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Material flow analysis for Norway's artificial turfs

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The artificial turf industry is a producer of waste in terms of plastic, microplastic and sand. It is the second largest source of microplastic lost to the environment in Norway, after wear of car tires, according to the Norwegian Environment Agency [1]. A new full-size synthetic football field contains about 100 tons of rubber granules as intentionally added microplastics. Maintaining these fields means refilling the turf with 3.5-6.5 tons granules each year due to a loss caused by the user, removal of snow, surface water runoff and degradation of the rubber granules. The turf also includes 4.8-12.8 tons of synthetic grass fiber, an underlying shock pad (PAD) and about 120-176 tons of sand. The total number of artificial turfs in Norway is approaching 2000, a number that has rapidly increased the last 20 years. Since the expected lifetime of a turf is around 10-12 years, it is soon due for a huge renovation process of existing turfs. The value chain of this complex product stock is not fully developed. This study analyses the material flow (MFA) of artificial turfs in Norway with a focus on the production of new turfs, refilling of granules in existing turfs, renovation of turfs and loss of grass fiber and granules. The results show that there is a significant amount of rubber granules and grass fibers unaccounted for, possibly lost to the environment. This is due to the current design, operation and maintenance of the artificial turfs. Therefore, there is a need for new design of turfs, new operations, maintenance equipment and procedures.

1. Introduction

The first-generation artificial turf (1G) field was built in Houston Texas in 1964. This turf was made of polyamide (nylon) fiber tafted on a synthetic backing. Since then, three more generations of artificial turfs (2-4G) has been developed (**Figure *1***). 2G artificial turfs use polypropylene fibers with sand infill, 3G artificial turfs use polyethylene fibers with sand and synthetic infill. The synthetic infill is often styrene-butadiene rubber granules (SBR), made of discarded car tires. But alternatives such as ethylene-propylene-diene-monomer (EPDM, a synthetic rubber), thermoplastic elastomer (TPE), bioplastic,

organic materials as cork, coconut fibers and olive cores, exists. Today, 4G artificial turfs made of polyethylene fiber in two layers with sand as infill or without infill are produced [2].

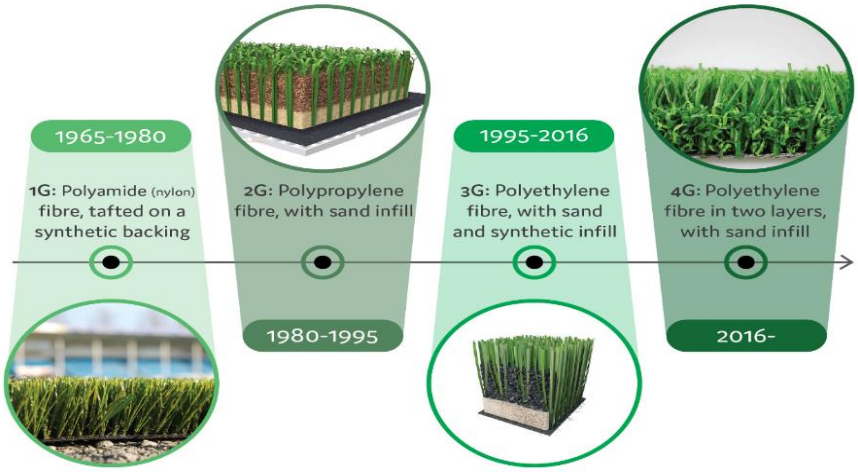

Figure 1. The evolution of artificial turf described as first generation (1G) to fourth generation (4G).

Around 1995, the building of new fields increased drastically in Norway (Figure 2). The total number of 11-, 9- and 7-a-side artificial football turfs is now approaching 2000 [3]. Annually around 150-200 of these fields need renovation. This number is based on the numbers of application regarding gaming funds from Norsk Tipping. This corresponds to a lifetime of approximately 10-12 years for a field. When investigating the numbers of granule infill, grass fibers and sand in the artificial turfs, it is noticed that the amount laid out as new is far less than the numbers reported at the end-of-life by the recycling industry [4].

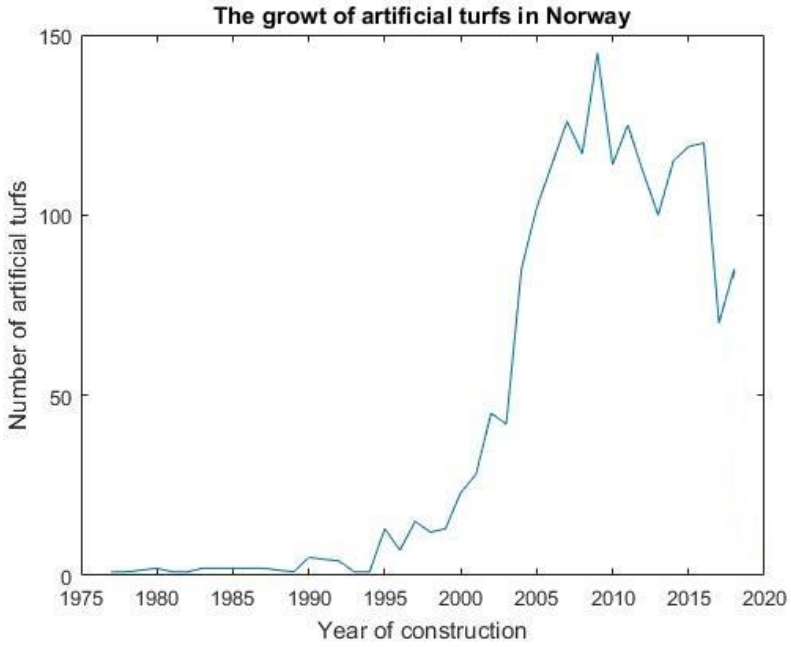

Figure 2. Growth of 11-, 9- and 7-a-side artificial football turfs in Norway. The total number built is now approaching 2000 [3].

This paper investigates the material flow of artificial turf fields in Norway. This is mainly 3G-fields. Thus, the turf consists of synthetic grass fibers, granule infill, sand infill and an underlying shock pad (PAD). A typical 11-a-side turf is 7992 m^2. This includes the safety zone of 2-3 meters outside the net area of the ground. It contains 0.6-1.6 kg/m^2 synthetic grass fibers, 10-14 kg/m^2 granules and 15-22 kg/m^2 sand [5]. This means that a typical 11-a-side turf contains approximately 4.8-12.8 tons synthetic grass fibers, 80-112 tons granules and 120-176 tons sand. In Norway, there is annual refill of granules of about 3.4 tons for turfs only used during summertime, and 6.4 tons for facilities used all year round [6] . There are multiple reasons for needing to refill the turfs with granules. Some of the main reasons are shoveling of snow [6], runoff to water and surrounding soil [7, 8] deposition on clothes/shoes [9] and compactation [10]. These granules are intentionally added microplastics, and is under the evaluation of being banned in artificial turfs [11].

2. Method

The model introduced in this article is a material flow analysis (MFA, Figure 3) for the artificial turfs and appurtenant materials used in Norway. It is inspired by Bergsdal et.al. [12] and adapted to artificial turfs. Knowledge about fundamental parameters determining stocks, flows and materials, the model gives an illustration of how the past is reflected in future projections of generated waste. This chapter presents numbers from the Artificial Turf Guide [5] made by the Norwegian Football Federation in collaboration with the Ministry of Culture unless stated otherwise.

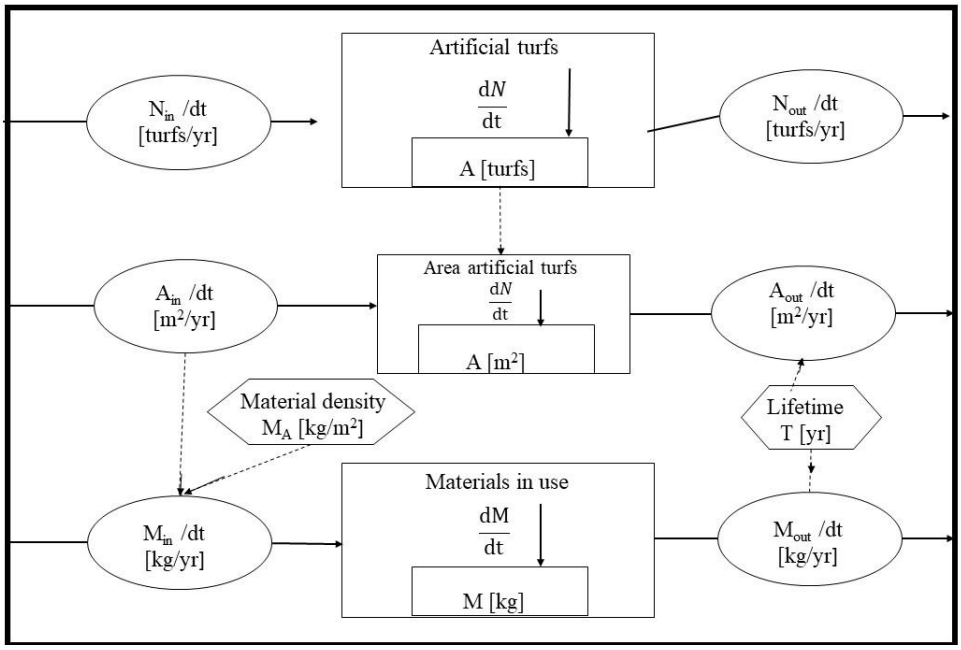

Figure 3. Conceptual outline of the stock dynamics model.

Processes are represented by rectangles, flows by ovals and drivers and determinants by hexagons. Stocks of number of artificial turfs, area of artificial turfs and materials are given by *N, A* and *M*, respectively. Net stock accumulation is given by d*N*/d*t,* d*A*/d*t* and d*M* /d*t*. Input flows to stock are given by N_{in}/d*t,* A_{in}/d*t* and M_{in}/d*t*, output flows are represented by N_{out}/d*t,* A_{out}/d*t* and M_{out}/d*t*.

Balance equation for the artificial turfs is given by equation (1) and (2). It follows from equation (1) that the number of artificial turfs is the number of built turfs minus discontinued turfs. The number of discontinued turfs is zero, since they are rehabilitated.

$$\frac{\mathrm{dA}(t)}{\mathrm{d}t} = \frac{A_{\mathrm{in}}(t)}{d\mathrm{t}} - \frac{A_{\mathrm{out}}(t)}{d\mathrm{t}} \tag{1}$$

$$\frac{\mathrm{d}M(t)}{\mathrm{d}t} = \frac{M_{\mathrm{in}}(t)}{d\mathrm{t}} - \frac{M_{\mathrm{out}}(t)}{d\mathrm{t}} \tag{2}$$

The artificial turf stock is driven by the demand of new artificial turfs and rehabilitation of old turfs, to satisfy the football federation, football clubs, members and other users. The demand of material is not only determined by the need formed when building and rehabilitating turfs, but also by a need of yearly refilling of granules. Refilling is increasing the demand of materials. Materials available through waste management plants, such as recycled and reusable materials, will lower the need for primary materials at construction.

The material dynamic is determined by lifetime parameters and the material density M_A, that is describing the material use per unit of new and rehabilitated artificial turf. Input to the material stock is determined as

$$\frac{M_{in}(t)}{\mathrm{d}t} = \frac{A_{\mathrm{in}}(t)}{d\mathrm{t}} \cdot M_A \tag{3}$$

2.1. Lifetime of artificial turf used in football pitches Norway

The Norwegian Football Federation has an overview of every artificial turf pitches built by the different regional associations in Norway [13]. The lifetime of 11-a-side, 9-a-side and 7-a-side outdoor artificial turfs was found by investigating the building year and the year of rehabilitation. Artificial turf consists of rubber granules, a synthetic grass-mat, sand and a shock pad. The first three are described below.

2.2. Granules

A 3G-turf has infill of granules. At installation the first year, the 11-a-side turf (7992 m^2) is filled with 80-112 tons of granules equivalent to 10-14 kg/m^2. There is yearly a need for refilling the turf with granules. The amount needed is determined by controlling the fill height of the turf. According to an investigation done by Rambøll for The Norwegian Environmental Agency, an average 11-a-side turf is filled with 3.4-6.4 tons of granules yearly. These numbers are of some uncertainty [6]. After approximately 10 years it is assumed that the turf needs rehabilitation, where the grass is rolled up and sent to an approved recycling facility. Granules can be separated from the silica sand then recycled [14], this is to some degree done by the industry[4].Then, a new turf is rolled out and new 80-112 tons of granules is added to the turf.

2.3. Grass

At installation of an average 11-a-side turf, about 4.8-12.8 tons of artificial grass, equivalent to 0.6-1.6 kg/m^2, is laid out. There is no intended addition or removal of grass before the renovation occurring after 10 years. The grass is then sent to an approved recycling facility.

2.4. Sand

At installation of an average 11-a-side turf, about 120-176 tons of sand, equivalent to 15-22 kg/m^2, is laid out. There is no intended addition or removal of sand before the renovation occurring after 10 years. The sand is then sent to an approved recycling facility.

2.5. Reported numbers from recycling industry and loss

The numbers for loss are found by using the number of granules, grass fibres and sand laid out at installation then subtracting them with the numbers reported by a recycling facility. Only one recycling facility has reported their numbers, in which these numbers will unilaterally represent the industry. These numbers should be used with caution.

3. Results

3.1. Lifetime of artificial turf used in football pitches Norway

The overall lifetime of 11-, 9- and 7-a-side artificial turf used in football pitches in Norway can be seen in Figure 4. The earliest rehabilitated turf was after 1 year, and the oldest was rehabilitated after 37 years. Most of the turfs have a lifetime between 8-15 years, where the mean lifetime is 11.4 years.

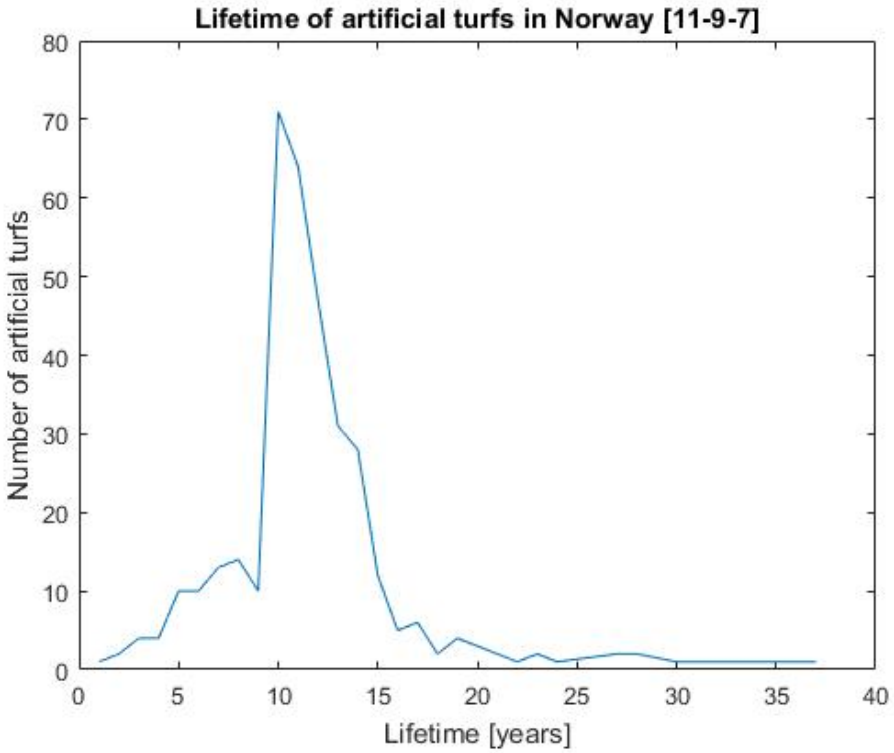

Figure 4. Lifetime of 11-, 9- and 7-a-side artificial football turfs in Norway. The lifetime was found by investigating the building year of the pitch and the time of rehabilitation from the overview of football facilities given by the Norwegian Football Federation [13].

3.2. Granules

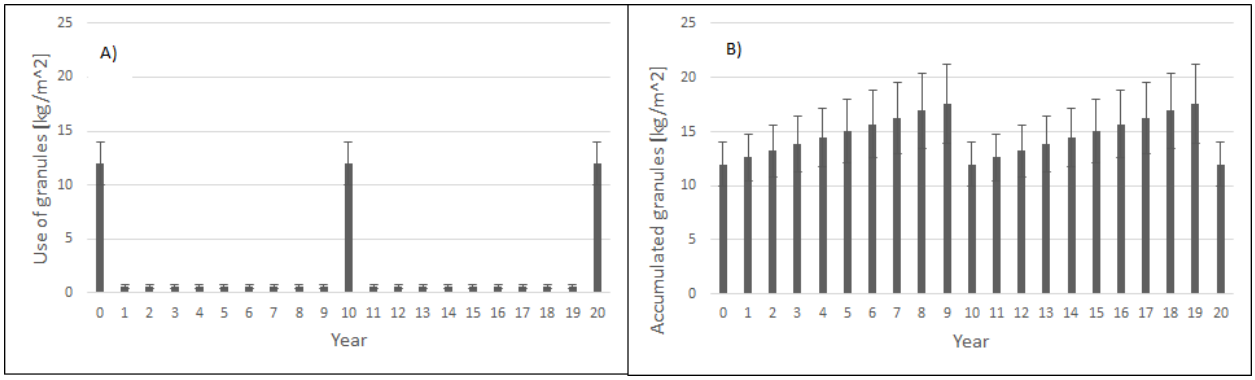

Figure 5. Annual (A) and accumulated (B) amount of granulate added to a 11 a-side artificial turf.

From figure 5b, we can see that after 9 years the accumulated amount of granules is 17.5±3.6 kg per m^2. This corresponds to about 140±30 tons of granulates for a 11-a-side turf accumulated over 9 years.

3.3. Grass

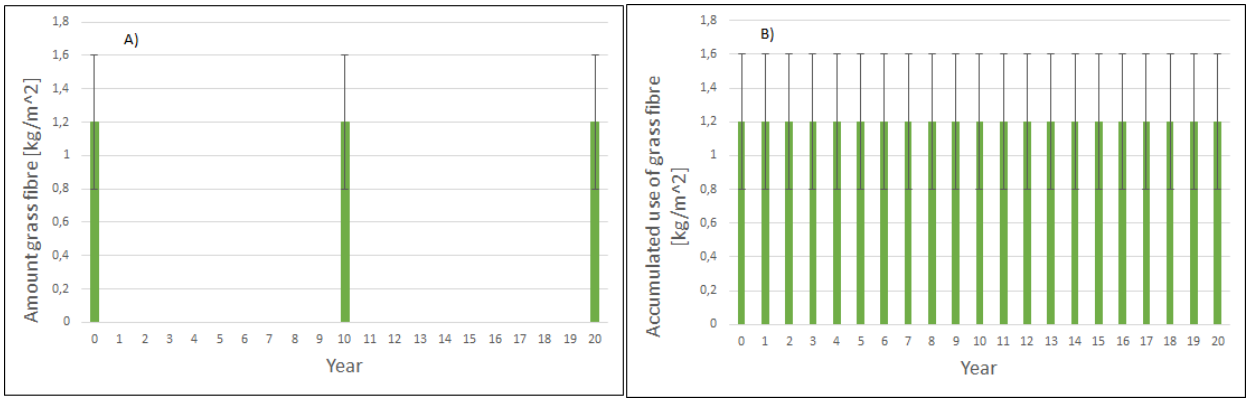

Figure 6. Annual (A) and accumulated (B) amount of artificial grass added to a 11-a-side artificial turf.

From figure 6b, we can see that after 9 years the accumulated amount of grass is 1,2±0,4 kg per m^2. This corresponds to about 9,6±3,2 tons of gras for a 11-a-side turf accumulated over 9 years.

3.4. Sand

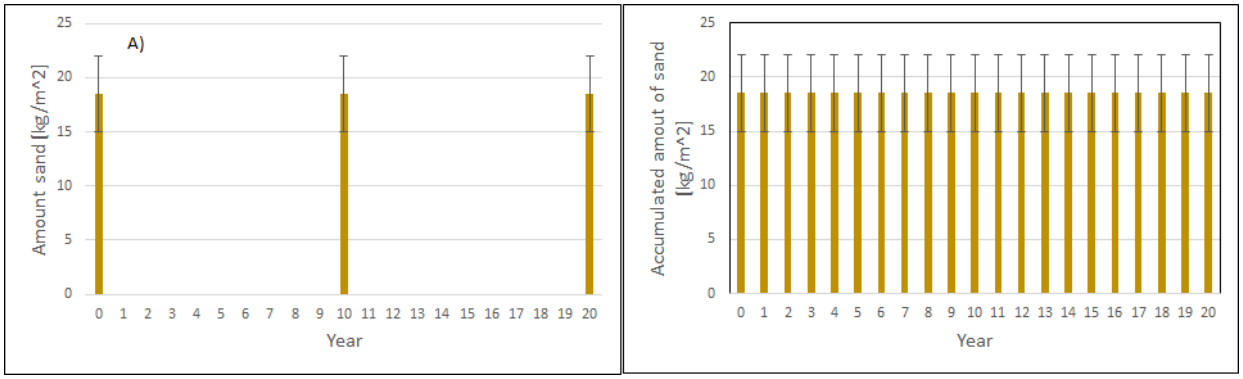

Figure 7. Annual (A) and accumulated (B) amount of sand added to a 11- a-side artificial turf.

From figure 7b, we can see that after 9 years the accumulated amount of sand is 18.5±3.5 kg per m^2. This corresponds to about 180±34 tons of sand for a 11-a-side turf accumulated over 9 years.

3.5. Reported numbers from recycling industry and loss

Reported numbers from the recycling facility can be found in Table 1. These numbers represent the average amount the recycling facility receives when the delivery is an 11-a-side artificial turf.

Table 1. Reported numbers from a recycling facility. These numbers represent the average amount the facility receives when the delivery is an 11-a-side artificial turf.

Component	Amount Added [Tons]	Amount Recycled [Tons]	Amount Added [kg/m^2]	Amount Recycled [kg/m^2]	Amount Missing [Tons]	Amount Missing [kg/m^2]
Granules	140±30	57	17.5±3.6	7.1	83	10.4
Grass fibres	9.6±3.2	9	1.2±0.4	1.1	0.6	0.075
Sand	180±34	137	18.5±3.5	17.2	43	5.4

4. Discussions

Each year there is a distribution of gaming funds from the surplus of Norsk Tipping [5]. Football facilities can apply each 10 year for funding of rehabilitation for existing turfs, matching the rehabilitation rate of the artificial turfs.

The PAD installed underneath the artificial turf carpet may be manufactured of different raw materials. A rubber shockpad comprised of rubber granulate and bitumen, mixed and applied as a liquidized blend on site. The layer thickness is normally 25-35mm. After a hardening period of 20-30hrs the layer ready for installation of turf carpet and infill materials. A shockpad of plastic may comprise of virgin polyethylene foam. Other pad products are available as well. The shockpad is disregarded because it is hard to determine amount of plastic in the PADs and the expected lifetime, though the product is expected to have an impact on the amounts of plastic.

The amount of rubber granules, grass fibers and sand reported to be used in artificial turfs does not correspond with the amounts received at the recycling fabric. There is a great loss, as can be seen in table 1. When investigating different ways rubber granules, grass fibers and sand can be lost from an artificial turf, several ways play out. The materials can be lost to the environment through shoveling of snow [6], something that is done to a large extent in wintertime in Norway. The loss can occur by runoff to water and surrounding soil [7, 8] and/or by deposition on clothes/shoes [9]. When removing the turfs, they are rolled up in smaller pieces and loaded into trucks for transportation to deposition/recycling site. There is reason to believe that rubber granules, grass fibers and sand will be lost in this process, but how much that disappears through this route is uncertain. Thus, this should be investigated.

Due to the current design of the artificial turfs used in Norway, the operations, maintenance equipment and procedures, there is now a significant amount of plastics and microplastics unaccounted for. Thus, there is a need for a renewal of the industry to secure that components from the artificial turfs are properly deposited/recycled and prevent loss to the environment.

The numbers given by the recycling factory (Table 1) should be used with care, as the received goods are from a variety of fields, with an equal variety of composition of the turf system. Nevertheless, there are only a couple recycling factories that are approved by the Norwegian authorities, so the numbers can be considered valid for the Norwegian market.

5. Conclusions

The results show that there is a significant amount of rubber granules and grass fibers unaccounted for, possibly lost to the environment. This is due to the current design, operation and maintenance of the artificial turfs. Therefore, there is a need for new design of turfs, new maintenance equipment and operation procedures.

The Norwegian market for football fields made of artificial turfs has grown noticeably the last 15 years. The construction of new turfs will produce large amounts of waste. We are only experiencing the beginning of a "waste-wave" that is expected to increase rapidly in the years to come. There is therefore a fast-growing market for removal and recycling of old artificial turf systems.

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