and pollution related issues of Synthetic turf - an Annotated Bibliography

Increasing use of synthetic surfaces and synthetic turf is problematic for Several reasons. Synthetic turf is:

* Derived from fossil fuel petrochemical industry
* Produces greenhouse gas emissions during manufacturing and as it degrades
* Increases landfill at end of life
* Produces micro-plastic pollution as synthetic turf breaks down
* increases urban heat island effect on local residents.
* replaces natural grass which allows soil organic carbon sequestration, provides oxygen
* reduces soil biota, grass seeds and insects with a trophic impact on local biodiversity primarily birdlife.
* compacts the soil increasing stormwater runoff
* Toxic Chemical leachates from rubber infill pollute waterways
* results in increased lower extremity injuries in elite players
* long term human health impacts uncertain, but vertebrate model confirms toxicity to human health of rubber infill leachates
* encourages a microbial community structure primarily defined by anthropic contamination
* appears to improve water conservation, but the situation is far more complex when life-cycle assessment and irrigation to reduce heat for playability is taken into account
* Other issues: increased fire risk, alternative infills, traffic, parking and cycling

This annotated bibliography was developed for the issue of conversion of existing grass sports fields to synthetic turf in Moreland Municipality, and includes specific documents relating to the issue in Moreland. Most of the articles are peer reviewed science studies plus some relevant grey literature. Most articles I have personally read, although for a small number I only had access to the scientific abstract to review.

Moreland Council needs to reassess current recommended plans to rollout synthetic surfaces in the municipality with regard to Council policies developed in recent years. These policies include, but are not limited to, the Climate Emergency Framework including the Zero Carbon Moreland 2040 Framework, Waste and Litter Policy (aiming for zero waste to landfill and a circular economy), and the Urban Heat Island Action Plan.

I have cast my scientific reading wide to encompass: total life-cycle assessment analysis related to synthetic fields and natural turf; water use and conservation; energy; soil carbon sequestration; greenhouse gas emissions; heat retention and urban heat island effect; microplastics and pollution; impact on biodiversity; health impacts and sports injuries.

John Englart for Climate Action Moreland, 27 March 2021

Annotated Biography:

Abraham, John (April 2019) Heat risks associated with synthetic athletic fields, International Journal of Hyperthermia 36(1):1-2, DOI: 10.1080/02656736.2019.1605096 https://www.tandfonline.com/doi/full/10.1080/02656736.2019.1605096
Keywords: Heat, Synthetic turf, health

A letter on the health risk from synthetic turf pitches, published in 2019 in the International Journal of Hyperthermia. "to the best knowledge of the author there have been no epidemiological studies on the prevalence of heat stress episodes associated with synthetic turf, compared with natural turf. Such a study could help answer the questions posed here, regarding dangers associated with elevated surface temperatures. These values should give pause to the use of synthetic turf in warm and sunny situations. Reliance upon regional weather reporting or the wet bulb temperature does not provide a full picture of the threat of heat on synthetic athletic fields."

Alm, Abigail., (May 2016), Is Synthetic Turf Really "Greener"? A Lifecycle Analysis of Sports Fields Across the United States, Undergraduate thesis, Carthage College, Kenosha, Wisconsin https://dspace.carthage.edu/handle/123456789/5520
Keywords: LCA, Water, Synthetic turf, Natural turf, irrigation

The author attempts to provide a life cycle analysis of synthetic turf in order to determine under what circumstances the environmental benefits of a synthetic turf field outweigh the long-term environmental costs. One of the interesting facts highlighted in this study is that synthetic turf uses about 4 years worth of water in the manufacturing process as one year of natural turf irrigation. Synthetic turf will also use water for cooling and cleaning. So proffered water savings of synthetic turf may be somewhat minimal when total life-cycle assessment is taken into account.

"...producing synthetic turf, a product that raves about its ability to "save" water, requires a significant amount of water to be produced.

"A natural grass athletic field, under the assumption a standard field is 1.32 acres and must be watered once a week with a volume comparable to an acre/inch, requires 1,290 kGal to maintain the field per year (Sports Turf Managers Association and SAFE: The Foundation for Safer Athletic Fields). Whereas, synthetic fibers used to produce turf, according to Table 2, requires 6880 kGal per one million dollars spent on production. "According to FieldTurf, one synthetic field costs 720,000 dollars to produce (Sports Turf Managers Association and SAFE: The Foundation for Safer Athletic Fields). When taken into consideration, it costs 4,985 kGal of water to produce one synthetic field. This amount is 4 times the amount required to adequately maintain a natural grass field over the course of one year (Table 4). Granted, synthetic turf will outlast a 4 year period, but may in some environments require small inputs of water to be properly maintained (cleaning and cooling) throughout the many years of use in addition to the manufacturing demands. Overall, synthetic turf may not be "saving" as much water as the companies claim when production demands are accounted for. The negative externalities featured in Table 1, 2, and 3 make artificial turf a product that should be more thoroughly evaluated before installation continues in areas across the country not featured in Figure 4."

Adachi, Jennifer., Jansen, Chris., Lindsay, Marina., (2016), Comparison of the Lifetime Costs and Water Footprint of Sod and Artificial Turf: A Life Cycle Analysis, Austin Park, Carolina Villacis UCLA Environment 159 Professor Deepak Rajagopal June 2, 2016.
https://www.ioes.ucla.edu/wp-content/uploads/sod-vs-artificial-turf.pdf
Keywords: LCA, Water, Synthetic turf, Natural turf, Costs

A life cycle assessment (LCA) on synthetic turf and natural grass for water footprint and lifetime costs for Southern California. From the study conclusions: "Based on our calculations, the cost of turf production is $75.29/m 2 compared to $53.41/m 2 for sod. In addition, the total water needed to maintain artificial turf is 1926 gal/ m 2 compared to 7926 gal/m 2 for sod. Clearly, from a water perspective, artificial turf will use less in the long run. However, when considering the greater cost of turf manufacturing and the impacts of its artificial materials this choice becomes less clear. Also, an individual living in an area with ample rainfall may find that turf is an inferior choice, environmentally as well as economically, based on their personal conditions. It is important to note that other factors such as chemical leaching and ecosystem disruption which are possible side-effects of artificial turf, have not been included in this analysis."

Beard, J. B.; Green, R. L. The role of turfgrasses in environmental protection and their benefits to humans (1994). J. Environ. Qual. 1994, 23 (3), 452−460.
https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1994.00472425002300030007x
Keywords: Biodiversity, Natural turf

This study outlines the many benefits of natural turf grass in urban environments. From the abstract: "Turfgrass benefits may be divided into (i) functional, (ii) recreational, and (iii) aesthetic components. Specific functional benefits include: excellent soil erosion control and dust stabilization thereby protecting a vital soil resource; improved recharge and quality protection of groundwater, plus flood control; enhanced entrapment and biodegradation of synthetic organic compounds; soil improvement that includes CO 2 conversion; accelerated restoration of disturbed soils; substantial urban beat dissipation-temperature moderation; reduced noise, glare, and visual pollution problems; decreased noxious pests and allergy-related pollens; safety in vehicle operation on roadsides and engine longevity on airfields; lowered fire hazard via open, green turfed firebreaks; and improved security of sensitive installations provided by high visibility zones. The recreational benefits include a low-cost surface for outdoor sport and leisure activities enhanced physical health of participants, and a unique low-cost cushion against personal impact injuries. The aesthetic benefits include enhanced beauty and attractiveness; a complimentary relationship to the total landscape ecosystem of flowers, shrubs and trees; improved mental health with a positive therapeutic impact, social harmony and stability;

improved work productivity; and an overall better quality-of-life, especially in densely populated urban areas.”

Begum, Tammana, 8 October 2020, How listening to bird song can transform our mental health, Natural History Museum, Accessed 7 March 2021
https://www.nhm.ac.uk/discover/how-listening-to-bird-song-can-transform-our-mental-health.html
Keywords: Health, Biodiversity

Argues the importance of birdsong to our general mental health. Converting a grass oval to synthetic oval will have a trophic impact on reducing local birdlife which will be another stressor adding to human mental health.

Bernat-Ponce, E., Gil-Delgado, J.A. & López-Iborra, G.M. Replacement of semi-natural cover with artificial substrates in urban parks causes a decline of house sparrows *Passer domesticus* in Mediterranean towns. *Urban Ecosyst* 23, 471–481 (2020).
https://doi.org/10.1007/s11252-020-00940-4
Keywords: Biodiversity, Synthetic turf

This is a rare academic study looking at the direct impact of increasing synthetic surfaces and other hard surfaces on urban biodiversity. The study focussed on decline of house sparrows, but the authors are at pains to point out other species could suffer similar decline. Urban surface changes have a trophic impact on a variety of urban birdlife. Abiotic surfaces such as synthetic grass had more impact on birdlife than conversion to hard soil. This is a cumulative impact that may not be visible with one field conversion, but biodiversity impact still needs to be included in decision making on natural grass conversion to synthetic turf.

“These park remodelling actions linked to reurbanisation processes are transforming traditional parks into domestic modified versions of them. For example, replacing natural lawn with artificial grass is seen as a way to save water (Moore 2009) and to reduce management requirements in Mediterranean climates. These changes could lead to a significant reduction of the diversity and number of available invertebrates which could have an important effect limiting the reproductive success and survival of urban bird species (Chamberlain et al. 2009; Peach et al. 2015).”

“...going back to traditional park models would probably be a better option to preserve biodiversity. … More research is urgently needed to precisely identify the short-, mid- and long-term effects of park remodelling and the use of artificial grass on urban biodiversity.”

Bosomworth, Karyn, Trundle, Alexei, McEvoy, Darryn (October 2013), Responding to the urban heat island: a policy and institutional analysis, VCCCAR, ISBN: 9780734048915
http://www.vcccar.org.au/publication/final-report/responding-to-urban-heat-island-policy-and-institutional-analysis
Keywords: Heat, UHIE, Synthetic turf, Australia

This science based report by the Victorian Centre for Climate Change Adaptation Research (VCCCAR was funded to 2014) deals with Green Infrastructure and heat stress in the context of a warming climate and urban heat island effect. It had wide stakeholder buy in from academic researchers from various Melbourne universities and certain Victorian State Government Departments. Rather than management of heat stress as a byproduct of making a decision to put in infrastructure increasing urban heat, it focuses on addressing and mitigating urban heat through Green Infrastructure. On page 17 the report says:
"Not all Green Infrastructure is 'Green'
A concern raised during this study was the suggestion by a number of interviewees that there is increasing use of artificial turf or grass on private and council-owned lands, because it is perceived to be 'environmentally friendly'. One industry representative stated that they don't call artificial turf 'green' infrastructure "because you can paint a wall green, but that doesn't make it sustainable".
Several interviewees argued that artificial turf is therefore not GI, even when coupled with underlying water retention tanks or other mechanisms. Although often portrayed as a solution to limited water availability, the literature suggests that artificial turf is not as green or eco-friendly as may have been claimed. McNitt et al (2008) state that "surface temperatures of synthetic turf are significantly higher than natural turfgrass surfaces when exposed to sunlight, with traditional synthetic turf being as much as 35-60°F higher than natural turfgrass surface temperatures". Additionally, Claudio (2008) refers to work by Stuart Gaffin of the Center for Climate Systems Research at Columbia University, stating that "synthetic turf fields can get up to 60°F hotter than grass, with surface temperatures reaching 160°F on summer days" and concludes that the fields rival black roofs in their elevated surface temperatures."

Braun, Ross C., and Bremer, Dale J., (21 March 2019), Carbon Sequestration in Zoysiagrass Turf under Different Irrigation and Fertilization Management Regimes, Agrosystems, Geosystems and Environment. https://doi.org/10.2134/age2018.12.0060
Keywords: Greenhouse Gas Emissions, Natural turf, Carbon sequestration, water, irrigation

This study was conducted on a Kansas golf course with Zoysiagrass. It highlights that Hidden Carbon costs, which are energy-based inputs from turf maintenance, should be factored into

soil C sequestration calculations. Importantly, it also took into account Nitrous Oxide (N2O), a powerful greenhouse gas in the emissions assessment.
"the net SOC sequestration rates in zoysiagrass were not statistically different at 0.412 to 0.616 Mg C ha^{-1} yr^{-1} in HMI and LMI, respectively."
Its conclusion is that "A higher-input management regime in turf will not increase net C sequestration compared with a low management input regime."
"The HMI had 76% more HCC than the LMI, mainly due to N fertilization application and higher irrigation amounts. Nitrogen fertilization and higher irrigation amounts in the HMI led to not only greater N2O emissions, but also 10.4 more mowing events per year."

Carbon Tracker. (2020). The Future's Not in Plastics: Why Plastics Sector Demand Won't Rescue the Oil Sector. London, UK: Carbon Tracker. Available at: https://carbontracker.org/reports/the-futures-not-in-plastics/
Keywords: Plastics, Environmental Context, Greenhouse gas emissions, Grey Literature

This is an important assessment of the future of plastics from a highly reputable international Climate think tank. Lifetime CO2 is estimated at an average of 5 tonnes of CO2 per tonne of plastics. It also imposes a massive "untaxed externality upon society of at least $1,000 per tonne ($350bn a year) from carbon dioxide, health costs, collection costs, and ocean pollution….plastic is responsible for roughly twice as much carbon dioxide per tonne as oil." For Moreland Council a decision to avoid conversion of natural grass to synthetic turf is a substantial carbon and externality cost saving.

"Plastics drive growth. As demand growth drivers like transportation have fallen, so plastics make up all the expected growth in oil for petrochemicals, and are the largest driver of expected oil demand, with 95% and 45% of oil demand growth in the central forecasts of BP and the IEA. Plastics are uniquely vulnerable. Plastics impose a massive untaxed externality upon society of at least $1,000 per tonne ($350bn a year) from carbon dioxide, health costs, collection costs, and ocean pollution. And yet 36% of plastic is used once and thrown away, 40% of plastics ends up in the environment, and less than 10% of plastic is really recycled. Polls by IPSOS indicate that 70-80% of people want radical action to change this."

"Every year, the world uses 4,500 mt of oil and 1,000 mt of petrochemical feedstocks but only around 350 mt 2 of plastics. Nevertheless, plastics play a key role in the petrochemical and oil industries.

"As set out in the IEA's seminal report on the future of petrochemicals, there are thousands of uses of petrochemicals, in two main areas – plastics and fertilizers. In this note, we focus specifically on the petrochemical demand for oil. We show as below that plastics make up two thirds of demand for oil in the petrochemical sector and all of the growth in demand for oil."

"There are technology solutions. There are three main solutions – reduce demand through better design and regulation; substitute with other products such as paper; and massively increase recycling. A recently published report, "Breaking the Plastic Wave" shows how to implement these solutions to deliver 2040 plastic utility at half the capital cost, half the virgin plastic, 25% less GHG emissions and 700,000 more jobs relative to BAU by 2040."

"Carbon dioxide
Carbon is produced at each stage of the plastic value chain: to produce oil; to convert into resins; and at the end of life when plastic is burnt, buried or recycled. A very detailed analysis of the issue by Zheng et al in Nature Climate Change in 2019 suggested that the total carbon footprint of plastics was 4.4 tonnes of CO2 per tonne of plastics. "Breaking the Plastic Wave" estimates the carbon footprint per tonne based on its final disposal method as below; if we multiply this by the share of plastic ending up in each area, it averages out a little higher at just over 5 tonnes of CO2 per tonne of plastics. In any event, a good rule of thumb number is likely to be 5 tonnes of CO2 per tonne of plastic. To put this into context, the World Energy Outlook in 2019 notes that the CO2 emissions of the 4,500 mt of oil used in 2018 were 11,500 mt, or 2.6 tonnes of CO2 per tonne of oil; so plastic is responsible for roughly twice as much carbon dioxide per tonne as oil."

"If we assume 350 mt of plastic demand with a total carbon footprint of around 5 tonnes of CO2 per tonne of plastic, that implies annual emissions of 1.75 Gt of CO2. Continuation of current growth rates would see the carbon footprint of plastics double by the middle of century to around 3.5 Gt. Meanwhile, the Paris Agreement implies that in order to get to 1.5 degrees, global CO2 emissions (33 Gt from the energy sector in 2018) will have to halve by 2030 and get to zero by the middle of the century. "Breaking the Plastic Wave" estimates that the plastic sector alone would therefore use up 19% of the entire global carbon budget if it continued to grow under business as usual. To have one sector planning on doubling its carbon footprint while the rest of the world plans to phase out emissions clearly makes no sense. This provides a clear driver for policymakers to take action. Air pollution - Each stage of the production of plastic produces pollutants such as PM 2.5, SOX and NOX which are harmful to human health."

Cardoso, Pedro., Philip S. Barton, Klaus Birkhofer, Filipe Chichorro, Charl Deacon, Thomas Fartmann, Caroline S. Fukushima, René Gaigher, Jan C. Habel, Caspar A. Hallmann, Matthew J. Hill, Axel Hochkirch, Mackenzie L. Kwak, Stefano Mammola, Jorge Ari Noriega, Alexander B. Orfinger, Fernando Pedraza, James S. Pryke, Fabio O. Roque, Josef Settele, John P. Simaika, Nigel E. Stork, Frank Suhling, Carlien Vorster, Michael J. Samways. Scientists' warning to humanity on insect extinctions. Biological Conservation, 2020; 108426 DOI: https://doi.org/10.1016/j.biocon.2020.108426
Keywords: Environmental context, biodiversity

Synthetic turf will have an adverse impact on insect life and soil biota. We need to keep in mind impacts on insect life due to scientific indications of a massive reduction of insects which has a trophic impact on higher levels of species. While replacing a grass oval with synthetic turf may be quite a marginal impact on insect numbers, it is part of a cumulative impact in urban areas of increasing hard built-up surfaces.

Celeiro M, Armada D, Ratola N, Dagnac T, de Boer J, Llompart M. (2021) Evaluation of chemicals of environmental concern in crumb rubber and water leachates from several types of synthetic turf football pitches. Chemosphere. 2021 May;270:128610. doi: 10.1016/j.chemosphere.2020.128610. Epub 2020 Oct 19. PMID: 33121811.
https://doi.org/10.1016/j.chemosphere.2020.128610
Keywords: Toxicity, synthetic turf, rubber, infill, pollution, health

A study from Portugal assessing 50 synthetic football pitches using crumb rubber infill and the health and environmental concerns of leachates.

“Results revealed the presence of most of the target PAHs in crumb rubber at total concentrations up to 57 m g g 1 , next to a high number of plasticizers and vulcanization agents. Runoff water collected from the football pitches contained up to 13 polycyclic aromatic hydrocarbons (PAHs) as well as other chemicals of environmental concern. In addition, continuous leaching of chemicals from the crumb rubber to the surrounding water was demonstrated. The transfer of target chemicals into the runoff water poses a potential risk for the aquatic environment.”
“However, the regulated levels for the eight ECHA (European Chemicals Agency) PAHs (B[a]P, D[ah]A, B[e]P, B[a]A, CHY, B[b]F, B[j]F, and(B[k]F) in rubber consumer products that can come into direct contact with the skin or the oral cavity such as toys are set at 1 m g g 1 or 0.5 m g g 1 (Barrero-Moreno et al., 2018). Due to the potential human health risk of the recycled rubber pitches and playgrounds, the European Commission limited, on September 2019, the total concentration of the eight ECHA PAHs to 20 m g g 1 in granules and mulches used in synthetic turf pitches and playgrounds (ECHA, 2019).”

The study concluded that “Runoff water samples collected from several of the studied sport facilities were also analyzed. The continuous leaching of these chemicals from the crumb rubber to the runoff water was simulated at lab-scale, as well. The results showed the presence of 30 of the 40 target compounds in the crumb rubber, including 14 of the 16 EPA PAHs, which reached total concentrations of 57 m g g 1 . Many of the PAHs reach concentrations above the limit of 1 m g g 1 that should fulfill plastic and rubber components that enter in repetitive contact with human skin, which could pose a health risk. In addition, plasticizers and other substances such as MBTZ that cause human toxicity and are included in the ECHA SVHCs list, were found in the samples.

“In the runoff water samples, 13 PAHs were detected reaching concentrations of 3.3 m g L 1 , as well as other hazardous compounds such as various phthalates considered as endocrine disruptors. The results demonstrated a continuous leaching of chemicals from the crumb rubber to surface water or other nearby water bodies, which represents a potential risk for the aquatic environment. In this context, there is a need to perform additional studies to gather more information. to evaluate how can affect aquatic pollution.

“It is worth underlining the scarce or no information available about the materials used in these sport facilities. It would be then valuable to ask suppliers to provide more information about the crumb rubber characteristics, which would help to draw conclusions. Definitely, it is essential to have comprehensive information and data on all these aspects for the proper assessment of the not negligible risk posed by these sports field infill materials, both to human health and to the aquatic environment."

Cheng, H., Hu, Y.,Reinhard, M., Environmental and health impacts of artificial turf: A review. (2014) Environ. Sci. Technol. 48, 2114–2129 (2014). **https://doi.org/10.1021/es4044193**
https://pubs.acs.org/doi/abs/10.1021/es4044193
Keywords: Health, synthetic turf, Toxicity,

A widely cited authoritative literature review from 2014. There has been further research done on: life cycle assessment of water use, energy, greenhouse gas emissions; leaching of heavy metals and organic contaminants and the risks to human health and to biota in local waterways. The review calls for more research in several of these areas.

It notes zinc as one of several hazardous heavy metals. A typical soccer pitch/field can contain a total of 1.2 tonnes of zinc:
"The impacts of artificial turf fields on the environment are expected to be localized but last throughout their functional lifetimes. To predict the long-term impacts of artificial turf fields and help designing appropriate environmental safeguards, it is necessary to understand the environmental release of toxic metals (e.g., Zn, Pb, and Cd) and organic contaminants (e.g., PAHs) on a fundamental basis. Heavy metals are non degradable in comparison with organic contaminants, and hence persist in the recipient environment. Thus the accumulation of heavy metals released from artificial turf fields over long-term is of particular concern. The high contents of ZnO, and to a lesser degree, PbO and CdO, in the tire rubber crumb present a significant point source of these hazardous substances. A typical soccer pitch/field can contain a total of 1.2 tonnes of zinc (assuming the rubber crumb has an average ZnO content of 1.5%). It has been estimated that under natural conditions 10−40% of the Zn could be released from the fine tire debris (<100 μm) mixed in soils within one year."

On the risks to human health it says that "Overall, studies evaluating end points in both children and adults consistently found that the tire rubber crumb in playgrounds and artificial turf fields poses low risk to human health through oral exposure." But it also calls for more research: "It is also important to assess more systematically the risk posed by the tire rubber crumb on the environment and human health."

It provides a table of the comparison of the benefits and disadvantages of Natural Grass and Artificial Turf.

Absent from this review: is any discussion of the urban heat island impact on local residents or heat health implications for those that use the artificial surfaces for sport or recreation, except in the briefest mentions of the need to cool artificial turf during summer. It also ignores the local impact on birdlife.

What this study doesn't provide at all is the meta context of a world grappling with a climate crisis, a biodiversity crisis, and a plastic pollution crisis.

Climate Council (February 2021), Game, Set, Match: Calling Time on Climate Inaction, ISBN 978-1-922404-14-5 (digital),
https://www.climatecouncil.org.au/resources/game-set-match-sports-climate-change/
Keywords: Environmental context, Grey Literature

Does not mention specific playing surfaces, although it highlights the SEA (Sports Environment Alliance) (2020) report in a Highlight Box. Outlines the climate science on how climate change will impact sport in Australia and globally. While the report lists a ban on fossil fuel sponsorship, it fails to mention phasing out fossil fuel infrastructure petrochemical products such as synthetic turf.

Coutts, A.M., Jason Beringer, Nigel J. Tapper, (2008) Investigating the climatic impact of urban planning strategies through the use of regional climate modelling: a case study for Melbourne, Australia. International Journal of Climatology. DOI: 10.1002/joc.1680
http://onlinelibrary.wiley.com/doi/10.1002/joc.1680/abstract
Keywords: environmental context, heat

Summary: Discusses the urban heat island (UHI) in relation to using Melbourne urban planning for improving local climate and human health outcomes and highlights the need for a comprehensive UHI mitigation strategy for Melbourne. The authors used an urban climate model, The Air Pollution Model (TAPM), to simulate the UHI intensity of 3–4 °C at 2 a.m. in January. Results for summer showed increased housing density results in increased intensity of night time UHI with growth areas and activity centres particularly affected. The model was calibrated against observational data from medium density Preston, a residential neighborhood in Melbourne's north. This was used to assess where urban planning should best be applied to mitigate UHI to improve local climates and identified in particular activity centres and growth areas.
Critique: Valuable modelling of UHI in Melbourne, although winter correlation was poor with the authors highlighting that further refinements of the model were required to use as a tool for year round urban climate modelling for urban planning in Melbourne. The research doesn't specifically cite what role of synthetic turf in adding to night time ambient air canopy temperatures.

Delaware Riverkeeper Network, Alternative Infills for Artificial Turf Fact Sheet, (October 2016)
http://www.synturf.org/images/DRK3_Artificial_Turf_Alternative_Infill_Fact_Sheet_10.18.16_0.pdf
Keywords: Synthetic turf, infill, Grey literature

There has been little research on alternative infills to crumb rubber. The Consultants report to Moreland Council in the Sports Surface Needs Analysis recommended using an organic infill to counter community perceptions on the health and safety of crumb rubber infill. This Factsheet summarises some of the alternative infills available and highlights the open issues about use including on toxicology, off-gassing, leaching. One issue not addressed in this is the potential for alternative infill material being sourced from tropical locations driving land clearing, greenhouse gas emissions and biodiversity loss.

“Very few toxicological and risk assessment studies regarding the health and environmental impacts of emerging alternative infill options have been completed but from the data that is available there are many concerns to be had. While there is insufficient data on the chemical composition, off-gassing, leaching, and associated health and environmental effects that may result, the data that is available demonstrates many reasons for concern. For these reasons, the precautionary principle should be used to avoid the unnecessary and potentially devastating harms to those who would come in direct contact with the infills and the environment surrounding them. All alternative infill options are significantly more expensive than traditional crumb rubber; with all artificial turf systems (including those with crumb rubber infill) costing more than natural turf grass.xlv There is no proven record of the durability, performance, and lifespan of these infills to warrant the cost—and many anecdotal references from schools and municipalities throughout the country illustrate flaws.

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

Díaz, S. et al. (December 2019) Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366, eaax3100 (2019).
https://science.sciencemag.org/content/366/6471/eaax3100
Keywords: Biodiversity, Environmental context

An important meta article on the decline of life on earth and the loss of biodiversity. Articulates that we need to reverse this process for our own health and wellbeing.

“For decades, scientists have been raising calls for societal changes that will reduce our impacts on nature. Though much conservation has occurred, our natural environment continues to decline under the weight of our consumption…. The fabric of life on which we all depend—nature and its contributions to people—is unravelling rapidly. Despite the severity of the threats and lack of enough progress in tackling them to date, opportunities exist to change future trajectories through transformative action. Such action must begin immediately, however, and address the root economic, social, and technological causes of nature's deterioration."

Conversion of a natural grass sports oval that supports some biodiversity and provides environmental services, as well as recreation and organised sport use, to a synthetic pitch epitomises at the micro level what is happening to varying degrees at the landscape and global level.

Englart, John (February 2015) Climate change and heatwaves in Melbourne - a Review
DOI: 10.13140/RG.2.1.3050.7688
https://takvera.blogspot.com/2015/02/climate-change-and-heatwaves-in.html
Keywords: Environmental context, heat

This review article provides important science background on climate change, heatwaves, the application of the urban heat island effect for Melbourne.

Englart, John (November 2020), Taking the temperature of Moreland Playgrounds and surfaces, Climate Action Moreland, 24 November, 2020,
https://climateactionmoreland.org/2020/11/24/taking-the-temperature-of-moreland-playgrounds-and-surfaces/
Synthetic turf, Natural turf, heat, UHIE, Australia
Local Moreland temperature survey from Clifton Park synthetic field and surrounds. The surface temperature at Clifton Park was measured. On a sunny day with the air temperature at 32/33 degrees C., wind gusting at 10 km/hr and humidity at 15%, natural grass in full sun was compared to synthetic turf in full sun and in shade and a concrete path in full sun. Results:

Natural grass in full sun	- 29.6 to 30.9 degrees C.
Concrete path in full sun	- 43.1 to 47.7 degrees C.
Synthetic turf in full sun	- 57.1 to 60.4 degrees C.

Only when in full tree canopy shade was the temperature of synthetic turf comparable to natural grass in full sun - 29.3 to 30.4 degrees C.(8)

Full Temperature Data can be viewed here:
https://docs.google.com/spreadsheets/d/1FUgd1VjkiQjW9t7TqvyXbro_cqXIRfc6t83yISBX4S4/edit?usp=sharing

Eunomia Research & Consulting Ltd for FIFA, (March 2017), Environmental Impact Study on Artificial Football Turf,
https://football-technology.fifa.com/en/media-tiles/environmental-impact-study-on-artificial-football-turf/
Keywords: Grey Literature, microplastics, waste, synthetic turf, infill, rubber, Environmental context, Sport

A report done for the global soccer federation - FIFA. Highlights lack of recycling and reuse, usually landfill used for disposal. Most materials in a synthetic field are fossil fuel based. It doesn't document the difference in environmental impact between natural grass and artificial turf. Highlights "organic alternatives to plastic based products come with their own problems - for example the growing of non-food crops to produce products can displace food production, and ultimately extend the agricultural frontier, leading to reduced biodiversity."

For marine microplastics it says "More recently plastic infill (including SBR, TPE and EPDM) has been identified as a possible source for microplastic marine pollution. Infill can get washed away during rain or stick to clothing and boots before being put in a washing machine. ... It is estimated that 1–4% of plastic infill is lost and replaced every year."

All synthetic turf in Australia currently ends up in landfill, although due to different landfill charges and taxes it is sometimes transported to a different state where landfill is much cheaper. "A standard pitch containing SBR infill could weight around 274 tonnes. This is the amount of material that will need to be disposed of or recycled when the pitch reaches the end of its life."

"There are no reports of organic infill pitches being recycled at present."

"majority of the manufacturers interviewed for this study claimed their products are 'recyclable', but none are taking significant steps to make sure this happens in practice."

Football Federation Victoria, (2018), State Football Facilities Strategy to 2026
https://www.footballvictoria.com.au/sites/ffv/files/2018-12/FV_Facilities_Strategy.pdf
Keywords: synthetic turf, Sports context

The strategy to increase both grass and synthetic soccer pitches in Victoria. There is no commitment to sustainable outcomes addressed in this strategy. A synthetic pitch has a 2:1 equivalence value - double the time can be allocated. The report casts a rosy picture of benefits: economic, health, social, financial. There are no negatives, such as light pollution, the environmental and greenhouse gas emissions of synthetic pitches, the traffic and parking issues generated in many residential neighborhoods by the growth of the sport.

It has has a goal "Increase the number of senior sized artificial pitches from 53 to 84 with priority for the inner LGAs who currently do not have any, such as Bayside, Boroondara, Stonnington and Yarra (where the opportunity for acquiring new land is limited and there are no artificial pitches). Other metro LGAs without senior sized artificial pitches to prioritise include Casey, Frankston, Greater Dandenong and Mornington Peninsula". It recommends Pitch capacity for well constructed grass as 26 hours, and double this for a synthetic pitch

In Moreland it identifies Cross Keys Reserve – Strathmore; and De Chene Reserve – Coburg as potential upgrade/development sites. Currently there are 10 pitches in Moreland. The strategy is pushing for an extra 6 pitches for Moreland by 2026 based on projected participation growth rate. “Moreland will require 16 pitches, the most in the zone based on current participation, by 2026” The Strategy lists a new Moreland synthetic pitch as a priority.

Gomes, F.O., Rocha, M.R., Alves, A., Ratola, N. (2021), A review of potentially harmful chemicals in crumb rubber used in synthetic football pitches, Journal of Hazardous Materials Volume 409, 5 May 2021, 124998.
https://www.sciencedirect.com/science/article/abs/pii/S0304389420329897
Keywords: Synthetic turf, rubber, infill, toxicity

(From the abstract only) the study highlights dangerous levels of toxic chemicals via air pollution and leachates into water pollution : “
* Crumb rubber (CR) from recycling end-of-life tires is used as synthetic turf infill;
* Potentially hazardous chemicals were reviewed in CR, water leachates and nearby air;
* 8-carcinogenic PAH levels from 1.91 to 24.67 ± 18.31 mg/kg surpass the legislated limit;
* Zn was the prevalent metal, up to 15,494 mg/kg in CR and 34,170 μg/L in water leachates;
* Other contaminants linked to tire making like VOCs, plasticizers or PCBs were found.”

Greenplay Organics, (July 2012), Naturally Cool Synthetic Turf, 3BL CSR newswire.
https://www.csrwire.com/press_releases/34424-naturally-cool-synthetic-turf
Keywords: Grey Literature, Synthetic turf, infill, heat, water, irrigation

Report that a synthetic field organic infill material developed by Italian sports turf company Limonta SPA, made up primarily of cork and coconut fibre, was able to limit temperatures to only slightly higher than natural grass. This cooling relies on regular weekly irrigation as the organic turf infill has a moisture carrying capacity which provides the cooling effect.

“Recently completed outdoor testing at the ISA Sport USA Lab in Lubbock, TX further substantiates the fact that Limonta Sport synthetic turf with organic InfillPro Geo© greatly reduces the surface temperature of the synthetic playing field to the point where it is compatible to playing on natural grass.” You can read the testing report here by ISA Sports in the US.
http://www.synturf.org/images/ISA_LAB_Temp_Study_-_Copy.pdf

There was an earlier testing report from 2010 done at Università IUAV di Venezia which backed Limonta’s claim that the corkonut infill was running substantially cooler than rubber infill.The Synturf alternative infill page (http://www.synturf.org/alternativeinfill.html) contains the report:
http://www.synturf.org/images/Limonta_Sport_Temperature_Comparison_Test_GEO_vs_Natural_vs_SBR.PDF

Comment: Water conservation is seen as an important justification for the transition from natural grass to synthetic. The ISA Sports test results on comparing the Limonta Sports synthetic turf with organic Infill with a synthetic field with rubber infill and Natural grass has implications for water use of synthetic fields. "Even under the most intense heat and with no naturally occurring precipitation we feel that the field will require no more than 12,000 gallons of water applied twice a week for the field to perform optimally." That translates as 1,200 kgals per year. A Natural grass field will use about 1,290 kgals per year, according to Alm (2016). Kanaan et al (2020) argue that synthetic field water use for managing field temperatures is comparable to the water requirements of a natural grass field. If Organic infill is used for a new sporting field, increased water use needs to be also part of the equation. Original source of the infill fibres need consideration to ensure this isn't causing emissions associated with landclearing and biodiversity impacts at source.

Hamido, S. , Guertal, E. and Wesley Wood, C. (2016) Carbon Sequestration under Warm Season Turfgrasses in Home Lawns. Journal of Geoscience and Environment Protection, 4, 53-63. doi: 10.4236/gep.2016.49005
https://www.scirp.org/journal/paperinformation.aspx?paperid=70666
Keywords: Carbon sequestration, Natural turf

This study indicates that turfgrass home lawns may be an important contribution to the global carbon sequestration level. Different species of warm season grasses sequester carbon at different rates. "Major sources of Soil Organic Carbon accumulation are from below ground plant root activities and above ground biomass decomposition."
"Carbon storage in lawns could also be increased by reducing mowing, and returning clippings. This study found that zoysiagrass had greater above- and below-ground biomass that resulted in greater C inputs to the soil than other warm-season turfgrasses, likely due to the individual or combined effects of species and plant density. However, more research is needed on inputs such as litter quality and quantity, mowing, irrigation and clipping management to better quantify C flux in home lawns."

Hanski, Ilkka., von Hertzen, Leena., Fyhrquist, Nanna., Koskinen, Kaisa., Torppa, Kaisa., Laatikainen, Tiina., Karisola, Piia., Auvinen, Petri., Paulin, Lars., Mäkelä, Mika J., Vartiainen, Erkki., Kosunen, Timo U., Alenius, Harri., and Haahtela, Tari., (April 2012) Environmental biodiversity, human microbiota, and allergy are interrelated, PNAS May 22, 2012 109 (21) 8334-8339; https://doi.org/10.1073/pnas.1205624109
Keywords: health, microbial, Natural turf

There is evidence that contact with natural grass and soil has a positive effect on human health for allergies and auto-immune response. Converting natural grass sporting fields to synthetic surfaces reduces this positive effect. This 2012 study highlights that environmental biodiversity, human microbiota, and allergy are interrelated. As Moreland population density grows natural spaces, including grass sporting ovals, will provide an important point in boosting children's immune systems. The study concludes: "Interactions with natural environmental features not only may increase general human well being in urban areas (45), but also may enrich the commensal microbiota and enhance its interaction with the immune system, with far-reaching consequences for public health."

Hardin, Garrett (1968). "The Tragedy of the Commons". Science. 162 (3859): 1243–1248. Bibcode:1968Sci...162.1243H. doi:10.1126/science.162.3859.1243 . PMID 5699198
https://science.sciencemag.org/content/sci/162/3859/1243.full.pdf

Keywords: Environmental context

A classic science article that articulates that we all to often focus on the benefits accruing to individuals or small groups in exploiting a common resource in the short term, rather than regulating usage to ensure impacts and damages are limited and the resource can continue to deliver shared benefits over the long term. We need to factor in externalities and costs and regulate the usage of individuals or specific groups. This philosophically applies to the situation at Hosken Reserve with the oval and east pitch being unfenced and shared by the community for active recreation and experiencing nature with the Sports Club for training and the school for use for sports and for lunchtime.

Hatfield, J. (2017), Turfgrass and Climate Change. Agronomy Journal, 109: 1708-1718. https://doi.org/10.2134/agronj2016.10.0626
Keywords: Natural turf, Greenhouse Gas emissions, carbon sequestration, water

Turf grasses will also feel the impact of climate change. This article outlines some of the issues facing natural turfgrass in a changing climate, with increasing temperatures and changing precipitation as it applies to the USA.
“The potential warming of soil temperatures has the potential to increase soil temperatures above the optimum root temperatures of 10 to 18°C for cool-season species and above 24 to 30°C in warm-season species (DaCosta and Huang, 2013). They cautioned that given the projections for temperature increases coupled with the potential for extreme events, there is the likelihood for more heat stress on both cool- and warm-season species.”
“The interplay between root temperatures and air temperatures in the physiological reactions of grasses reveal that exposure to high root temperatures reduces shoot growth, photosynthesis, root viability, and increases senescence (DaCosta and Huang, 2013). Heat stress reduces root number, root length, and root biomass and increases root mortality, which in turn affects the ability of the plant to extract water and nutrients from the soil.”
“Xin et al. (2013) suggested that screening turfgrass species for water use efficiency and drought resistance using a combination of phenotypic studies (morphology, growth rate, and cell physiology), gene quantitative trait loci (QTL) mapping for the morphological and physiological characteristics of different species, and quantifying the understanding of the molecular mechanisms of water use efficiency in turfgrass would provide a path toward breeding genotypes to withstand drought stress.”
“Increased CO 2 effects on water use efficiency would increase the number of days a perennial grass could maintain non-limiting transpiration, thereby, making more efficient use of water in the soil profile. This would reduce exposure to potential drought stress for a perennial grass, which will become increasingly important in water-limited environments or with more variation in summer precipitation.
“Turfgrass stands have the potential to mitigate climate change by sequestering C and reducing greenhouse gas emissions from turfgrass stands. Bremer (2006) found nitrous oxide (N 2 O) emissions were a function of N management practices with N rate being the primary factor related to emissions. There have been some recent assessments of the value of turfgrass

stands to sequester C and through a modeling assessment for lawns, Zirkle et al. (2011) showed the potential sequestration rate."

IPBES (2019): Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. 56 pages.
https://www.ipbes.net/sites/default/files/2020-02/ipbes_global_assessment_report_summary_for_policymakers_en.pdf
Keywords: biodiversity, Environmental Context

Major report by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) outlining that nature and ecosystems have deteriorated worldwide, with the process accelerating in the last 50 years. It argues we need to make transformative changes across economic, social, political and technological factors for conserving and sustainably using nature and achieving sustainability. This provides a meta context for preserving the grass oval for its limited biodiversity values in an urban environment.

IPCC, (2018): Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.
https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf
Keywords: Environmental context

This Special report by the IPCC, published in 2018 was significant it drawing wide public attention to the trends in climate change and the need to take rapid and ambitious action if we are to avoid more catastrophic impacts in the future. It outlines the strong need to address climate action and reduce greenhouse gas emissions at all levels of society from all sectors.

Itten, René., Glauser, Lukas., and Stucki, Matthias., (Jan 2021) Life Cycle Assessment of Artificial and Natural Turf Sports Fields – Executive Summary , Institute of Natural Resource Sciences, Zurich University of Applied Sciences.
https://digitalcollection.zhaw.ch/bitstream/11475/21510/3/2021_Itten-etal_LCA-turf-sports-fields_Executive-Summary.pdf

Keywords: LCA, Synthetic turf, natural turf, Greenhouse gas emissions

This study uses the ecological scarcity method for LCA analysis for calculating relative greenhouse gas emissions comparing natural grass to synthetic turf based on usage hours. Under the triple bottom line accounting this weights social outcomes above environmental outcomes. This is only the executive summary and does not contain specific data which is likely in the full report in German.

"However, since natural and hybrid turf allows for fewer hours of use, on average an artificial turf causes lower greenhouse gas emissions and a lower total environmental impacts per hour of use according to the Ecological Scarcity Method than a natural or hybrid turf. A natural turf with a drainage layer construction, which is played on for 800 hours per year, causes approximately the same amount of greenhouse gas emissions per hour of use as an unfilled artificial turf, which is played on for 1,600 hours. However, if an unfilled artificial turf is only used for 800 hours per year, it causes significantly more greenhouse gas emissions per hour of use than a natural grass turf with a drainage layer or a hybrid turf."

"The filled artificial turf sports field has the highest environmental impacts per hour of use for greenhouse gas emissions, freshwater eutrophication, mineral resource use as well as total primary energy demand and non-renewable primary energy demand, mainly due to the required filling material. The replacement as well as the disposal of the filling material causes additional impacts for the filled artificial turf sports fields in the renovation and operation life cycle stages. Furthermore, the filled artificial turf sports field causes microplastic emissions due to the discharge of filling material. There is no established methodology to account for the environmental impacts caused by microplastic emissions recommended by the Joint Research Council of the European Commission for the Organisational and Product Environmental Footprint (Fazio et al., 2018). Therefore, the microplastic emissions are not represented in Fig. S.1."

Jim, C. Y., 2017. Intense summer heat fluxes in artificial turf harm people and environment. Landscape and Urban Planning, Volume 157, pp. 561-576
https://doi.org/10.1016/j.landurbplan.2016.09.012
Keywords: Heat, UHIE, synthetic turf, health

Research in Hong Kong in 2017 highlighted that high air and surface temperature of artificial turf raises concerns on player health. Artificial turf with low specific heat and moisture incurs fast heating and cooling. The study identified cooler periods fit for matches on sunny, cloudy and overcast days.

" AT materials, with low specific heat and moisture and scanty evapotranspiration, induce fast warming and cooling with little time lag to synchronize with insolation rhythm. On sunny day, AT turf-surface, heated to 72.4 °C comparing with NT at 36.6 °C, dissipates heat by conduction and convection to near-ground air and by strong ground-thermal emission. Exceeding the heat-stress threshold most of the time, AT cools quickly from late afternoon for heat-safe use soon after sunset. On cloudy day, subdued AT heating allows earlier cooling in late afternoon. Both sites are heat-safe on overcast day."

Joshi, Ketan (February 2021) Plastics: A carbon copy of the climate crisis, Client Earth.
https://www.clientearth.org/latest/latest-updates/stories/plastics-a-carbon-copy-of-the-climate-crisis/ Accessed 27 February 2021.
Keywords: Grey Literature, Environmental context, microplastics

A general or Meta-article to highlight the problem with plastics used on an industrial product scale. Argues that the plastics crisis is equal to the climate crisis. Synthetic turf fibres and mats degrade into smaller and smaller plastics that contribute to the micro-plastics problem we have.

Kamal, Masud., (December 2019), Natural grass vs synthetic surfaces for recreation and sports: An evidence review. DOI: 10.13140/RG.2.2.20840.08969
https://www.researchgate.net/publication/342852314_Natural_grass_vs_synthetic_surfaces_for_recreation_and_sports_An_evidence_review
Keywords: Synthetic turf, Natural turf, Australia

A study weighing up the benefits and disadvantages of synthetic turf and natural grass sports fields for Adelaide. It covers the issues reasonably well, although there are a couple of points based on very recent science and poor referencing. On Water use it references Cheng et al (2014) which is a literature review. I would have preferred to see direct references as water use with total life cycle assessment (LCA) is far more complex than Cheng makes out. On public health and safety there is now evidence of health risk as per Xu et al.(2019). This study sets out to provide a knowledge base for decision making for "the selection of a surface option in Adelaide Parklands for engaging more people in outdoor sports needs to consider the long-term vision for parkland management and sustainability." It articulates the organised sports drivers for increasing synthetic turf to increase pitch use and wear, but fails to also articulate the wider social considerations with regards to the climate crisis and plastics pollution crisis. This context is just as important in triple bottom line decision making.

Kanaan, Ahmed, Sevostianova, Elena, Leinauer, Bernd and Sevostianov, Igor (August 2020), Water Requirements for Cooling Artificial Turf, in Journal of Irrigation and Drainage Engineering, August 2020 DOI link:
https://doi.org/10.1061/(ASCE)IR.1943-4774.0001506
Keywords: Synthetic turf, water, heat, irrigation

This study would appear to reduce the water savings argument for synthetic turf. It is based upon experimental data from New Mexico and confirms a water usage for cooling model that Synthetic Turf and Natural turf water usage may be comparable during the maintenance part of the total life cycle assessment. Synthetic turf is also water intensive during manufacture using 4 times the quantity of water as needed for one year of natural turf irrigation according to Alm (2016)

"This model indicates that the amount of water required to maintain AT temperatures at levels comparable to irrigated NT over a 24-h period exceed the water requirements of bermudagrass NT in the same environment. Thus, the argument for using AT- instead of bermudagrass-based NT in arid climate zones for water conservation is nuanced and depends on the presence of an irrigation system, desired playing conditions, and the length of time irrigation will be used to maintain the target temperature during daylight hours."

Kong, Ling., Shi, Zhengjun,. Chu, L.M. (2013), Carbon emission and sequestration of urban turfgrass systems in Hong Kong. Science of the Total Environment 473-474 (2014) 132-138. [**https://doi.org/10.1016/j.scitotenv.2013.12.012**](https://doi.org/10.1016/j.scitotenv.2013.12.012)
Keywords: Carbon sequestration, Natural turf

"This study investigated the carbon storage and release of urban turfgrass systems using empirical data and determined the impact of maintenance in determining an urban lawn as a carbon sink or source." It outlines that soil is the largest contributor to carbon storage in urban areas, however soil respiration also emits CO2 and is a major flux in the global carbon budget. It notes a positive correlation with soil carbon and site age in urban spaces with Soil Organic Carbon concentration higher in soils 25 years or older, but with a shift in storage from belowground to aboveground at 30-40 years after lawn construction. The study discussed "it is the practice of turf management that may ultimately decide whether the turf is a net emitter or sink for CO 2 . Thus, we propose that a rational design of maintenance schedule should be implemented for each turf based on its carbon stock and functional purposes to achieve a net carbon budget beneficial to the environment. The study suggested in the conclusion that turf maintenance carbon footprint be reduced: "For example, mowing, which uses fuel and is the most carbon intensive maintenance, should be carried out less often without compromising the quality of the turf or with more efficient technologies such as solar-powered devices to reduce carbon emission. Similarly, green technologies should be applied for more efficient watering and chemical application to reduce carbon emission. On the other hand, urban soil served as a carbon sink while management practices remained the major source of carbon emissions. Since the carbon emission increased with age, the turfgrass systems could shift from carbon sink to carbon source in just a few years. Thus, one can certainly try to replace the turf which may renew the carbon sequestration capacity of the turfs."

Kukfisz, B., (2018) "The degree of flammability for an artificial grass surface system", in E3S Web of Conferences, vol. 45. doi:10.1051/e3sconf/20184500038
[**https://www.e3s-conferences.org/articles/e3sconf/abs/2018/20/e3sconf_infraeko2018_00038/e3sconf_infraeko2018_00038.html**](https://www.e3s-conferences.org/articles/e3sconf/abs/2018/20/e3sconf_infraeko2018_00038/e3sconf_infraeko2018_00038.html)
Keywords: Synthetic turf, fire risk, health

Flammability is not often raised as an issue with conversion of natural grass sports surfaces to synthetic surfaces. This study highlights the fire and possible health risks involved in synthetic surfaces. "As artificial turf is produced of plastics, it is a material clearly susceptible to ignition." "Taking into account the components of artificial turf systems, especially SBR from recycled tyres and plastics such as TPE and EPDM, there is an ever increasing concern for potential environmental and health hazards. The most important pollutants that can be released from synthetic surfaces and surfacing are compounds of zinc of the zinc oxide used as a catalyser in the vulcanisation process [2], using polycyclic aromatic hydrocarbons (PAH) as softeners [9], volatile compounds and such admixtures, as benzothiazole, as well as aniline and phenol [9, 10]."

One wonders if local residents have been canvassed about increased fire risk and possible health impacts from smoke from ignited synthetic surfaces.

Law, Q.D., and Patton, A.J.. (2017). Biogeochemical cycling of carbon and nitrogen in cool‐season turfgrass systems. Urban Forestry and Urban Greening 26: 158– 162.
https://doi.org/10.1016/j.ufug.2017.06.001
Keywords: Natural turf, Carbon sequestration

No access to full article but study says if managed conservatively urban turf grass can act as a net carbon sink. No detail whether N2O emissions taken into account.
"All of the turfgrasses and management practices in this experiment resulted in a system-wide net C sink, though the magnitude of the sink varied by turfgrass selection and management strategy. In general, higher-yielding grasses and management practices increased soil C but also increased mowing requirements and thus emissions. Returning grass clippings was found to increase yield, soil and leaf tissue N, and soil C, but it also marginally increased mowing requirements. The results of this experiment support the assertion that managed turfgrass areas can act as a net C sink to help curb the increasing atmospheric GHG concentrations. The C sequestration potential of managed turfgrass is another of the numerous functional benefits of urban grasslands."

Loveday, Jane; Loveday, Grant; Byrne, Joshua J.; Ong, Boon-lay; Morrison, Gregory M. (2019), "Seasonal and Diurnal Surface Temperatures of Urban Landscape Elements" Sustainability 11, no. 19: 5280. https://doi.org/10.3390/su11195280
Keywords: Heat, UHIE, Synthetic turf, Natural turf, Australia

A Perth based study on the urban heat island effect of various surfaces including turfgrass and synthetic turf. The study correctly notes that the urban heat island effect is most prominent as a night time impact, although it also is seen during the daytime. Quite an interesting study that highlights UHIE also manifests not only during summer, but also Spring and Autumn in Perth. This is important for Melbourne as Perth average temperatures give a glimpse of our future. The study also looks at the change in evening temperatures. This is where artificial turf will cool through convection of the heat to the atmosphere thus keeping the ambient air temperature high. This accentuates the night time impact of the urban heat island effect. This will especially impact local residents around a synthetic field. Some interesting graphical representations of the comparative data.

Phase 1 discussion: "Despite similarity in colour however, the differences in thermal behaviour were notable for the artificial turf grass and the natural turf grass. Artificial turf grass was on average 11.2 ◦ C hotter than turf grass in summer over the measurement period.

Evapotranspiration is assumed to be the main cause of this difference, as well as the perviousness of the natural turf grass allowing any moisture from the soil to evaporate up though the surface, providing extra cooling. The artificial turf grass, consisting of a tightly woven plastic mat, does not allow significant moisture through from the soil and is thus likely to preclude any evaporative cooling."

For phase 2 the study comments on artificial turf: Despite being a low thermal mass product, artificial grass also only goes below ambient between 20:30 and 21:00, indicating its close ground coupling is increasing its thermal mass dramatically."

"The ∆T av [average change in temperature] ranking is relevant for overall urban heat as it quantifies how much heat is convected into the atmosphere from each LE (landscape element). The daytime ranking is important for landscapes where daytime use is prevalent, whilst the evening ranking is important for when people are trying to cool their homes in the evening. Previous literature on separating the data into these specific categories has not been found, but this method may be useful for understanding temporal UHI variations."

Lundstrom, Marjie., and Wolfe, Eli., (December 19, 2019), Fields of Waste: Artificial Turf, Touted as Recycling Fix for Millions of Scrap Tires, Becomes Mounting Disposal Mess, Fair Warning, USA
https://www.fairwarning.org/2019/12/fields-of-waste-artificial-turf-mess/
Keywords: Waste, synthetic turf, pollution, infill, Grey literature

Marjie Lundstrom and Eli Wolfe did an investigative journalism article published at Fair Warning highlighting the lack of any recycling of synthetic turf in North America and the growing problem of used synthetic grass as landfill along with associated rubber infill.

Mack CD, Hershman EB, Anderson RB, Coughlin MJ, McNitt AS, Sendor RR, Kent RW. (2019) Higher Rates of Lower Extremity Injury on Synthetic Turf Compared With Natural Turf Among National Football League Athletes: Epidemiologic Confirmation of a Biomechanical Hypothesis. Am J Sports Med. 2019 Jan;47(1):189-196. doi: 10.1177/0363546518808499. Epub 2018 Nov 19. PMID: 30452873.
https://journals.sagepub.com/doi/full/10.1177/0363546518808499
Keywords: Health, Synthetic turf, Natural turf, Injuries

It is clear from this study that synthetic turf produces more sports injuries associated with lower extremities than on grass fields. The researchers attempted to eliminate other factors by relying on 5 years of data from the USA National Football league. The study concluded that "These results support the biomechanical mechanism hypothesized and add confidence to the conclusion that synthetic turf surfaces have a causal impact on lower extremity injury."

Background: Biomechanical studies have shown that synthetic turf surfaces do not release cleats as readily as natural turf, and it has been hypothesized that concomitant increased loading on the foot contributes to the incidence of lower body injuries.

This study evaluates this hypothesis from an epidemiologic perspective, examining whether the lower extremity injury rate in National Football League (NFL) games is greater on contemporary synthetic turfs as compared with natural surfaces.

Hypothesis: Incidence of lower body injury is higher on synthetic turf than on natural turf among elite NFL athletes playing on modern-generation surfaces.

Results: Play on synthetic turf resulted in a 16% increase in lower extremity injuries per play than that on natural turf (IRR, 1.16; 95% CI, 1.10-1.23). This association between synthetic turf and injury remained when injuries were restricted to those that resulted in ≥8 days missed, as well as when categorizations were narrowed to focus on distal injuries anatomically closer to the playing surface (knee, ankle/foot). The higher rate of injury on synthetic turf was notably stronger when injuries were restricted to noncontact/surface contact injuries (IRRs, 1.20-2.03; all statistically significant).

Madden, A.L., Arora, V., Holmes, K.A., Pfautsch, S. (2018) Cool Schools. Western Sydney University. 56 p.
http://doi.org/10.26183/5b91d72db0cb7
Keywords: Heat, UHIE, Australia, Environmental Context

Important research from the University of Western Sydney on the impact of heat on schools. It includes Mean temperatures (°C) of surface materials used in outdoor play spaces, including synthetic surfaces.

“Outdoor play spaces – as well as urban parks and playgrounds - are important spaces for urban sustainability, social connection, physical activity, and general community well-being (Boldemann et al., 2006; Vanos et al., 2016). Well-designed play spaces provide comfortable and safe areas for children to engage in activities for improved health and well-being (Vanos, 2015) and also contribute to microscale cooling, providing heat refuges in high seasonal temperatures. Conversely, improperly designed, outdoor play spaces can contribute to micro urban heat island effects (see, for example, Moogk-Soulis, 2010), and become intolerably hot and unsafe for children.”

Magnusson, Simon., and Macsik, Josef., (14 April 2017) “Analysis of energy use and emissions of greenhouse gases, metals and organic substances from construction materials used for artificial turf”, Resources, Conservation and Recycling.
https://doi.org/10.1016/j.resconrec.2017.03.007
Keywords: LCA, energy, Greenhouse gas emissions, Synthetic turf

This provides a total life-cycle assessment for an artificial turf sports field in Sweden. It appears to be more rigorous than Meil and Bushi (2006).

This study concluded total energy use was 5.9GJ and the GHG emissions was 527 ton CO2 equivalents. The authors point out that these totals can vary with a factor of 1.5 and 2.2 respectively depending upon the infill type chosen, and method of disposal whether incineration or landfill (both are problematic for a closed loop circular economy which Moreland is aiming for)

It is clear in both studies that Synthetic turf loads both energy and emissions at the start and end of the total emissions life cycle: in the initial manufacture and processing, and in the end of life disposal.

The study also raised some concern over leachates: “Substances which are known to be harmful for the aquatic environment and/or humans was detected in all infill leachates. Eight harmful substances were detected from RT with a total of 46 □g/l in the leachate….The results show that all infills tested produced leachates containing substances harmful to aquatic life. For the leachates from TPE, EPDM and R-EPDM, information about potential toxicity could not be found for a large share of the total S-VOCs identified and seems to be missing.”

Mah, Alice., (Feb 2021) Future-Proofing Capitalism: The Paradox of the Circular Economy for Plastics. Global Environmental Politics 2021; doi:
https://doi.org/10.1162/glep_a_00594
Keywords: Plastics, environmental context, circular economy

This is quite a powerful discussion of the plastics and petrochemical industry. While synthetic turf is not mentioned, it is an important growth product from the plastics and petrochemical companies. These companies seek to pivot their business models to encompass the ‘circular economy’ and ‘sustainability’ criteria. Alice Mah is a Professor of Sociology at Warwick University and her critique is highly insightful. “Reducing plastics needs to be seen as part of the necessary green transition away from fossil fuels, as opposed to expanding plastics as a hedge against it.” she argues. The first paragraph of her Study Conclusions:

“The circular economy for plastics is both a corporate battleground for containing environmental crises and a catalyst for intensifying expansion. Faced with industry-level threats to public legitimacy and future markets, corporations across the petrochemical value chain have banded together to contain the circular economy policy agenda, appearing to be sustainable while proliferating unsustainable markets. Corporations have achieved this through deploying their advantage in technological expertise and understandings of complexity. The industry attempts to future-proof capitalism from the shocks of green transition by designing and controlling the new systems. Yet within intensifying wars of position over global environmental issues, the battleground is never stable. While industry has become more sophisticated at dealing with complexity, it has also exposed its vulnerability to systemic threats through the speed and extent of its response. There has been mounting pressure for industrial transformation of plastics, including climate divestment, plastic-free, environmental justice, and zero-waste campaigns, coming not only from grassroots movements but also from regulators and investors.”

McNitt, A.S., D.M. Petrunak and T.J. Serensits. (2008). Temperature amelioration of synthetic turf surfaces through irrigation. Acta Hort. 783:573-582.
https://plantscience.psu.edu/research/centers/ssrc/documents/temperature-irrigation.pdf
Keywords: Synthetic Turf, heat, irrigation, water

A study from Pennsylvania State University on the heat retention of synthetic turf. Outlines 4 experiments and concludes that synthetic turf was found to have substantially higher surface temperatures than natural turfgrass. Suggests there are benefits in cooling synthetic surfaces with irrigation to reduce heat retention when needed, although that comes with the cost of installing irrigation. Comment: this would reduce the water savings benefit of synthetic turf that is often used as a justification.

“Reports indicate the surface temperatures of traditional synthetic turf can as much as 35-60 °C higher than natural turfgrass surface temperatures. Surface temperatures of infill synthetic turf systems have been reported to be as high as 93°C on a day when air temperatures were 37°C. Researchers have concluded that the heat transfer from the surface to the sole of an athlete's foot is significant enough to contribute to greater physiological stress that may result in serious heat related health problems.”

Meil, J., and L. Bushi, “Estimating the required global warming offsets to achieve a carbon neutral synthetic field Turf system installation: Athena Institute.” (2006).
http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.562.9393
Keywords: Grey Literature, LCA, Greenhouse gas emissions, carbon sequestration

An early attempt in Canada to do total life-cycle assessment of synthetic and natural turf sporting field. The results show a substantial difference in Greenhouse Gas emissions between natural turf and synthetic turf. The study assumes synthetic surface would be recycled and evidence points to a total lack of recycling in North America. This would potentially double the emissions from 55 to over 100 tonnes CO_2e in a ten year period. The study put forward that natural grass, depending on maintenance regime could potentially operate as a carbon sink sequestering 17 tonnes CO_2e per 10 years. Subsequent research by others highlight that carbon sequestration would likely be minimal, if at all, on athletic and sporting fields.

Monash Climate change Communication Research Hub, (March 2021) Temperature check: Greening Australia's warming cities. Australian Conservation Foundation. Available from the Analysis and Policy Observatory https://apo.org.au/node/311336
Keywords: Grey Literature, Environmental context, heat, UHIE

Review of the temperature and heatwave trend for Sydney, Melbourne and Brisbane and the rising impact of the urban heat island effect on liveability. A general article on rising urban heat and implications for urban living. Does not mention the role of synthetic surfaces that add to urban heat, but advises that putting in place green infrastructure to address growing urban heat takes time, early action is essential. Extreme and average maximum temperatures are projected to increase, the number of days over 35C will increase. This will reduce useability of synthetic surfaces unless water is used for temporary cooling, which then reduces the justification for synthetic turf providing a water saving.

Moore, G.M., Urban Trees: Worth More Than They Cost (2009), Burnley College, University of Melbourne.
https://202020vision.com.au/media/1021/moore-urbantreesworthmorethantheycost.pdf
Keywords: Natural turf, carbon sequestration, water, irrigation, synthetic turf, Australia

The main focus of this article is on trees as Green infrastructure, and relates directly to the Melbourne environment and climate context. It particularly highlights the issues of watering vegetation during drought, and applies this to the dilemma over maintaining sports fields and the push for conversion to synthetic turf to save water. Note that after the millennial drought Councils started putting in much more stormwater harvesting and storage systems to provide irrigation opportunities for parks, trees and sporting ovals to help manage them through drought conditions.

“Despite the current, popular view that turf and lawns are profligate water users and are unsustainable in the Australian environment, natural turf is usually a more sustainable option than sealed surfaces or artificial turf if you consider the latter’s fossil fuel chemical base and imbedded energy. Turf is quite a complex ecosystem that has a significant effect on temperature and the heat island effect, and if properly managed also sequesters a considerable amount of carbon. Perhaps it is not the villain that many think it is when they consider only the water component of a more complex equation.

“Consider the following scenario. In a small backyard the lawn (8 x 4m) has been replaced with artificial turf at a cost of $6000. The owner has done so because they have heard that lawn is not good for water use or the environment. The artificial turf is made from fossil fuel, imported from overseas and has high embedded energy. The purchase and installation of a locally made 5000L tank would cost $1200 and provide enough water for such a small lawn year round. Already the owner misses the birds that used to come fossicking in the lawn. Her local council is also replacing a turf oval, which they cannot irrigate due to local water authority restrictions, with artificial turf. They are doing so as part of their water policy. However, the product is imported with high embedded energy and carbon, and the council is not harvesting the water that runs off or passes through the new artificial turf surface. Efficient irrigation and water recycling and a water efficient native grass would be a far more sustainable option for a low use oval. The council has also used couch grass on many of its other sporting ovals, unaware that its high binding strength could cause serious knee injuries to teenage football, hockey or cricket players.

“Trees and urban landscapes are assets in every sense of the word and resources for allocated for their proper and sustained management. Amongst these resources may be the need for an allocation of water, used wisely and sustainably. If the focus is solely on water such that trees and other vegetation are left to die, then consequently the carbon that they sequester would be released into the atmosphere.”

Moreland Council, (April 2018), Sports Surface Needs Analysis (D18/102018), Moreland Council Agenda 11 April 2018
https://www.moreland.vic.gov.au/globalassets/key-docs/meeting/agenda-council-upc/council-agenda-11-april-2018.doc (Doc 161MB)
An excerpt of Sports Surface Needs Analysis (D18/102018) is also available here: https://fawkner.org/2018-04-11-sports-surface-needs-analysis/
Keywords: Grey Literature, Synthetic turf, Sport, UHIE

This is the Council Officers report and a consultants report that details the program for roll out of synthetic and hybrid surfaces in Moreland Municipality. It includes Hybrid and Synthetic Sports Surfaces Needs Analysis prepared by Smart Connection consultancy dated February 2018. It recommended 9 sports fields be converted to hybrid or synthetic fields in Moreland, subject to funding and budgetary considerations. The consultants report failed to adequately take into account Greenhouse gas emissions (total life cycle assessment), impact on biodiversity, and heavily prioritised organised sport above active informal recreational activity and environmental impacts, and offered limited measures to ameliorate the extra urban heat of these fields.
As part of a triple bottom line decision making it was greatly skewed to social (sports club) outcomes, and largely ignoring informal active recreation, above the economic and environmental impacts and factors.
Executive summary and recommendation fails to mention Hosken Reserve north, though it is mentioned in the full detail section. This is highly misleading for anyone reading the executive summary of what work was being proposed (whether already agreed to in some form or not).
Section 7.5 on Heat stress is a major issue for synthetic turf limiting the playability. ‘Cool Grass’ versions will only marginally address this issue.
Section 8 deals with sustainability considerations.
8.3.4 says “It is thought that the carbon footprint for natural grass is lower than that of an artificial surface. This is when you compare the installation and Maintenance of grass (eg fertiliser production, mowing and maintenance) with the synthetic surface option and what’s involved in its production, transportation and disposal of materials.” In the next section - 8.3.5 Carbon offset it detailed the 2006 Canadian study of CO2e emissions of 55.6 tonnes for a synthetic field but failed to mention likely soil organic carbon sequestration of 19 tonnes. It failed to mention Magnusson and Macsik (April 2017) which provides a Greenhouse Gas emissions total life-cycle assessment of a synthetic field for 10 years as 527 ton CO2e. It also used a Californian study to say that natural turf grass is unlikely to be a net sequester of GHG emissions, There was an update to this study, not denoted as a reference, to suggest that under some circumstances urban grasslands/lawns may be net carbon sinks. It also used a petrochemical industry study (BASF corporation) which nominally compared synthetic to natural grass and “found that the average life cycle over 20 years of natural grass fields are 15 per cent higher than the synthetic alternatives.” This study was not an independent total life cycle assessment study and the results and conclusions must be questioned as to bias given its origin from a major Chemical company, especially as it is not peer reviewed academically.

Section 8.3.2 dealt with The Urban Heat Island Effect, but does not address local area impacts or prioritise this impact in assessing synthetic turf for local residents in a warming climate with more extreme heat days.
Section 8.5.2 Green engineering - conversion to synthetic turf would seem to go against this being Green Engineering. See VCCCAR (2013) report.
The Sports Surface Needs Analysis consultants report does not mention Environmental impacts on soil biota, grass seeds and insects which will likely have a trophic impact on local urban birdlife. This is a cumulative impact in highly urbanised environments. Research has been very limited, but there is at least one recent study identifying this issue.
There is little mention of emissions and energy and micro-plastics pollution with disposal of synthetic turf. This is essential to include when assessing decisions to install hybrid or synthetic turf.
Science has progressed even in the 3 years since this consultants report which should necessitate a reappraisal of environmental impacts, including Total life-cycle assessments analysis, and reconsideration of the triple bottom line priorities, taking into account in particular more recent Council policies on waste and circular economy, climate emergency and zero carbon framework and targets.

Moreland Council, (10 April 2019) Plastic Wise Policy
https://www.moreland.vic.gov.au/environment-bins/environment/plastic-wise-moreland/plastic-wise-sports-clubs/
Keywords: Grey Literature, Environmental context, microplastics, pollution

This policy identifies that Moreland Council is taking action in limiting single use plastic at all Council sponsored or organised events. It highlights leadership on reducing plastic use and provides a sharp contrast to the Sport and Recreation Department drive to convert natural grass sporting fields to synthetic surfaces. Council actively applies the Plastic Wise policy to sporting clubs.

Moreland Council, Zero Carbon Moreland 2040 Framework
https://www.moreland.vic.gov.au/globalassets/key-docs/policy-strategy-plan/moreland-zero-carbon-2040-framework.doc
See also ZERO CARBON MORELAND – Climate Emergency Action Plan 2020/21 – 2024/25 (November 2019)
https://www.moreland.vic.gov.au/globalassets/key-docs/policy-strategy-plan/zero-carbon-moreland-climate-emergency-action-plan-2020-21-2024-25.pdf
Keywords: Grey Literature, Greenhouse gas emissions, carbon sequestration, Environmental context.

These are Moreland Council’s principal climate action policy and first five year plan, incorporating a community net zero by 2040 emissions reduction target. The Zero Carbon Moreland 2040 Framework refers to several challenges in managing scarce infrastructure resources, including “Preserving, creating and enhancing green open spaces as the city population grows” . Clearly this will be a challenge taking into account formal community and professional sporting organisations growing need for using green spaces, and informal recreational activities that also use these spaces with a growing need due to increasing urban consolidation and densification highlighting their environmental importance and the environmental services they deliver.

The 2040 vision also includes Moreland being a circular economy with zero waste. (See Moreland Waste and Litter Strategy that incorporated a zero waste to landfill target by 2030) Yet while synthetic turf products, including synthetic grass, are marketed as “recycleable”, like many plastics they are not recycled but instead disposed of mostly to landfill due to the exorbitant costs and energy in setting up a recycling stream process.

Under the Climate Emergency Action Plan 2020/21 - 2024/25 Council has a responsibility under section 4.6 to “Act to reduce Council’s operational waste and the ecological footprint of Council’s facilities and services.” This includes sporting fields and use of synthetic pitches.

Moreland Council, Waste and Litter Strategy (2018)
https://www.moreland.vic.gov.au/globalassets/key-docs/policy-strategy-plan/waste-and-litter-strategy-2018---2022---version-for-web-pdf.pdf
Keywords: Waste, landfill, synthetic turf

In May 2018 Moreland Council voted 9/2 for NOM15/18 - Zero Waste to Landfill by 2030 (D18/151809) which "Seeks to refocus the new Waste and Litter Strategy with a goal of zero waste to landfill across the municipality by 2030. The strategy as a minimum shall:
a) Establish a 2030 Zero Waste to Landfill framework.
b) Seek to embed and give weight to the '5R's - Refuse, Reduce, Reuse, Repurpose, Recycle' as core values in all future contracts and procurement"

This became part of the Moreland Council Waste and Litter Strategy 2018 (PDF) as adopted at 12 December 2018 Council meeting.

Use of synthetic surface and it’s disposal seems to be greatly at odds with Moreland Council commitment to zero waste to landfill by 2030, and commitment to a circular economy. These zero waste and circular economy principles are also embedded within the Zero Carbon Moreland 2040 Framework.

PBS Frontline production, (August 2020), Plastic Wars. As presented by Craig Reucassel for Four Corners on ABC TV.
https://www.abc.net.au/4corners/plastic-wars:-recycling-spin-in-the-plastics/12529956
Keywords: Grey Literature, Plastics, Environmental context, pollution

While synthetic turf products, including synthetic grass, are marketed as “recycleable”, like many plastics they are not recycled but instead disposed of mostly to landfill due to the exorbitant costs and energy in setting up a recycling stream process. This documentary production investigates the hype and marketing spin behind plastics and its marketing as products that are recycled. Nothing seems different with synthetic turf...

“Industry insiders expose the cynicism at the heart of the strategy.
“There was never an enthusiastic belief that recycling was ultimately going to work in a significant way.” Former plastics industry executive

“The program shows how tactics brought in decades ago are still fooling consumers.

“At the bottom of all these plastic containers is this little chasing arrow—the little recycling symbol with a number…there are no curbside programs that would accept any of these tubs.” Environmental scientist”

Pennsylvania State University Center for Sports Surface Research, (2012) Synthetic Turf Heat Evaluation-Progress Report.
https://plantscience.psu.edu/research/centers/ssrc/documents/heat-progress-report.pdf
Keywords: Synthetic turf, Heat

Experiment on heat retention of various different coloured synthetic fibres and infills (including Black Rubber, Ecofill and TPE). Results summary:
“No product in this test substantially reduced surface temperature compared to the traditional system of green fibers filled with black rubber in both the indoor and outdoor test. Reductions of five or even ten degrees offer little advantage when temperatures still exceed 150° F. Until temperatures can be reduced by at least twenty or thirty degrees for an extended period of time, surface temperature will remain a major issue on synthetic turf fields.”

Pfautsch, S., Tjoelker, A R. (Oct 2020) The impact of surface cover and tree canopy on air temperature in Western Sydney. Western Sydney University, 140 p.
https://doi.org/10.26183/bk6d-1466
Keywords: heat, UHIE, Australia, Environmental context

Sebastion Pfautsch and his team have been doing a lot of research on addressing extreme heat, and the urban heat island effect in Western Sydney including a number of reports to Western Sydney Councils.

“This research shows:
» Increasing the area of hard surfaces and buildings leads to warming
» Increasing the area of open spaces and tree canopy leads to cooling
» When provided in equal proportions warming from hard surfaces exceeds cooling from open space
» The largest cooling benefits are generated by open space
» Increasing tree canopy cover has no effect on peak heatwave conditions, yet plays a significant role in cooling nighttime air temperatures
» The magnitude of attainable cooling effects in urban space is 0.8-1.3°C for mean summer air temperatures

» The capacity to lower peak heatwave air temperatures is very limited
» Open space and tree canopy cover can markedly reduce summer nighttime air temperatures"

Pfautsch S., Rouillard S., Wujeska-K l ause A., Bae A., Vu L., Manea A., Tabassum S., Staas, L., Ossola A., Holmes, K. and Leishman M. (Sept 2020) School Microclimates. Western Sydney University, 56 p.
DOI: https://doi.org/10.26183/np86-t866
Keywords: heat, UHIE, Australia, Environmental context

This is important research on urban heat within a school in the Western suburbs of Sydney that includes two large areas of artificial surfaces. It examines how to improve outcomes to limit heat health impact on users of the school. Heat influences learning outcomes and also represents a serious health risk. It includes examination of the potential burn hazard from hot surface materials.

"Assessment of surface temperature of different materials in full sunshine revealed that artificial grass and bare soil were the hottest surfaces, regardless of ambient temperatures (Table 8). Sunlit artificial grass reached a mean temperature of 52°C during the normal summer day despite the air temperature being below 30°C. The surface temperature of artificial grass increased when ambient air temperatures rose and a maximum value of close to 70°C was measured for this material." says the report.

One of the recommendations of the report is that "Use of artificial grass should be avoided or restricted to areas with zero exposure to direct sunshine."

Poeplau, C., Marstorp, H., Thored, K., Kätterer, T., (2016) Effect of grassland cutting frequency on soil carbon storage – a case study on public lawns in three Swedish cities Soil, 2 (2016), pp. 175-184 **https://soil.copernicus.org/articles/2/175/2016/**
Keywords: Carbon Sequestration, Natural turf

This study found that frequently cut urban lawns were found to contain 55% more soil C than surrounding arable soils.
"The higher aboveground NPP in the utility lawns had a significant positive effect on soil carbon. This was expected, since the clippings were not removed and were thus able to contribute directly to soil organic matter formation."
"Overall, our findings and those of previous studies (Christopher and Lal, 2007; Poeplau et al., 2015a) confirm that plant input driven by NPP is the major driver for SOC dynamics. Root carbon input is recognised as being of major importance for building up soil organic matter, since a higher fraction of root-derived carbon is stabilised in the soil than in aboveground plant material (Kätterer et al., 2011). In temperate grasslands, up to 70 % of the total NPP is allocated to roots and their exudates (Bolinder et al., 2007)."
"in the present study we were able to show that SOC storage in urban lawns can be increased at comparatively low cost under temperate climate conditions by optimising NPP and leaving residues on the lawn….However, for a full greenhouse gas budget, the effects of lawn

management on other trace gases, primarily nitrous oxide (N2O), have to be considered (Townsend-Small and Czimczik, 2010). In that case, management of the clippings will most likely play a key role, since coverage of the soil with organic material increases soil moisture and the availability of labile carbon but decreases soil oxygen, all of which favour N2O formation (Larsson et al., 1998; Petersen et al., 2011)."

Power, Julie, (14 March 2021), Fake grass may be greener, but much hotter and less friendly to environment, Sydney Morning Herald. Accessed 14 March 2021.
https://www.smh.com.au/national/nsw/fake-grass-may-be-greener-but-much-hotter-and-less-friendly-to-environment-20210312-p57a95.html
Keywords: Grey literature, Environmental context, UHIE, microplastics, pollution, synthetic turf

News article about community campaigns in Sydney highlighting urban heat and micro-plastics pollution problem of the growing trend for state government funding Councils to install synthetic turf sporting fields. NSW Planning Minister Rob Stokes has asked his department to investigate sustainable alternatives to synthetic grass.
"New research by the Australian Microplastic Assessment Project (AUSMAP) with Northern Beaches Council, funded by NSW's Environment Protection Authority, has found 80 per cent of the waste entering stormwater drains was black crumb (recycled tyres used for the base of these fields) and microplastics from astroturf – compared to 5 per cent in areas without these playing fields.

"USMAP director of research Dr Scott Wilson said they were "definitely finding a proliferation of the crumb and some grass" particularly when many games had been played and after wet or windy weather."

On urban heat impact it quoted a researcher:
"On a hot day, temperatures on synthetic grass can be more than twice as high as on a grass playing field. Sebastian Pfautsch from Western Sydney University found temperatures on a synthetic play area reached 106 degrees in western Sydney during a heatwave in January 2020.

"I absolutely loathe synthetic grass," Dr Pfautsch, who specialises on the impact of rising temperatures in urban environments, said. "It is possibly the worst materials for heat and it is made from completely unsustainable, non-recyclable plastic that goes straight to landfill."

Pronk, M., Woutersen, M. & Herremans, J., (2020) Synthetic turf pitches with rubber granulate infill: are there health risks for people playing sports on such pitches?. J Expo Sci Environ Epidemiol 30, 567–584 (2020). https://doi.org/10.1038/s41370-018-0106-1
Keywords: health, toxicity, synthetic turf, infill

Most health studies have found that sports player exposure to heavy metals and chemicals from infill poses little risk, with this risk being further ameliorated if organic infills are used such as coconut husks, cork or crushed walnut shells. For example, a 2018 Dutch study concluded:

“on the current evidence available, it is considered safe to play sports on STP with the rubber infill in place in the Netherlands. No immediate action was thus required. It was recommended though to review the conclusions when the results of the ongoing, large-scale studies in the US become available. Further, it was recognised that, should the rubber granulate have contained concentrations of PAHs as high as the European concentration limits for mixtures, safe use might not be guaranteed. To ensure therefore the supply of rubber granulate with only very low concentrations of hazardous substances (PAHs in particular) and thus the safety for people playing sports, it was recommended to set regulatory limit values specifically for (substances in) rubber granulate.”

Qian Y., Follett R. (2012) Carbon Dynamics and Sequestration in Urban Turfgrass Ecosystems. In: Lal R., Augustin B. (eds) Carbon Sequestration in Urban Ecosystems. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-2366-5_8
Keywords: Carbon sequestration, Natural turf

Highlights importance of leaving grass clippings in place, minimising fertiliser and irrigation, electrifying maintenance carbon costs (mowing).

From the abstract: “Turfgrasses exhibit significant carbon sequestration (0.34–1.4 Mg ha^{-1} year^{-1}) during the first 25–30 years after turf establishment. Several studies have reported that residential turfgrass soil can store up to twofold higher soil organic carbon (SOC) content than agricultural soils. Published research suggests that the dynamics of nitrogen (N) is controlled by C transformation. Turfgrass areas have high levels of SOC and microbial biomass creating a carbon-based “sink” for inorganic N. Therefore, lower than “expected” nitrate leaching and N2O emissions have been measured in the majority of the experiments carried out for turfgrass ecosystems. Increased SOC in turfgrass soil can result from: (1) returning and recycling clippings, (2) appropriate and efficient-fertilizer use, and (3) irrigation based on turfgrass needs. Some turfgrass management practices (such as fertilization, mowing, and irrigation) carry a carbon “cost”. Therefore turfgrass’s contribution to a sink for carbon in soils must be discounted by fuel and energy expenses and fertilizer uses in maintaining turf, and the flux of N2O.”

Royer, Sarah-Jeanne., Ferrón, Sara., Wilson, Samuel T., Karl, David M. (August 2018) “Production of methane and ethylene from plastic in the environment”, Plos One. https://doi.org/10.1371/journal.pone.0200574
Keywords: Synthetic turf, microplastics, Greenhouse gas emissions

Synthetic turf is made of polyethylene yarn fibres. Polyethylene fibres are a source for greenhouse gas pollution as the polyethylene plastic breaks down, producing methane and ethylene.

This continues during the life (and disposal) of the product. If synthetic turf is disposed of by incineration you get a burst of greenhouse gas emissions. If the synthetic turf is sent to landfill as part of disposal, it slowly emits greenhouse gases as the plastic fibres degrade and break down. This also contributes to micro-plastics pollution, including leaching out of landfill into local waterways.

“The release of greenhouse gases from virgin and aged plastic over time indicates that polymers continue to emit gases to the environment for an undetermined period. We attribute the increased emission of hydrocarbon gases with time from the virgin pellets to photo-degradation of the plastic, as well as the formation of a surface layer marked with fractures, micro-cracks and pits [24–26]. With time, these defects increase the surface area available for further photo-chemical degradation and therefore might contribute to an acceleration of the rate of gas production. It is also known that smaller particles of secondary origin termed ‘microplastics’ [27,28] are eventually produced and may further accelerate gas production. The initial shape of the polymer is also a potential factor contributing to the variability in hydrocarbon production because items of the same mass but with different shapes have different surface-to-volume ratios. Small fragments not only have a greater surface-to-volume ratio than larger items, but they also tend to have longer edge lengths relative to their volume [29]. This predicts that in the environment, as plastic particles degrade and become smaller, they will also emit more hydrocarbon gases per unit mass.”

Concluding remarks: “Given the ongoing rate at which plastic is being produced, used and exposed on land and the future trend in mismanaged plastic waste ending up in marine systems [32], the amount of plastic exposed to the environment will likely increase with time and so too will the amount of CH_4 and C_2H_4 emitted from polymers. In addition, degradation of plastics in the environment leads to the formation of microplastics with greater surface area, which may accelerate hydrocarbon gas production. Due to the longevity of plastics and the large amounts of plastic persisting in the environment, questions related to the role of plastic in the CH_4 and C_2H_4 global budgets should be prioritized and addressed by the scientific community.”

SEA (Sports Environment Alliance) (2020) Future Proofing Community Sport & Recreation Facilities - A Roadmap for Climate Change Management for the Sport and Recreation Facilities Sector.
https://www.sportsenvironmentalliance.org/resources/guide-to-future-proof-sport-recreation **Accessed 7 March, 2021.**
Keywords: Grey Literature, Environmental context, Sports

Project developed by the Sports Environment Alliance in partnership with the Victorian State Government. Although this report does not mention synthetic surfaces it includes strong sustainability guidelines on pp19.
“In the face of changing climate, it is recommended that ecological impact is strategically considered across the planning of places where we play, and embedded as business as usual in design and operations.
Furthermore, there are no ‘end points,’ only successes and milestones along the ever changing conditions and demands for mitigation and adaptation (McCullough, Pfahl, & Nguyen, 2015).

In future proofing our places of play, there are two key areas of opportunity: built environment and stakeholder engagement. How we design, build and then engage stakeholders to behave in alignment with how we operate our places of play must be focused on protecting our clean future. To address the built environment:
• consult internationally and locally recognised standards for 'green' and 'healthy' infrastructure
• conservation of the natural environment and positive impact on biodiversity;
• conservation of historic buildings and other cultural heritage;
• conservation of water resources;
• minimisation of energy use and of greenhouse gas emissions;
• minimisation of adverse impacts on land, water, noise and air quality;
• use of long-lasting environmentally and socially responsible materials;
• minimisation of waste and maximising reuse and recycling of materials;
• universal design;
• internal environments that foster health and well being; and
• creation of opportunities to leave a positive legacy for local businesses and communities.
("Sustainability Essentials: Introduction to Sustainability", n.d., p. 47)

Slater G (2010) The Cooling Ability of Urban Parks.
https://www.asla.org/2010studentawards/169.html
Keywords: heat, UHIE

A study on the cooling impact of parks (or park cooling effect) in moderating the Urban Heat Island Effect conducted in the Canadian city of Toronto. According to the researcher:
"The most important findings of this research were that:

- parks were cooler than the surrounding urban environment by up to 7°C
- park cooling was variable but could extend almost 100m downwind into the neighborhood
- not all parks produced cool air extension
- busy streets appeared to inhibit cool air movement
- street trees could substantially reduce air temperatures underneath them"

Sport and Recreation Victoria (Feb 2011), Artificial Grass for Sport Guide.
https://sport.vic.gov.au/publications-and-resources/community-sport-resources/artificial-grass-sport-guide **Accessed 21 March, 2021**
Keywords: Grey Literature, Sports

See in particular Part 3 of 8. Does not do a life cycle assessment analysis of greenhouse gas emissions, instead uses 2010 study to highlight athletic/sports fields may not be carbon sinks in sequestering CO2e but ignores the high emissions of synthetic turf, especially in manufacturing and disposal. Emissions in disposal (landfill for Australia) are virtually ignored.

Su, Yinglong., Zhang, Zhongjian., Wu, Dong., Zhan, Lu., Shi, Huahong., Xie, Bing., (2019) Occurrence of microplastics in landfill systems and their fate with landfill age,

Water Research, Volume 164, 2019, 114968, ISSN 0043-1354,
https://doi.org/10.1016/j.watres.2019.114968
(https://www.sciencedirect.com/science/article/pii/S0043135419307420)
Keywords: Microplastics, waste, pollution, Synthetic turf

While the study doesn't mention synthetic turf explicitly, it does mention polypropylene and polyethylene in its analysis of landfill refuse and leachates.

"Microplastics have the potential to absorb organic contaminants and heavy metals, and then transport these contaminants or enrich them in biota, thus imposing major impacts on human health and ecosystems (Bouwmeester et al, 2015)...."

"the MPs were generally irregular in shape and hackly in structure; thus, the breakdown of plastic debris was the primary contributor to MPs (i.e., secondary MPs). Furthermore, the hackly surface of MPs would benefit the enrichment of contaminants such as heavy metals and organic contaminants (Koelmans et al., 2016), which could enhance the environmental risk of leachate discharged to the environment."

In most of my reading very little attention has been placed on end life disposal of synthetic turf and long term environmental impact. As the synthetic fibres breakdown into Microplastics they cause greenhouse gas emissions as well as Microplastics pollution of waterways and ecosystems and may operate as a vector for organic contaminants and heavy metals due to their inherent structure.

At present all synthetic turf in Australia ends up in landfill, with very little recycling done globally. While manufacturers may specify their fibres are 'recycleable', there are no process capacity set up to do the recycling due to the high costs involved.

Thoms, Adam William, "Sources of Heat in Synthetic Turf Systems. " (2015) PhD diss., University of Tennessee. https://trace.tennessee.edu/utk_graddiss/3475
Keywords: Heat, Synthetic turf

Looked at the heat impact of synthetic turf and assessed possible ways to partially reduce the surface temperature of the synthetic turf. It concluded: "Forced air applied either to the synthetic turf surface or forced through the sub-surface aggregate base lowered the synthetic turf surface temperature. Synthetic turf painted with reflective pigments also reduced surface temperature compared to the non-treated control. These findings indicate that synthetic turf surface temperatures can be reduced without the use of water." This likely led to the development of 'Cool Grass' 4th generation synthetic turf technology which increases grass fibre reflectivity so the grass surface heats up about 10-15 per cent less, reflecting this heat to the air above.

Tidåker, P., Wesström, T. and Kätterer T., (2017) Energy use and greenhouse gas emissions from turf management of two Swedish golf courses, Urban For. Urban Green., 21 (2017), pp. 80-87 https://doi.org/10.1016/j.ufug.2016.11.009
Keywords: LCA, Energy, Greenhouse Gas Emissions, natural turf, carbon sequestration

A study on turf management of 2 Swedish golf courses and implications for energy use and greenhouse gas emissions. Used Life-cycle Assessment methodology to evaluate primary energy and greenhouse gas emissions. Highlighted the problem of N20 emissions with fertiliser application and decomposition of grass clippings. Highlighted high energy use in mowing and need to electrify machinery to reduce energy and hidden carbon costs, and to minimise fertiliser use for both energy and GHG savings.

"Soil organic C stocks are generally higher in grassland soil than in arable soil (Poeplau and Don, 2013). Since the golf courses studied here were established on arable land, which probably had a history of mixed farming, it is likely that C stocks in the turf have increased since establishment of the golf courses about 50 years ago. The topsoil (0–20 cm depth) in the fairway and rough areas currently contains about 80 Mg C ha^{-1} on average over the two sites (unpublished data), which is 23% more than the C content in mineral agricultural topsoils in the region (Andrén et al., 2008). If this difference in C storage is attributed to turf management over 50 years, soil sequestration in fairway and rough areas would amount to 0.3 Mg C ha^{-1} $year^{-1}$. Thus including soil C sequestration reduced the GHG emissions from fairways considerably and turned roughs into a sink for GHG."

The study recommends: "Appropriate measures for reducing energy use and carbon footprint from lawn management are thus: i) reduced mowing frequency when applicable, ii) investment in electrified machinery, iii) lowering the mineral N fertiliser rate (especially on fairways) and iv) reducing the amount and transport of sand for dressing. Lowering the mineral fertiliser rate is of particular importance, since GHG emissions originate from both the manufacturing phase and from N turnover after application."

Townsend-Small, A. and Czimczik, C. (2010a). Carbon Sequestration and Greenhouse Gas
Emissions in Urban Turf. Geophys. Res. Lett. 37.
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2009GL041675
Keywords: Carbon sequestration, Greenhouse gas emissions, natural turf

While urban lawns and grasslands, if managed carefully, can operate as carbon sinks due to Organic Carbon Sequestration in soil, this research argues that in athletic fields there is no Organic Carbon sequestration because of frequent surface restoration. The research particularly highlights the problem of fertiliser/irrigation use associated with higher Nitrous Oxide (NO2) emissions (Global warming potential is 300x stronger than CO2)

"In athletic fields, there is no net storage of CO_2 to offset N_2O emissions. Overall, according to our careful measurements, N_2O emissions are too low to overcome the high rates of OC sequestration in ornamental lawns…. High CO_2 uptake in lawns is not without a "carbon cost" from fossil fuel CO_2 emitted during maintenance. We made rough estimates of CO_2 emissions derived from fuel consumption, irrigation and fertilizer production."

Townsend-Small, A. and Czimczik, C. (2010b). Correction to Carbon Sequestration and Greenhouse Gas Emissions in Urban Turf. Geophys. Res. Lett. 37.
https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2010GL042735
Keywords: Carbon sequestration, Greenhouse gas emissions, natural turf

One also needs to read the correction to the study issued two months later, based upon "error in the calculation of carbon dioxide (CO_2) emissions from fuel consumption during turfgrass maintenance." :
"This changes the total global warming potential (GWP) of both ornamental lawns and athletic fields (Figure 3b). Based on this correction, the total GWP of ornamental lawns ranges from −108 g CO_2 m^{-2} yr^{-1} for the low fertilization scenario (10 g N m^{-2} yr^{-1}) to +285 g CO_2 m^{-2} yr^{-1} for the high fertilizer scenario (75 g N m^{-2} yr^{-1}). In athletic fields, which do not store OC in soils, there is a positive GWP ranging from +405 to +798 g CO_2 m^{-2} yr^{-1} for the low and high fertilizer scenarios, respectively."

Final conclusion: "This reanalysis shows that there may be a potential for urban ornamental lawns to sequester atmospheric CO_2 if they are managed conservatively (Figure 3b). However, intensive management practices such as frequent application of inorganic fertilizers, irrigation, and fuel consumption from mowing and leaf blowing all decrease the likelihood that urban turfgrass can mitigate greenhouse gas emissions in cities."

UNEP (February 2021) Making Peace with Nature. A scientific Blueprint to tackle the climate, biodiversity and pollution emergencies. ISBN 978-92-807-3837-7
https://www.unep.org/resources/making-peace-nature
Keywords: Grey Literature, Environmental context, biodiversity, microplastics

A meta report from the United Nations Environment Program (UNEP) highlighting the multiple crises we face with climate, biodiversity and pollution. It highlights we need to tackle these problems simultaneously with nature based solutions playing a vital role.

"Global warming exacerbates the urban heat island effect in cities and their surroundings, especially during heatwaves, increasing people's exposure to heat stress." pp 26

"Disposal, release and leaks of chemicals, nutrients and waste are driving environmental declines, especially in aquatic ecosystems. Pollution is regarded as the third most important driver of biodiversity loss in freshwater and the fourth in terrestrial and marine systems (see figure 3.1). Up to 400 million tons of heavy metals, solvents, toxic sludge and other industrial wastes are dumped annually into the world's waters, and fertilizers entering coastal ecosystems have produced dead zones. 96 Marine plastic pollution has increased tenfold since 1980, constituting 60 to 80 per cent of marine debris, and is found in all oceans at all depths and concentrates in the ocean currents. Marine plastics cause ecological impacts from entanglement and ingestion and can also act as a vector for invasive species and pollutants. 97,98,99 There has been a near-doubling of the global chemical industry's production capacity between 2000 and 2017." pp63

"Given the interconnected nature of climate change, loss of biodiversity, land degradation, and air and water pollution, it is essential that these problems are tackled together urgently. Actions needs to be taken now even where the benefits may not be realized for years due to the long-lasting nature of environmental effects or to inertia in the socioeconomic system." pp107

"Substantial gains in the protection of nature can be achieved through the sustainable management and restoration of landscapes and seascapes that are productive and often inhabited. Transformative actions to reduce the drivers of biodiversity loss must necessarily occur mostly in human-populated and production-oriented landscapes and seascapes outside of protected areas. This requires the development of new land- and resource-use rules and objectives that are beneficial, neutral or at least much less harmful to biodiversity, while permitting uses benefitting humans." pp 109

Valeriani, Federica., Margarucci, Lory Marika., Gianfranceschi, Gianluca., Ciccarelli, Antonello., Tajani, Filippo., Mucci, Nicolina., Ripani, Maurizio., Spica, Vincenzo Romano., (August 2019) Artificial-turf surfaces for sport and recreational activities: microbiota analysis and 16S sequencing signature of synthetic vs natural soccer fields, Heliyon, Volume 5, Issue 8, 2019, e02334, ISSN 2405-8440,
https://doi.org/10.1016/j.heliyon.2019.e02334
(https://www.sciencedirect.com/science/article/pii/S2405844019359948)
Keywords: Synthetic turf, Natural turf, Microbiota, Health, infection

A study looking at the bacterial and microbiotic differences between natural turf and synthetic grass sporting pitches. There are more incidents of abrasions and turf burns from artificial grass which may provide a pathway for bacterial and microbial infections. A major factor driving microbial diversity on synthetic surfaces is contamination with human sweat or saliva as well as from the natural microflora in the surrounding area. This highlights the importance of regular disinfecting maintenance required.

"Recent studies have showed higher rates of abrasion injuries on artificial turf surfaces compared to natural grass playing fields (Twomey et al., 2018; Meyers, 2013; Williams et al., 2016)..... The microbiological risk has been less investigated, even if several studies raised a possible association between turf burns and infections in injured athletes, identifying the synthetic turf as a possible source of pathogens, including community-acquired methicillin-resistant Staphylococcus aureus and other antibiotic resistant microorganisms (CDC, 2003; Kirkland and Adams, 2008; Cohen, 2008). It was suggested that the turf infill may represent a favourable niche for the accumulation and selection of bacteria species, especially if maintenance is not regularly and appropriately performed (Bass and Hintze, 2008).”

“Interestingly, bacteria from different sources can be found in synthetic turfs, but not conversely in natural ones. Different synthetic materials already were shown to provide a cozy microenvironment to harbour bacteria from anthropic, animal (e.g. Staphylococcus, Streptomyces, Nocardioldes, Hymenobacter), or other natural sources (Williamsia, Chryseobacterium, Rhodococcus) (Mafu et al., 1990; Carniello et al., 2018; Sharma et al., 2018; Masoud, 2017). Therefore, a major factor driving beta-diversity variance in artificial surfaces may likely be due to contamination with human sweat or saliva as well as from the natural microflora in the surrounding area. This was not observed in natural turfs probably due to the competition driven by the rich endophytic microflora (Simon et al., 2019; Hassani et al., 2018; Mafu et al., 1990). Mesophilic bacteria, including pathogens, were detected more frequently in the penalty area and centre circle of synthetic turfs, even if the analysis of similarities for the several sampling points showed no changes in microflora profile. These results suggest that microbial communities fluctuate around a common biodiversity centroid, as already reported for other sport plants (Wood et al., 2015). However, within the same facility clear differences can be observed between different sampled areas. The whole of observed results suggests that in synthetic fields the microbial community structure is primarily defined by the anthropic contamination. Management, use, and maintenance of the facility may also play a major role in determining the microbial load and its composition. Infill materials can represent a potential source for bacterial grow posing putatively higher infection risks respect to natural fields, as previously reported for cased of cutaneous infections in soccer players using synthetic turfs (CDC, 2003; Kirkland and Adams, 2008; Cohen, 2008).”

Velasco, Erik., Roth, Matthias., Norford, Leslie., Molina, Luisa T., (2016) Does urban vegetation enhance carbon sequestration?, Landscape and Urban Planning, Volume 148, Pages 99-107, ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2015.12.003. (https://www.sciencedirect.com/science/article/pii/S0169204615002455)
Keywords: Carbon sequestration

This study looked at the carbon fluxes in 2 residential neighborhoods: one in Singapore and one in Mexico city and the role of vegetation and soil respiration. The authors suggest the “impact of urban vegetation to reduce GHG emissions directly through carbon sequestration is very limited or null.”
While interesting, it does not really shed light on natural turf vs synthetic turf debate, except to highlight the need for “complete assessment should include emissions associated with greenery management (i.e. pruning, mowing, watering, fertilizing, debris removing, etc.) which could further offset any carbon reduction (e.g., Townsend-Small & Czimczik, 2010).”

WA State Government Department of Sport, (2011) Natural Grass vs Synthetic Turf Decision Making Guide.
https://www.dlgsc.wa.gov.au/department/publications/publication/natural-grass-vs-synthetic-turf-study-report

Keywords: heat, synthetic turf, natural turf, LCA, water, Costs, Australia

The WA State Government Department of Sport prepared a detailed Natural Grass vs Synthetic Turf report and Decision Making Guide. The guide devotes a section to Heat issues – natural grass and synthetic surfaces which contains temperature comparisons between natural grass and artificial turf from studies carried out in the US, Japan and elsewhere, focusing on third generation artificial turf.
In looking at the social impact this report really only considers organised sport and not informal active recreation use of sporting grounds, including informal playing of common sports.

The report does provide some total life cycle cost comparisons. Synthetic turf costs more than double natural grass on both 25 year and 50 year time scales.

"In conclusion, detailed consideration of a variety of environmental factors needs to be taken into account when planning the installation of a synthetic turf or natural grass surface. It is advisable to conduct and seek further research and information in this area, as there are many helpful resources available that are referenced but not fully expanded on within this report."

Good background, but more recent research over the last decade in all the areas need to be considered. There is also a need to consider a change in the general context over the last decade to include the climate emergency, a biodiversity crisis and plastics pollution crisis that needs to be given much more weight against the social considerations and benefits for sporting organisations.

Williams, Frank C., and Pulley, Gilbert E., (2002), Synthetic Surface Heat Studies, Brigham Young University
https://aces.nmsu.edu/programs/turf/documents/brigham-young-study.pdf
Keywords: Heat, Synthetic turf,

One of the early studies highlighting the urban heat of synthetic surfaces and often for the need of water cooling to ensure safety of users of the sports field. The study found that surface temperatures on synthetic plastic fields can reach temperatures up to 21.1 degrees C higher than on natural grass fields, with temperatures in some cases reaching greater than 65.6 degrees C. (37 degrees Fahrenheit, or 20.5 degrees C, higher than the air temperature.)

"The heating characteristics of the A.T. make cooling during events a priority. The Safety Office at B.Y.U. set 120º F as the maximum temperature that the surface could reach. When temperature reaches 122º F it takes less than 10 minutes to cause injury to skin. At this temperature the surface had to be cooled before play was allowed to continue on the surface. The surface is monitored constantly and watered when temperatures reach the maximum. The heat control adds many maintenance dollars to the maintenance budget."

Final conclusion:
“Artificial turf surfaces have their place in the turf industry. They can work in environments where grass will not grow and are marginal. However, they are costly and not maintenance free. It is important to take all the factors in to consideration before making a large investment. Don’t take the manufacture’s word for the factors of concern i.e. don’t let the fox guard the hen house. The propaganda on BYU’s installation is charts with surface temperatures less than the air temperature and claims for drainage of 60 inches per hour. The question still remains is A.T. 11.47 times better than natural turf?”

Xu, E.G., Lin, N., Cheong, R.S., (...), Larsson, H.C.E., Tufenkji, N. (2019) Artificial turf infill associated with systematic toxicity in an amniote vertebrate, PNAS December 10, 2019 116 (50) 25156-25161; first published November 25, 2019; https://doi.org/10.1073/pnas.1909886116
Keywords: Synthetic turf, toxicity, infill, rubber, health, leachates

The health risk of the use of crumb rubber infill in synthetic sporting fields is far from settled as shown in this toxicology study using a vertebrate model using Crumb Rubber leachate published in the highly respected PNAS journal. It supports various studies showing environmental impacts of Crumb rubber leachates on aquatic life.

“Significance: Athletes and children are playing on artificial turfs. However, the health risk associated with exposure to crumb rubber from artificial turfs is unknown for higher vertebrates. Here, we employed chicken embryo as a developing amniote vertebrate model to show that toxic leachate from artificial athletic turf infill impairs the early development of chicken, notably brain and cardiovascular system. This study triggers a scientific discussion as to whether crumb rubber is an appropriate infill material for artificial fields.”

“Over 300 chemicals have been identified in CR, of which nearly 200 are predicted to be carcinogenic and genotoxic (1). The majority of these potential carcinogens are not listed in the databases of the United States Environmental Protection Agency (US EPA) nor the European Chemicals Agency (ECHA) due to the absence of toxicological evaluation.”

“The results showed that CR leachate injected into the yolk caused mild to severe developmental malformations, reduced growth, and specifically impaired the development of the brain and cardiovascular system, which were associated with gene dysregulation in aryl hydrocarbon receptor, stress-response, and thyroid hormone pathways. The observed systematic effects were probably due to a complex mixture of toxic chemicals leaching from CR, such as metals (e.g., Zn, Cr, Pb) and amines (e.g., benzothiazole). This study points to a need to closely examine the potential regulation of the use of CR on playgrounds and artificial fields.”

“Existing risk assessments of artificial athletic turf or CR have suggested low or negligible environmental and human health risks (2–5). However, none of these studies used a vertebrate model. Human health assessments often focused on youth or adult professional players, but the potential risk to younger children could be higher due to their earlier stage of development and frequent hand and facial ground contact. Moreover, the risk to human embryos via maternal exposure to CR is unknown. Environmental risk assessments are usually based on acute toxicity tests with invertebrate species on limited simple toxicological endpoints such as mortality. Chronic tests of CR on vertebrate species are lacking but critically needed because the release of toxic chemicals from CR is continuous and the leaching of contaminants from aging CR can be significant over the field's functional lifetime."

Yaghoobian, N., Jan Kleissl, E. Scott Krayenhoff (2010) Modelling the Thermal Effects of Artificial Turf on the Urban Environment. Journal of Applied Meteorology and Climatology. Vol 49 332-345
http://journals.ametsoc.org/doi/abs/10.1175/2009JAMC2198.1
Keywords: Synthetic turf, energy, water, heat, UHIE

Summary:This study models the thermal properties of artificial turf when used in the urban environment of California and compares its urban canopy energy balance to other surfaces such as concrete and asphalt. Synthetic grass has a lower albedo than most urban surfaces resulting in a reduction in shortwave radiation and an equal increase in longwave radiation, so there is less radiation being reflected to warm up surrounding walls. Synthetic grass warms up more than natural vegetation due to lack of evapotranspiration. The researchers note that there is anecdotal and evidence that synthetic turf surfaces can warm up as much as 20C more than regular grass surfaces. Using a 3D heat transfer model the researchers studied the effects of synthetic grass on the energy balance of nearby buildings and the temperature of the urban area. One of the major differences between artificial grass and manicured lawns is the water required to maintain natural lawns. The results indicated that the largest heat flux from ground to canopy occurs over artificial grass, but due to the low albedo, there is less shortwave radiation through windows in buildings near artificial grass resulting in a 17% lower design cooling load. However due to air temperature canopy heating it causes a 60% increase in the cooling loads for ventilation and conduction. The researchers point out that there is also embodied energy in water used in maintaining manicured lawns. When this energy in transport, delivery and use of water is accounted for there is a total energy use saving resulting in water and energy conservation. Drought tolerant plants which require significantly less water than lawn may have a similar effect as artificial turf conjecture the researchers.
Critique: This study raises many questions about how different surfaces in urban environments contribute to the urban heat island effect. NASA satellite photos of zonal temperature measurements of urban environments show artificial turf increases local surface temperatures. The researchers were surprised that artificial grass actually resulted in a total energy use saving once water use was factored in to the equations as compared to manicured and watered lawn surfaces.

"Using a simple offline convection model, replacing grass ground cover with artificial turf was found to add 2.3 kW h m -2 day -1 of heat to the atmosphere, which could result in urban air temperature increases of up to 4C." The study also found that on energy usage for maintenance, “the net effect of replacement of grass surfaces with AT in coastal Southern California is a net water and energy savings’, however the study analysis did not include energy use related to production and disposal of Artificial Turf, as well as grass maintenance (lawn mowing, fertilizer), and was based on water use rates and costs specific to the location.

Yi, W., Cong, T., Chun-yue, L., Tredway, L., Lee, D., Snell, M., Xing-chang, Z., & Shuijin, H. (2014). Turfgrass management duration and intensities influence soil microbial dynamics and carbon sequestration. International Journal of Agriculture and Biology, 16, 139-145.
https://www.researchgate.net/profile/Yi-Wang-464/publication/286297628_Turfgrass_Management_Duration_and_Intensities_Influence_Soil_Microbial_Dynamics_and_Carbon_Sequestration/links/57e88a3a08aed7fe466bd91d/Turfgrass-Management-Duration-and-Intensities-Influence-Soil-Microbial-Dynamics-and-Carbon-Sequestration.pdf
Keywords: Carbon sequestration, natural turf,

A study conducted on two golf courses to assess the role of management practices in soil microbial activity and carbon sequestration. Results concluded: “Long term turfgrass planting accumulated soil organic C and N at rates of 71.9 and 10.6 g m-2 y-1 over 80 years. Moderate management intensity resulted in highest soil organic C and microbial biomass C. High N and water inputs stimulated decomposition and reduced the C accumulation in highly managed areas such as the tee area. These results suggest that management practices may critically affect organic C sequestration in turfgrass management systems.”

Zembla (September 2018), What happens to plastic and polluting artificial turf?, Netherlands. video documentary (36 mins 27 secs) with English subtitles.
https://youtu.be/Y5o3J7uy4Tk
Keywords: Waste, Synthetic turf, pollution, infill, leachates

Investigative Journalism team Zembla probed the end of life disposal of synthetic turf, highlighting the extent of the problems. This highlights that even in Europe where there is some recycling of artificial turf, much of it is stockpiled as landfill left to cause pollution by companies contracted to recycle.

Zirkle, G., Rattan, L., and Augustin, B.. (2011) Modeling carbon sequestration in home lawns. HortScience 46: 808– 814. https://doi.org/10.21273/HORTSCI.46.5.808
Keywords: Carbon sequestration, Natural turf

This study looked at and developed a model for carbon sequestration in home lawns in the USA. It included Nitrous Oxide (N2O) emissions in Hidden Carbon Costs. Home lawn maintenance practices differ from athletic sports fields maintenance.
“Net SOC sequestration in lawn soils was estimated using a simple mass balance model derived from typical homeowner lawn maintenance practices. The average SOC sequestration rate for U.S. lawns was 46.0 to 127.1 g C/m2/year. Additional C sequestration can result from biomass gains attributable to fertilizer and irrigation management. Hidden C costs are the

amount of energy expended by typical lawn management practices in grams of carbon equivalents (CE)/m2/year and include practices including mowing, irrigating, fertilizing, and using pesticides. The net SOC sequestration rate was assessed by subtracting the HCC from gross SOC sequestration rate. Lawn maintenance practices ranged from low to high management. Low management with minimal input (MI) included mowing only, a net SOC sequestration rate of 25.4 to 114.2 g C/m2/year. The rate of SOC sequestration for do-it-yourself (DIY) management by homeowners was 80.6 to 183.0 g C/m2/year. High management, based on university and industry-standard best management recommendation practices (BMPs), had a net SOC sequestration rate of 51.7 to 204.3 g C/m2/year. Lawns can be a net sink for atmospheric CO2 under all three evaluated levels of management practices with a national technical potential ranging from 25.4 to 204.3 g C/m2/year."