African Vision and Eye Health
ISSN: (Online) 2410-1516, (Print) 2413-3183

Spectacle lens and contact lens recycling in South Africa

Authors:
Rayishnee Pillay[1]
Rekha Hansraj[1]
Nishanee Rampersad[1]

Affiliations:
[1]Discipline of Optometry, School of Health Sciences, University of KwaZulu-Natal, Durban, South Africa

Corresponding author:
Rayishnee Pillay,
9300354@stu.ukzn.ac.za

Dates:
Received: 22 May 2022
Accepted: 30 Nov. 2022
Published: 21 June 2023

How to cite this article:
Pillay R, Hansraj R, Rampersad N. Spectacle lens and contact lens recycling in South Africa. Afr Vision Eye Health. 2023;82(1), a777. https://doi.org/10.4102/aveh.v82i1.777

Background: The increase in global plastic waste generation poses a threat to human, animal and plant life. As such, industries world-wide are encouraged to review waste management systems to prevent, minimise, recycle or recover plastic waste. There is a paucity of information on plastic waste generation by the local optical industry in South Africa, especially with respect to spectacle lens and contact lens recycling.

Aim: The purpose of this review article was to provide a current outlook on spectacle lens and contact lens recycling in South Africa.

Methods: Literature review of scientific papers from online databases, websites and lens material patents.

Results: No studies regarding lens recycling in South Africa were found. However, data for this review were collated based on lens constituent materials.

Conclusion: This review article provided an overview of lens recycling, identified the barriers and potential measures to advance plastic spectacle lens and contact lens recycling in South Africa, and suggested controlled energy recovery as an alternative pending implementation of lens recycling programmes.

Contribution: This paper contributes useful information on a previously unexplored aspect of recycling in South Africa. Ophthalmic lens recycling is currently not available in South Africa, and as such, this review focuses on the current outlook, barriers and considerations for implementation of such programmes.

Keywords: spectacle lenses; contact lenses; recycling; waste management; plastic waste.

Introduction

Spectacles and contact lenses are vision-corrective devices that are in common use. It is anticipated that an ageing population along with the predicted increase in myopia will result in a consequent increased demand for vision correction.[1,2] Spectacle lenses and contact lenses are typically made of synthetic polymeric materials. The lifespan of use of these lenses varies from spectacle lenses being replaced on average every two years[3] and disposable soft contact lenses that can be replaced either monthly, weekly or daily. Upon end-of-use, these lenses may be disposed of as waste. Studies have shown that 31% of lens wearers have discarded spectacles into the wastebin[3] and 21% have disposed contact lenses into waste-water streams.[4]

It is predicted that plastics could take centuries to decompose under natural environmental conditions.[5] Therefore, there is a global concern about the increase in waste generation, disposal and subsequent adverse effects.[6] Likewise, eye care practitioners and lens wearers have expressed concern about the possible environmental impact of lens waste and disposal in light of global climate change.[7] Some optical companies have implemented recycling programmes for spectacle lenses and contact lenses in the United States (US), United Kingdom (UK) and European Union[8,9,10,11]; however, to date no such recycling schemes exist in South Africa (SA). Spectacle frame degradation has been previously explored[3]; hence, the purpose of this review article is to present the current outlook, barriers experienced and potential measures that could be adopted to encourage the recycling of plastic spectacle lenses and contact lenses in SA.

Methods

A search was conducted on various online databases, such as EBSCOhost, Google Scholar, ScienceDirect and PubMed for scientific articles using the following keywords and phrases: 'disposal and recycling of spectacle lenses' and 'disposal and recycling of contact lenses'. Because

of the paucity of scientific papers on this topic, an expanded search was conducted incorporating the lens material classification in terms of thermoset, thermoplastic and hydrogel. Sixty resources, including articles, websites and patent literature, were selected for use.

Literature review

The findings of the literature search are presented with a brief description on the use, disposal and recycling of plastic waste followed by the chemistry of spectacle and contact lenses as pertaining to current recycling processes. The barriers to lens recycling and measures to promote lens recycling in SA conclude this review.

Plastic materials: Use and disposal

Plastic materials are used extensively because of their versatile properties that can be adapted for various applications. Some of their characteristics include being lightweight, durable, easily processed, can be mass produced, transparent and yet also easy to dye, corrosion-free with electrical and heat insulation properties.[12] This low-cost option has become a substitute for many materials such as wood and metal,[12] and consequently its widespread adoption has resulted in increased waste generation upon end-of-use.[13]

Global waste generation is projected to increase by 69% between 2016 and 2050, mainly attributed to the growth in global population, urbanisation and affluence.[14] Estimates suggest that almost 76% of the 8300 million tonnes of plastic produced globally between 1950 and 2015 became waste, of which ~9% was recycled and ~79% was landfilled or discarded as litter.[13] In addition, ~95% of current global plastics are synthesised from non-renewable fossil fuel sources, and significant amounts of energy are expended to extract and process the raw materials.[15] Plastic manufacturing processes also emit greenhouse gases which contribute to rising global temperatures and climate change.[6]

Conventional plastics have poor degradation capacity and may take many centuries to decompose naturally.[5] This poses a serious threat because of a shortage of landfill space,[16] and landfills also emit gases, such as methane, which further contributes to rising regional temperatures and global warming.[6] In addition, some plastics may contain additives that could contaminate its disposed environment.[16] Ophthalmic lens constituents may include cadmium, phthalates, bisphenol A (BPA) and isocyanates, used in pigments, plasticisers, polycarbonates and polyurethanes, respectively, all of which pose some threat to human, animal and plant life.[17]

Recycling of plastic waste

A waste management hierarchy has been advocated to restrict waste volumes.[6] Herein, waste prevention and reduction is most preferred, followed by recycling, composting and energy recovery, while landfill disposal is the least preferred waste management option.[6] Some plastics are not recyclable and this contributes to the growing volumes of landfill waste. Recycling refers to the processing of post-industrial or post-consumer waste in order to recover material value,[18] and has the advantages of reducing landfill disposal and keeping materials in circulation longer. The product of recycling, known as a recyclate,[12] may be used in similar or new applications and requires less energy to reprocess compared to virgin raw materials.[19] It is noteworthy that there are limited number of times that plastics can be recycled before it is degraded and becomes unfit for reuse.[20] The International Organization for Standardization, ISO 15270 (2008), provides guidelines for the recovery of waste plastics.[16,21] The four major categories of plastic recycling include mechanical, chemical, biological and energy recovery, as depicted in Figure 1.

Chemistry of plastic spectacle lenses and contact lenses

Spectacle lenses and contact lenses were traditionally manufactured from glass until the introduction of synthetic plastic materials in the form of poly(methyl methacrylate) (PMMA) in the 1930s.[22] A surplus of left-over resins from the world war necessitated a search for alternate uses and resulted in the adoption of the CR39 material for spectacle lens use in the mid-1940s.[22] Synthetic polymeric materials dominated the optical industry thereafter. This section will introduce basic information on the chemistry of spectacle lenses and contact lenses that is relevant to the recycling process.

Plastics are made of many repeating units known as monomers.[12,17] These monomers are polymerised to create long chains, the average size of which determines the molecular weight of the material and therefore impacts on the material properties.[12,17] Ophthalmic lenses may be categorised as thermoset or thermoplastic based on their thermal behaviour. Because of its network of highly cross-linked structures, thermosets provide dimensional stability as well as thermal and chemical resistance.[21] The presence of the cross-linked network presents a challenge as thermosets

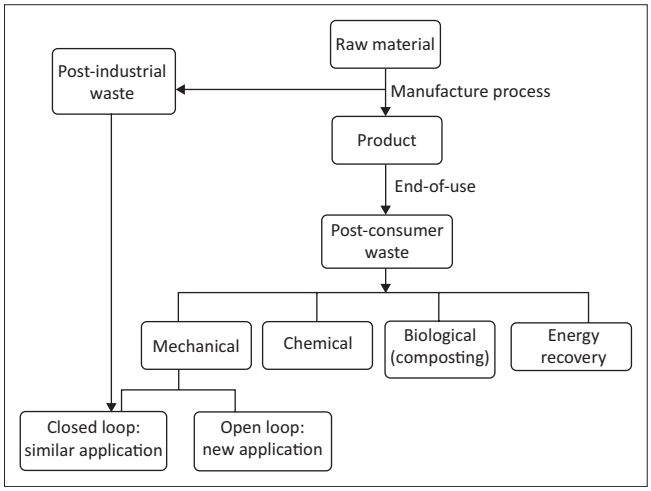

FIGURE 1: Overview of recycling options for plastic waste.

are unlikely to be recycled, remoulded or reformed upon the application of heat.[21] Thermoplastic materials, however, contain fewer crosslinks and can soften if heated beyond its glass transition temperature and resolidify if cooled thereafter.[12] These materials can be recycled upon the application of heat.[12,17]

Spectacle lenses and contact lenses have an array of chemical constituents which may be summarised as follows:

- Thermoset spectacle lenses comprise the low, mid- and high index lenses (1.49 to 1.60 index) which have a common constituent monomer in diethylene glycol bis(allyl carbonate).[23] The mid- and high index lenses have co-polymers of polyurethane with added sulphur or nitrogen to improve the refractive index to achieve a thinner lens profile.[24] Dummy lenses used to maintain the shape of unglazed spectacle frames and lenses from ready-made reading spectacles are also thermoset materials. These materials are melt-processed and cured into its final highly cross-linked configuration and cannot be reformed upon further heat application.[12]
- Thermoplastic spectacle lenses include impact resistant lenses such as polycarbonate (1.59 index) while Trivex (1.53 index) is considered quasi-thermoset, having properties of both thermoset and thermoplastic materials. Polycarbonate may be synthesised from dimethacrylates of BPA[25] while Trivex has diisocyanates as constituent monomers.[26] These lenses are technically recyclable.
- Contact lenses are classified as being either hard (water content less than 10% by weight) or soft (water content greater than 10% by weight).[27] Poly(methyl methacrylate) material is categorised as thermoplastic[28] while soft contact lenses comprise either hydrogel or silicone hydrogel materials.[29] Major monomers used in the manufacture of hydrogel lenses are 2-hydroxyethyl methacrylate (HEMA) while silicone hydrogel lenses may be manufactured from HEMA, N,M-dimethylacrylamide and silicone macromers, among others.[29] These materials do not biodegrade under natural conditions.

Additives may be incorporated as processing aids into the spectacle lens and contact lens matrix, such as thermal stabilisers and mould release agents.[23,24,25] Furthermore, optical brighteners, ultraviolet (UV) blockers, dyes and solid or photochromic tints as well as anti-reflective coatings may be incorporated, all of which impact on the chemical and physical properties of the lenses.[23,24,25,26]

Recycling of plastic spectacle lenses and contact lenses

The literature search did not provide scientific papers on the recycling of spectacle lenses or contact lenses; therefore, the recycling processes described in the next section were based on the recycling of thermoset, thermoplastic and hydrogel materials.

Thermoset materials

The low, mid- and high index lenses, dummy lenses used in unglazed spectacle frames, and lenses from ready-made reading spectacles have thermoset properties:

- Thermosets are considered non-recyclable because of their inherent rigid cross-linked polymer network; therefore, to reduce thermoset waste entering landfills, thermosets can be ground into fine powder and used as a filler in new polymers.[12] The cost of using said filler is cheaper than using new polymer in the final product.[12] Similarly, post-industrial CR39 materials, and mid-to-high refractive index lenses could be crushed and chemically converted to synthesise polyurethane materials.[30] Recycled thermosets may be used as a blast media as well as a friction modifier to reduce wear in coatings.[31] These methods of reducing thermoset waste are currently expensive, and bypass the full potential material value in terms of the circular economy model of recycling which promotes material circulation.[32]
- Investigations have been conducted on methods to convert thermoset materials into 'vitrimers'.[33] These have similar mechanical strength as traditional thermosets, and contain dynamic covalent bonds that dissociate into a flexible network in the presence of specific stimuli, like heat, light, pH or catalysts.[33,34] This property enables recycling of thermosets for a secondary application.[33,34] In order for vitrimer materials to be considered for optical use, investigations are required on its transparency, Abbe value, suitability for lens processing, durability under all conditions of use, and acceptance of various coatings, tints, and UV blockers, and others. In addition, this process uses catalysts to dissociate bonds; therefore, material biocompatibility needs to be ensured with no adverse side effect associated with secondary use of the material.

Thermoplastic materials

The impact resistant lenses and PMMA contact lenses have thermoplastic properties. The lack of a permanent cross-linked matrix allows thermoplastics to be reprocessed:[12]

- Polycarbonate lenses may be synthesised from BPA and phosgene along with methyl methacrylate (MMA) derivatives.[25] This confers durability, impact and heat resistance as well as transparency, which makes it ideal for optical lens applications.[25,28] Studies suggest that it is cheaper to manufacture polycarbonates from virgin materials than from recycled materials.[35] Therefore, cost-efficient processes are essential if recycling of polycarbonates is to be promoted. Polycarbonates can be depolymerised through various mechanisms, including hydrolysis (use of supercritical water), aminolysis, glycolysis, and methanolysis (use of methanol to attack the carbonate linkage of the polymer backbone).[35] These are currently expensive processes, and such recycling is typically conducted in industries that synthesise polycarbonates, as they would be able to collect the

volumes of post-industrial waste required to sustain such recycling processes.[35]

- Poly(methyl methacrylate) is an ideal lens material as it provides desired optical properties, such as transparency and good mechanical strength.[28] It is synthesised by polymerising the MMA monomer through a free-radical process.[28] It can be recycled through mechanical and chemical recycling processes.[28] Poly(methyl methacrylate) material can be crushed and thermally treated at temperatures of ~500 °C or depolymerised to its starting monomer which can then be used as feedstock for new PMMA material.[12,36]

Hydrogels

Hydrogels rose to prominence from seminal work on contact lens materials by scientists[37] in the early 1960s and are described as cross-linked, three-dimensional (3D) polymeric networks that are capable of retaining water.[38] Hydrogels have been used in various applications, including drug delivery systems, tissue scaffolding, remediation of polluted waters, water retention for soils in water-scarce areas[38] and controlled release of fertiliser and pesticides.[39] Contact lenses do not biodegrade naturally, and upon disposal and dehydration, soft contact lenses can embrittle and fragment into microplastic-sized particles, potentially causing soil and water pollution.[4] The small size (average diameter of 14 mm) and weight (on average ~20 mg) of contact lenses preclude generation of large volumes of plastic waste. However, in the interest of adopting the circular economy model, recycling of contact lenses should be considered. Recycling has been attempted on hydrogels used in other applications, such as 3D printed hydrogel materials[40] and injectable hydrogels used for tissue healing that can biodegrade once their function is completed.[41]

Current outlook on lens recycling

There is currently a lack of dedicated recycling programmes for spectacle lenses and contact lenses in SA. An international lens manufacturer based in SA has indicated that they have the technology to recycle polycarbonate material (Clark M, 2019, personal communication, July 2). An optical group in the US has initiated collection and recycling of lenses to make safety glasses, scuba masks and shields for motorcycle helmets.[8] With respect to contact lenses, Terracycle has linked with Bausch and Lomb in the US, Johnson and Johnson in the UK and CooperVision in Sweden to collect and recycle contact lens waste in those respective regions.[9,10,11]

Barriers to lens recycling in South Africa

Several barriers have been identified that may hamper prospective lens collection and recycling efforts in SA. These include:

- The lack of awareness regarding whether spectacle lens materials can be recycled successfully which may result in disinterest in lens collection schemes. Anecdotal evidence from eye care practitioners suggests that they are uncertain about the recycling of lenses, and that unwanted lenses are typically discarded as waste. These lenses are then diverted to landfills. South Africa has a large informal waste collection community that depends on the income received from the sale of waste plastics.[42] Waste pickers are paid according to the weight and demand of waste plastic collected, so they are likely to focus on collecting the types of plastic that will guarantee an income.[43] Because of uncertainty regarding their recycling characteristics, lenses may be ignored by waste pickers. Furthermore, the lightweight nature of the lenses suggests that larger volumes will be needed to generate a better income; therefore, lenses are less likely to be picked for recycling.
- The heterogeneity of lenses poses a collection problem as the lenses could have thermoset or thermoplastic properties, which affect the recycling process, especially with thermosets being a challenge to recycle at present. Therefore, there is a need to sort and separate the various lenses to achieve the best material value from recycling processes.[43]
- The collected spectacle lenses would require manual sorting which is a labour-intensive process and incurs additional costs.[12] It is not possible to differentiate between thermoset and thermoplastic materials by sight alone; therefore, the recyclate can become contaminated if these materials are mixed during recycling. Lenses may also have additives, coatings and tints that may affect the quality of the recyclate.
- Without dedicated and sustained collection efforts, there will be small volumes of lenses available for recycling. This will not be economically viable to the materials reprocessing facility (MRF) especially when considering the volume of water and energy required for profitable recycling. In addition, a comparison of the cost of recycling lenses as opposed to landfilling will determine whether it would be feasible to collect lenses for recycling or dispose of them instead. At present, landfilling is the cheapest and, unfortunately, preferred option in SA.[44]
- There is a need for new technology and facilities to recycle the various types of lens materials. Some materials such as polycarbonate may have smaller market share and may require specific recycling processes and technology.[45] Smaller volumes and higher processing costs will affect recyclate costs and a low economy of scale is a disincentive to recycle such materials.[43] Currently, it is more cost effective to recycle materials such as polyethylene terephthalate or polypropylene which are available in larger volumes and can be recycled with 'mature' technology when compared to spectacle or contact lens materials. In addition, the method of recycling is important, for example, mechanical recycling of materials containing toxic components like BPA may perpetuate and cascade this contaminant into its secondary use. This would create a health risk if the secondary use of the recyclate involves food contact. Therefore, knowledge of lens monomer constituents and implementation of

appropriate recycling processes (mechanical or chemical) are vital.

- A further consideration is the market demand for lens recyclates.[12,45] Good-quality recyclates can secure a higher price; therefore, consistency in recyclates is important.[12] Research would be needed to verify if recycling of the various lenses, comprising different constituents and additives in different batches, would affect the composition of recyclate, the type of applications this recyclate would be suitable for, and if there is a demand for such an application.[21]
- A well-planned and dedicated system of lens collection is required, involving eye care practitioners, optical laboratories, and lens wearers in SA. Lens wearers may purchase lenses from any number of eye care practitioners who in turn may purchase frames and lenses from a range of lens suppliers and optical laboratories. It would not be practical or cost-efficient to return lenses that are unwanted or at end-of-use to the supplier or laboratory that originally provided the lens. A lens wearer who purchases spectacles on average every two years[3] may not know or remember which optical laboratory supplied their last pair of lenses and further, eye care practitioners may not have the time to track the source that originally provided the lenses that are being discarded. Therefore, a unified system will be required for collection and identification of lenses.
- Thermoplastic materials may be recovered through chemical recycling. These methods are still being investigated on a small-scale and are energy-intensive processes and require solvents that are expensive.[20] Such facilities require significant capital investment, and utilisation of concentrated acids can damage the equipment used in recycling.[18] Therefore, such facilities are cost-intensive to maintain, and are currently not a commercially viable option.[43]
- Spectacle lenses have high calorific values, comparable to that of coal. Calorific value describes the amount of energy released upon combustion in oxygen.[46] Polycarbonate lenses have an average calorific value of 30.3 megajoules per kg (MJ/kg)[47] while that of coal is ~27 MJ/kg to 29 MJ/kg.[17] A comparison of chemical recycling and energy recovery indicates that the latter is potentially less expensive as it saves on labour cost (no need for source separation), whereas chemical recycling incurs costs through use of specific chemicals and stringent instrument maintenance.[12,18] However, even though it may be cost-effective to send lenses to a waste-to-energy facility, energy recovery is not strictly a goal of the circular economy model as incineration removes plastic materials out of circulation and increases the potential for air pollution from uncontrolled combustion.[12,32] Furthermore, the *Carbon Tax Act* (*Act 15 of 2019*) imposes additional taxes on MRF that generate or recover heat or energy from waste.[48] The added taxation will impact on the economic feasibility of waste-to-energy and material recovery projects.

Implications of and measures to promote lens recycling in South Africa

The above sections provided details on the challenges and barriers to lens recycling in SA, and considering that waste systems in SA reported to be at least two to three decades behind that of developed regions,[42] the current outlook for lens recycling does not seem promising. A lack of funding and access to technology has hampered recycling efforts. However, based on the literature review, potential measures have been identified which could encourage the development of a recycling ethos in the optical industry in SA:

- Concerned eye care practitioners and optical suppliers can engage with their local MRF or organisations such as Plastics SA regarding facilities in SA that may have the capacity to recycle lens materials. Trial runs may be conducted to assess if lens recycling is achievable with locally available technology as well as to assess the type of recyclate achieved, the market demand for such recyclate and the potential for long term success. A further consideration is whether market-leading international lens suppliers based in SA would be willing to import and share technical recycling knowledge and skills to develop such facilities in SA and invest in local research and development. Widespread use of technical advancements in recycling will eventually result in lower recycling costs and close the gap in price between recyclates and virgin materials thus creating a market demand for recyclates.[21]
- If lens recycling trial runs are successful, it will be essential to create and sustain awareness of lens recycling. Studies have shown that for recycling programmes to be effective, clear and concise information should be provided on how the programme works and what participants would need to do.[49] The effectiveness of such schemes is dependent on environmentally conscious or incentivised participants.[45,49] Posters appealing to the altruistic spirit of the lens wearer or offering of a refund deposit[45] may encourage lens collection campaigns. Eye care practitioners and optical laboratories would need to be consistent in forwarding unwanted lenses for recycling to sustain such recycling programmes.
- A central collection point for all lens waste may be more economically feasible. Eye care practitioners and laboratories could collect unwanted lenses and forward to this central facility for recycling. Additional costs, however, will be incurred through the transportation and storage of waste plastic. This cost could be met by the Extended Producer Responsibility (EPR) regulation that was recently gazetted in SA.[50] Under this regulation, the manufacturer assumes responsibility for their products even at the post-consumer stage. The EPR is currently mandatory for the paper and packaging industry, and voluntary for other industries.[50] If optical suppliers are thus inclined, an EPR fee could be directed to set up such a facility for lens recycling in SA.
- Research should be conducted into the use of compatibilisers[17,35] to recycle mixed thermoset and thermoplastic lenses. These are catalysts that are used in

the recycling of immiscible plastic materials.[35] If successful, this may eliminate the need for separation of lenses as all lenses could be chemically recycled together. Although this would avoid the labour costs involved with source separation, it may incur costs through the requirement of specific chemicals and processes. Failing which, it may be suggested that optical laboratories engrave a code on lenses to identify lens materials[51] to aid with lens sorting. With the advent of 3D lens printing, research would also need to be conducted on recycling capacity of the monomers used in the manufacture of such lenses.

- Creation of an end market for lens recyclates would encourage lens recycling.[12,36,45] The price of virgin polymers impacts on the demand for recyclate materials,[12,36,45] and should be reviewed and brought in line with that of recyclates to limit or prevent the use of fossil fuel sources.[43] Legislation could be introduced to encourage the use of recyclates,[43,45] and mandates to specify the percentage of recycled materials that certain products should contain.[43] Some countries, like the UK, have imposed a landfill tax to divert waste from landfills to recycling facilities.[43] Furthermore, as the recyclate material would have been taxed on first use there are suggestions that value added taxation should be lowered on recycled materials thereby encouraging market demand for these secondary materials.[43] Stable markets for recyclates are essential to ensure growth towards a sustainable circular economy.[43]
- Considering that SA is a developing economy, funds may not be available to develop chemical recycling facilities. However, it is still essential to divert lens waste from landfills, and the next preferred option after recycling in the waste hierarchy is incineration with energy recovery. The high calorific values of lenses[47] would be useful in energy recovery programmes. A state-of-the-art waste facility was opened in Western Cape in 2017 to serve various functions, one of which is to convert waste to fuel or energy.[52] Similar small-scale projects may currently be operational in various provinces, and eye care practitioners and optical laboratories in these locations could develop a regional collection and delivery system for unwanted lenses to be sent to such facilities. Such schemes may prove beneficial, especially considering South Africa's electricity generating woes.[53] These facilities should have the necessary air scrubbing units to prevent toxic emissions from the incineration process. It is important to note that incineration and energy recovery should be conducted on the unrecyclable portion of waste as the concept of circular economy requires material value to be kept in circulation for as long as possible.[12,32]
- Education and awareness campaigns regarding lens recycling would be vital to ensure sustained volumes of collected lenses. This requires buy-in from all interested parties in the recycling and eye care industries. In addition, the perception that recycled materials are of inferior quality needs to be addressed and the public needs to be assured of the safety of recyclates. This may help with wider acceptance of recycled material and improve plastic waste collection schemes.[12]

Industry perspective on lens recycling

Reports from the optical industry suggest that attaining a sustainable cost-effective recycling model may be challenging as mixed post-industrial ophthalmic lens waste is expensive to collect, transport and recycle.[54] The future of lens synthesis and processing is likely to be additive manufacturing or 3D printing whereby lenses are created from a digital model, layer-by-layer, using thermoplastic materials.[54,55] The benefits of print-on-demand technology include minimal supply chain challenges and associated emissions, no material wastage and reduced need for warehouse space or extensive stock-on-hand.[51] Three-dimensional printing has also been extended to the manufacture of contact lenses using poly(hydroxylethyl acrylate) and methacrylate monomers.[56] Closed loop recycling is reported to be successful in the reuse of 3D print wastes;[57] however, this only resolves the challenges of post-industrial waste and not post-consumer waste.

Current trials and patent literature describe the synthesis of mid-index spectacle lenses, dummy lenses and hydrogels from plant-derived materials, namely, corn and soy proteins.[58,59,60] Lenses produced from these materials are reported to have a reduced carbon footprint in comparison to traditional lens manufacture and will also minimise volumes of optical swarf (lens waste) being sent to landfills.[58]

Summary

Waste management policies will only be effective if citizens and organisations modify disposal behaviours and embrace recycling ethos.[45,49] To align with this, eye care practitioners should include recycling awareness as part of patient education. Extensive research and development is needed to redesign lens materials and manufacture processes to reduce waste and emissions as well as to secure demand for post-industrial and post-consumer recyclate. Eye care practitioners should encourage manufacturers to invest in these materials, and prescribe these lens materials upon commercial availability. The timeframe for widespread adoption of lenses manufactured from renewable materials is uncertain; hence, alternate end-of-use measures are required to reduce volumes of plastic waste emanating from current ophthalmic lens manufacture and disposal. At present, energy generation processes in SA rely mainly on coal, and because of environmental concerns of global warming and climate change, the phasing out of coal is required. A potential solution could include utilisation of unwanted ophthalmic, ready-made reading and dummy lenses as feedstock to generate energy, under controlled energy recovery processes.

Conclusion

This review article presented the current outlook of spectacle lens and contact lens recycling in SA. At present, ophthalmic lens recycling is not available, and the barriers to lens recycling were identified and potential measures towards developing a lens recycling ethos were described. Ophthalmic lens manufacturers, lens distributors, eye care providers and lens

wearers should be encouraged to adopt measures to prevent and reduce ophthalmic lens waste. Potential solutions include redesign towards biodegradable lens materials, and energy-efficient manufacturing processes while upholding the circular economy model in each step of the lens lifecycle. The lack of lens recycling technology and facilities is a significant barrier in SA, and requires further research and investment. In the absence of recycling, unwanted ophthalmic lenses may be useful in controlled energy recovery processes thereby offering a two-fold advantage of reducing plastic waste to landfill and providing an alternative to coal as a fuel source. This review suggests that a collective effort by all interested parties is required to implement and sustain ophthalmic lens recycling initiatives in SA.

Acknowledgements

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

All authors were involved in the conceptualisation and methodology of the article. R.P. completed the literature search and drafted the research article. R.H. and N.R. were involved in review and editing of the article to the final version.

Ethical considerations

This study received ethical approval by the University of KwaZulu-Natal Humanities and Social Sciences Research Ethics Committee (HSS/1649/018D).

Funding information

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability

Data sharing is not applicable to this article, as no new data were created or analysed in this study.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

References

1. Euromonitor International Passport. Eyewear: Ageing population and its impact on eyewear [homepage on the internet]. Euromonitor; 2020 [cited 2022 Apr 18]. Available from: https://www.euromonitor.com/ageing-population-and-its-impact-on-eyewear/report
2. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. Ophthalmology. 2016;123(5):1036–1042. https://doi.org/10.1016/j.ophtha.2016.01.006
3. Hansraj R, Govender B, Joosab M, Magubane S, Rawat Z, Bissessur A. Spectacle frames: Disposal practices, biodegradability and biocompatibility – A pilot study. Afr Vision Eye Health. 2021;80(1):a621. https://doi.org/10.4102/aveh.v80i1.621
4. Rolsky C, Kelkar VP, Halden RU. Nationwide mass inventory and degradation assessment of plastic contact lenses in US wastewater. Environ Sci Technol. 2020;54:12102. https://doi.org/10.1021/acs.est.0c03121
5. Barnes DKA, Galgani F, Thompson RC, Barlaz M. Accumulation and fragmentation of plastic debris in global environments. Phil Trans R Soc B. 2009;364(1526):1985–1998. https://doi.org/10.1098/rstb.2008.0205
6. United Nations Environment Programme. Global waste management outlook. Nairobi: United Nations Environment Programme; 2015.
7. Smith SL, Orsborn GN, Sulley A, Chatterjee NB, Morgan PB. An investigation into disposal and recycling options for daily disposable and monthly replacement soft contact lens modalities. Cont Lens Anterior Eye. 2022;45(2):101435. https://doi.org/10.1016/j.clae.2021.03.002
8. Eyecare Business. Plastic lens recycling program expands to labs [homepage on the Internet]. Eyecare Business; 2019 [cited 2022 Apr 18]. Available from: https://www.eyecarebusiness.com/news/2019/plastic-lens-recycling-program-expands-to-labs
9. Terracycle. Bausch + Lomb ONE by ONE free recycling program [homepage on the Internet]. Terracycle; 2019 [cited 2022 Apr 18]. Available from: https://www.terracycle.com/en-US/brigades/bauschrecycles
10. Terracycle. The ACUVUE® contact lens free recycling programme [homepage on the Internet]. Terracycle; 2019 [cited 2022 Apr 18]. Available from: https://www.terracycle.com/en-GB/brigades/acuvue#@54.39586446195522:-2.83447377734376zoom:6
11. CooperVision. CooperVision launches soft contact lens recycling program for all brands in Sweden [homepage on the Internet]. CooperVision; 2019 [cited 2022 Apr 18]. Available from: https://coopervision.com/our-company/news-center/press-release/coopervision-launches-soft-contact-lens-recycling-program-all
12. Goodship V. Recycling issues in polymer matrix composites. In: Robinson P, Greenhalgh E, Pinho S, editors. Failure mechanisms in polymer matrix composites. Oxford: Woodhead Publishing; 2012: p. 337-367.
13. Geyer R, Jambeck JR, Law KL. Production, use, and fate of all plastics ever made. Sci Adv. 2017;3(7):e1700782. https://doi.org/10.1126/sciadv.1700782
14. Kaza S, Yao L, Bhada-Tata P, Van Woerden F. What a waste 2.0: A global snapshot of solid waste management to 2050. Urban Development Series. Washington, DC: World Bank; 2018.
15. Geyer R. A brief history of plastics. In: Streit-Bianchi M, Cimadevila M, Trettnak W, editors. Mare plasticum – The plastic sea. Combatting plastic pollution through science and art. Cham, Switzerland: Springer Nature; 2020: p. 31–47.
16. Hopewell J, Dvorak R, Kosior E. Plastics recycling: Challenges and opportunities. Phil Trans R Soc B. 2009;364(1526):2115–2126. https://doi.org/10.1098/rstb.2008.0311
17. Andrady AL, editor. Plastics and the environment. Hoboken, New Jersey: John Wiley & Sons, 2003.
18. Worrell E, Reuter MA. Handbook of recycling: State-of-the-art for practitioners, analysts, and scientists. Oxford: Elsevier; 2014.
19. Francis R. Recycling of polymers: Methods, characterization and applications. Weinheim: Wiley-VCH Verlag; 2017.
20. Rudolph N, Kiesel R, Aumnate C. Understanding plastics recycling. Munich: Carl Hanser Verlag; 2020.
21. Kulkarni GS. Introduction to polymer and their recycling techniques. In: Thomas S, Rane AV, Kanny K, Abitha VK, Thomas MG, editors. Recycling of polyurethane foams. Oxford: Elsevier; 2018: p. 1–16.
22. Bruneni J. More than meets the eye. The story behind the development of plastic lenses [homepage on the Internet]. PPG Optical; 1997 [cited 2019 May 22]. Available from: http://www.ppgoptical.com/getmedia/47e39594-6472-48e7-8e2c-8f48015284c8/CR39_50years_booklet.pdf
23. Dyball CJ, inventor, Arkema Inc., assignee. Diethylene glycol bis(allyl carbonate) compositions containing crosslinkable copolymers. United States patent. US4217433A. 1980 Aug 12.
24. Yean L, Bochu C, inventors, EssilorLuxottica SA, assignee. Polymer compositions based on polythiourethanes for the manufacture of organic glasses. United States patent. US5310847A. 1994 May 10.
25. Kato N, Hirakawa M, Motoi T, Kitamura M, inventors, Mitsubishi Gas Chemical Company, Inc., assignee. Polycarbonate resin and optical lens. United States patent. US20170276837A1. 2017 Sep 28.
26. Kumar A, Foller PC, inventors, Transitions Optical Inc., PPG Industries Ohio Inc., assignees. Polarizing devices and methods of making the same. United States patent US7044599B2. 2006 May 16.
27. Gasson A, Morris J. The contact lens manual. 3rd ed. Edinburgh: Butterworth-Heinemann; 2003.
28. Ullmann F. Ullmann's encyclopedia of industrial chemistry. 7th ed. Weinheim, Germany: Wiley-VCH; 2011.
29. Efron N, editor. Contact lens practice. 3rd ed. Edinburgh: Elsevier; 2018.
30. Liangcheng X, Xinping X, Weibin G, Libo M, Shanshan L, Ziying W, inventors, Changzhou Xiaoguo Information Services Co., Ltd, assignee. Recycling method of thermosetting resin lens waste. Chinese Patent CN103483620A. 2016 Jan 20.
31. Polymer Properties Database. Allyl diglycol carbonate (ADC) [homepage on the Internet]. Polymer Properties Database; 2012 [cited 2022 Jan 19] Available from: http://www.polymerdatabase.com/Polymer%20Brands/ADC.html
32. World Economic Forum, Ellen MacArthur Foundation, McKinsey and Company. The new plastics economy – Rethinking the future of plastics [homepage on the Internet]. WEF, EMF; 2016 [cited 2019 May 22]. Available from: http://www.ellenmacarthurfoundation.org/publications

33. Yue L, Bonab VS, Yuan D, Patel A, Karimkhani V, Manas-Zloczower I. Vitrimerization: A novel concept to reprocess and recycle thermoset waste via dynamic chemistry. Glob Chall. 2019;3(7):1800076. https://doi.org/10.1002/gch2.201800076
34. Zheng J, Png ZM, Ng SH, et al. Vitrimers: Current research trends and their emerging applications. Mater Today. 2021;51:586–625. https://doi.org/10.1016/j.mattod.2021.07.003
35. Bhogle CS, Pandit AB. Ultrasound assisted methanolysis of polycarbonate at room temperature. Ultrason Sonochem. 2019;58:104667. https://doi.org/10.1016/j.ultsonch.2019.104667
36. Godiyaa CB, Gabriellia S, Materazzib S, Pianesic MS, Stefaninia N, Marcantonia E. Depolymerization of waste poly(methyl methacrylate) scraps and purification of depolymerized products. J Environ Manage. 2019;231:1012–1020. https://doi.org/10.1016/j.jenvman.2018.10.116
37. Wichterle O, Lim D. Hydrophilic gels for biological use. Nature. 1960; 185(4706):117–118. https://doi.org/10.1038/185117a0
38. Turioni C, Guerrini G, Squartini A, Morari F, Maggini M, Gross S. Biodegradable hydrogels: Evaluation of degradation as a function of synthesis parameters and environmental conditions. Soil Syst. 2021;5(3):47. https://doi.org/10.3390/soilsystems5030047
39. Nikolić LB, Zdravković AS, Nikolić VD, Ilić-Stojanović SS. Synthetic hydrogels and their impact on health and environment. In: Mondal IH, editor. Cellulose-based superabsorbent hydrogels. Cham, Switzerland: Springer Nature AG; 2019: p. 1–29.
40. Charlet A, Hirsch M, Schreiber S, Amstad E. Recycling of load-bearing 3D printable double network granular hydrogels. Small. 2022;18(12):2107128. https://doi.org/10.1002/smll.202107128
41. Li Y, Yang HY, Lee DS. Advances in biodegradable and injectable hydrogels for biomedical applications. J Control Release. 2021;330:151–160. https://doi.org/10.1016/j.jconrel.2020.12.008
42. Godfrey L, Oelofse S. Historical review of waste management and recycling in South Africa. Resources. 2017;6(4):57. https://doi.org/10.3390/resources6040057
43. OECD. Improving markets for recycled plastics: Trends, prospects and policy responses. Paris: OECD Publishing; 2018.
44. Nahman A. Incentives for municipalities to divert waste from landfill in South Africa. Waste research development and innovation roadmap research report. Pretoria: Council for Scientific and Industrial Research; 2021.
45. Ignatyev IA, Thielemans W, Vander Beke B. Recycling of polymers: A review. ChemSusChem. 2014;7(6):1579–1593. https://doi.org/10.1002/cssc.201300898
46. Núñez Regueira L. Bomb calorimeter. In: Cleveland CJ, Morris C, editors. Dictionary of energy. 2nd ed. Oxford: Elsevier; 2015: p. 67.
47. Pillay R, Hansraj R, Rampersad N, Bissessur A. Environmental impact and end-of-life options of disposed polymeric spectacle and contact lenses. Afr Vision Eye Health. 2023;82(1), a775. https://doi.org/10.4102/aveh.v82i1.775
48. RSA. Carbon Tax Act 15 of 2019. Pretoria: Government Printer; 2019.
49. Conke LS. Barriers to waste recycling development: Evidence from Brazil. Resour Conserv Recycl. 2018;134(1):129–135. https://doi.org/10.1016/j.resconrec.2018.03.007
50. DFFE. National Environmental Management: Waste Act, 2008 (Act No 59 of 2008) Amendment of the regulations and notices regarding extended producer responsibility. Pretoria: Department of Forestry, Fisheries and the Environment; 2021.
51. Pillay R, Rampersad N, Hansraj R. Freight-related greenhouse gas emissions in the supply of spectacles and contact lenses. Afr Vision Eye Health. 2021;80(1):a619. https://doi.org/10.4102/aveh.v80i1.619
52. Fountain Green Energy. New horizons waste to energy [homepage on the Internet]. FGE; 2017. Available from: http://www.fge.co.za/project/a-large-waste-to-energy-plant/
53. Smit S. More money won't end Eskom's load-shedding woes. Mail and Guardian [newspaper online]. 2022 Mar 11 [cited 2022 Apr 20]. Available from: https://mg.co.za/news/2022-03-11-more-money-wont-end-eskoms-load-shedding-woes/
54. The Vision Council. Optical manufacturing solutions. Bazell Technologies Corporation. COLA Meeting 29 April 2016 [homepage on the Internet]. The Vision Council; 2016 [cited 2022 Apr 18]. Available from: https://www.thevisioncouncil.org/sites/default/files/Swarf%20Panel%20-%20Phil%20Bazell.pdf
55. Chiu H, Jallouli A, Shan H, inventors, Essilor International, assignee. Method for making optical lenses using 3D printed functional wafers. European patent. EP3760423A1. 2021 Jan 6.
56. Su L, Feng WM, Ruoyi W, et al, inventors, Yueyang Hospital of Integrated Traditional Chinese and Western Medicine Shanghai University of TCM, assignee. 3D contact lens printing method. Chinese patent. CN104827671A. 2015 Aug 12.
57. Mikula K, Skrzypczak D, Izydorczyk G, et al. 3D printing filament as a second life of waste plastics – A review. Environ Sci Pollut Res. 2021;28(10):12321–12333. https://doi.org/10.1007/s11356-020-10657-8
58. SBIR. Novol, Inc. Corn based chemistries for making renewable optical polymers [homepage on the Internet]. SBIR; 2019 [cited 2022 Apr 18]. Available from: https://www.sbir.gov/sbirsearch/detail/1548671
59. Yamanaka K, Kushida K, Ueda T, inventors, Arukee, Toray Ind Inc., assignees. Dummy lens for eyeglass. Japanese patent JP2010197761A. 2010 Sep 9.
60. Dorishetty P, Balu R, Sreekumar A, et al. Robust and tunable hybrid hydrogels from photo-cross-linked soy protein isolate and regenerated silk fibroin. ACS Sustainable Chem Eng. 2019;7(10):9257–9271. https://doi.org/10.1021/acssuschemeng.9b00147