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Viewpoint

Managing Asbestos Waste Using Technological Alternatives to Approved Deep Burial Landfill Methods: An Australian Perspective

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Abstract: Given Australia's significant and aged asbestos legacy, the long-term sustainability of effective and accessible asbestos waste management is a national priority of Australia's Asbestos National Strategic Plan. The current policy for managing hazardous asbestos waste is via deep burial in landfill. Technological alternatives to approved deep burial landfill methods exist and could be considered innovative and sustainable additional options for managing asbestos waste, where these are proven viable, and where appropriate policy and regulatory changes are implemented. We present a summary of alternative asbestos waste management technologies and discuss issues influencing their potential application in the Australian context. Increasing the options for asbestos waste management in Australia may additionally facilitate the safe, planned removal of asbestos-containing materials (ACMs) from the built environment. Altogether, this will reduce the potential for exposure to asbestos fibres and work towards eliminating asbestos-related disease in Australia, therefore contributing towards achieving the overarching aim of Australia's Asbestos National Strategic Plan.

Keywords: asbestos; asbestos-containing materials (ACMs); asbestos waste; waste management; waste technology; landfill; circular economy

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1. Introduction: Asbestos Waste in Australia

Australia is one of the highest per capita waste generators in the world [1]. In the most recent reporting period (i.e., 2019–2020), hazardous waste made up approximately 10% of Australia's total waste volume, and asbestos represented the second highest hazardous waste type by weight [2]. This is due to the country's previous heavy use of asbestos—approximately 13 million tonnes of ACMs were used in Australia's built environment and about 6.4 million tonnes are still in place today [3]. Both reported volumes and projected trends for asbestos waste are increasing [2,3]. The long-term sustainability of effective and accessible asbestos waste facilities is therefore a national priority of the Australian Government's National Strategic Plan for Asbestos Awareness and Management (Asbestos National Strategic Plan) [4].

The Asbestos National Strategic Plan forms part of Australia's framework for managing asbestos exposure risks, which also includes a network of asbestos-related laws. This combined framework means state, territory and commonwealth governments, as well as other stakeholders, work cooperatively and consistently to prevent exposure to asbestos fibres in homes, workplaces and the environment. Preventing asbestos exposure is necessary to eliminate the development of asbestos-related diseases such as asbestosis, mesothelioma and cancers of the lung, ovary, and larynx [5]. Asbestos was completely banned in Australia from 31 December 2003, but an estimated 4000 Australians still die annually from asbestos-related diseases [6]. This is due to the large amounts of legacy ACMs remaining in our built environment which have reached the end of their product life and are deteriorating, posing exposure risks in a number of different scenarios [7]. Given the growing ACM waste stream (described in detail in [3]), and that managing the asbestos-related public health challenges continues to be a concern [6–8], achieving the effective waste management strategic actions of the Asbestos National Strategic Plan is important in tackling the development of avoidable and life-threatening asbestos-related diseases [4].

Technological alternatives to approved deep burial landfill methods for asbestos waste exist and have the potential to reduce the large volumes of legacy ACM waste going to landfill while also eliminating the toxicological properties which cause asbestos-related diseases. This would occur by diverting ACMs into potentially harmless re-usable resources that, instead of the current onerous economic burdens, would create economic value in a number of ways. An identified megatrend, or large-scale driver of potential change in asbestos-related work, is ACMs becoming part of a circular economy [9].

The national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), is guiding Australia's shift into the circular economy. The CSIRO describes the circular economy as 'business models and practices that ensure sustainable materials management [by] optimis[ing] processes and products for lower material and waste intensity ... [and] therefore value adding to materials ... multiple times across their life cycle' [10]. While asbestos is not currently a focus of Australia's transition to the circular economy [11], ACMs shifting from a linear to a circular waste stream aligns with Australia's overarching National Waste Policy, which recognises the need to generate less waste and improve resource recovery from waste to provide benefits for human health, the environment and the economy [12]. In Australia, waste management is a service industry that generates $12.6 billion annually, while $2.9 billion is generated through the re-sale of recovered materials [12]. Diverting asbestos from landfill could significantly contribute to these figures, but the implementation of alternative technologies must be actively managed to prevent creating new exposure pathways to asbestos fibres [9].

The aim of this paper is to summarise the state-of-play of alternative asbestos waste management technologies, with a focus on the most recent technological developments that are closest to or are in the implementation phase, as well as on less developed technologies being explored. A desktop review exploring their current commercial status, as well as broader policy factors, has been undertaken to better understand if they represent additional options for managing asbestos waste compared with traditional deep burial landfill methods. This is necessary to address the challenges of landfill capacity (and related resourcing) to meet future demand for managing asbestos waste and that derive from the fact that landfill disposal does not intrinsically make asbestos fibres safe. Implementation of additional asbestos waste technologies would specifically contribute towards achieving the effective waste management strategic priorities and targets of Australia's Asbestos National Strategic Plan [4]. A secondary, but highly desirable, consequence could also be proactive ACM removal from the built environment, facilitated by the improved options.

2. Regulation of Asbestos Waste

Dealing with asbestos waste requires compliance with several different legal frameworks including those relating to work health and safety, environment protection and public health. Since asbestos waste is classified as hazardous waste, stringent provisions apply in relation to how it is packaged, transported, stored and disposed. Obligations include notification to environmental regulators (e.g., Environment Protection Authorities or EPAs), as well as documenting and tracking asbestos waste movement, depending on volumes. All asbestos must be disposed of at facilities that are licensed to accept it.

Current law in Australia also prohibits any re-use or recycling of asbestos waste (e.g., in the state of New South Wales (NSW) [13]). At present, the only approved method for asbestos waste disposal is deep burial in landfill, and this is regulated primarily by jurisdictional environmental protection laws (e.g., the *Protection of the Environment Operations (Waste) Regulation 2014* in NSW [14]). The minimum burial level is deeper than for other wastes, to reduce the likelihood of future asbestos disturbance and therefore exposure risk. Asbestos waste needs to be covered (or capped) with a set level of clean fill (or alternative cover option such as general solid waste, if approved by jurisdictional waste regulators, e.g., NSW EPA [15]) at the end of each day's operation. Part of the licensing of an asbestos waste facility means that the site needs to be recorded as contaminated, which may restrict future land use.

This all makes landfill well-accepted as a safe way to dispose of asbestos waste. In 2020, there were 267 facilities (landfills and transfer stations) licensed to accept asbestos waste across Australia [16]. However, our research has shown that, considering Australia's large land mass and relatively small population, logistical challenges to accessing asbestos waste facilities may exist, particularly for those living in regional and remote areas [16]. Accessibility (geographical, as well as economical) and the capacity of licensed asbestos waste facilities are longer-term considerations that jurisdictions are actively investigating (e.g., in the Australian state of Victoria [17]), aligned with the waste-related strategic actions of the Asbestos National Strategic Plan [4]. Making asbestos waste disposal more convenient and affordable, with additional licensed facilities potentially including technological alternatives, could reduce the prevalence of illegal asbestos disposal, a major problem across Australia [18,19] that also contributes to the asbestos exposure risk. Furthermore, the current landfill method for managing asbestos waste requires enduring maintenance of the facilities by appropriately trained workers, to ensure asbestos waste remains undisturbed, representing another long-term consideration.

Ultimately, while asbestos containment in deep burial landfill prevents exposure risk as long as the sites are appropriately maintained, this disposal process does not intrinsically make asbestos safe, because it does not alter the chemical composition of the hazardous asbestos fibres; therefore, the potential toxicological impact of the harmful asbestos legacy carries into future generations. However, any re-direction of asbestos waste from landfill would require regulatory changes, and therefore lawmakers would require evidence that such alternative approaches meet or exceed the current conditions for the safe management of asbestos waste. Furthermore, by offering additional alternative asbestos waste treatment technologies, the potential impacts on the entire asbestos management system will also need to be considered, including any increases in expected waste volumes, and whether the current workforce capacity (e.g., licensed asbestos assessors, removalists and transporters) can meet any extra demands. Despite this, the availability of alternative asbestos waste treatment options could assist in addressing the waste sustainability challenges Australia is currently facing, and contribute to the eradication of asbestos-related diseases.

3. Alternative Asbestos Waste Technologies

Alternative asbestos waste technologies aim to render asbestos fibres inert, mainly by altering their fibrous mineral structure, to eliminate their toxicological properties. Treating asbestos waste in this manner can, in some instances, produce a reusable end-product that is claimed to be harmless to human health. The techniques can be broadly categorised as thermal, chemical, mechanical and biological, based on their main mechanism of action [20–23]. Often, a combination of techniques is used to make the process more efficient. A summary of asbestos waste technologies is below (Table 1).

Briefly, thermal techniques work by subjecting ACMs to high temperatures for a designated period of time to cause the asbestos fibre structure to become unstable and decompose; this process can be accelerated, and therefore made more efficient at lower temperatures, by using other chemicals in the reaction (i.e., thermochemical processing). Chemical techniques cause the decomposition of asbestos fibres mainly by dehydration, typically by including organic waste or mineral solutions of varying acidity or alkalinity levels as reagents; this process sometimes involves manipulating temperature (e.g., cooling after a chemical reaction) and pressure parameters to act as accelerants. Mechanical techniques interrupt both the physical and chemical properties of asbestos fibres using kinetic energy. Biological techniques rely on micro-organisms to decompose asbestos fibres by chelating magnesium or iron from the chemical structure; this involves reproducing processes that can occur very slowly in nature [20–23].

Table 1. Asbestos waste technologies (based on [20–23]).

Thermal	Chemical	Mechanical	Biological
Thermochemical		Mechanochemical	
plasma technology (e.g., vitrification)	acid decomposition	high energy milling	bioremediation with fungi and/or bacteria
ceramitisation	alkaline destruction		phytoremediation
denaturation	iron chelation		
microwave	CO_2 carbon capture/mineral carbonation		
self-propagating high temperature synthesis (SHS)			
laser-induced rapid melting			

As discussed in the following sections, all techniques have had varying levels of verification and testing, with development in the patent or proof-of-concept stage all the way up to small- or large-scale pilot treatment plants and even a limited number of commercial scale facilities (see Sections 3.1 and 3.2). Internationally, asbestos waste management facilities that avoid deep burial landfill methods have existed for some years, particularly in Europe (see Section 3.1). The European Commission also planned to launch a study by the end of 2022 to identify and compare current asbestos waste management practices versus novel asbestos waste treatment technologies, to evaluate whether changes are warranted in European Union (EU) asbestos waste legislation to accommodate for alternative asbestos waste technologies [24]. Such international precedent and lessons learned from early adopters elsewhere may be a potential driver for policy and regulatory changes in Australia, to pave the way for new asbestos waste technologies being implemented.

3.1. Current Non-Landfill Asbestos Waste Facilities

In France, *Inertam* (Groupe Europlasma) has been operational since 1992. This uses a plasma torch vitrification technique, a very high-temperature (1400–1600 °C) fusion process powered by thermal plasma technology, to process asbestos waste (both friable and non-friable types) and create an inert by-product (Cofalit). Development of this facility was initially self-financed, with a prototype plant built first, and commercial scale processing of asbestos waste commencing in 2001. Initially, there were two lines with 0.5 tonnes/hour capacity each. In 2003, a third processing line began to be developed and commenced operations in 2005 with a two tonnes/hour capacity, processing up to 30 tonnes of asbestos waste per day. In 2005, the by-product Cofalit was also approved for recycling as a road-building substrate, and other uses (e.g., storage of solar energy) are currently being examined. Ongoing investments have focused on plant modernisation and optimisation, focused on productivity gains and reduction of the environmental footprint [25].

In November 2022, the *Inertam* facility received a first delivery of 100 tonnes of asbestos waste from neighbouring Italy [26], taking advantage of the United Nations Environment Programme (UNEP) Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. The Basel Convention is a multilateral environmental agreement with the aim to protect human health and the environment against the adverse effects of hazardous wastes (such as asbestos), of which 166 countries are signatories [27]. A similar arrangement has been agreed between an Algerian company specialising in asbestos removal and *Inertam*, with the creation of an 'asbestos waste treatment chain' in September 2022 [28].

The *Tetronics* company (United Kingdom (UK)-based) also provide plasma technology as a trial facility service. The facility allows for hazardous material treatment, including for ACMs. Investment in the trial facility was received in 2007 and it became operational in 2017. Their direct current plasma arc vitrification process produces an inert reusable by-product called Plasmarok, which has been certified for use in a range of civil engineering building applications (e.g., an unbound pipe bedding and road construction aggregate) [29].

Thermal Recycling is another advanced facility in the UK, with initial testing commencing in 2008 and an operational demonstration plant open since 2020. The demonstration plant was built with funding from private investors. Thermal Recycling uses a denaturing technique to transform chrysotile-containing asbestos cement roof sheets into a new material, that is then recycled to produce a sustainable aggregate (Calmag). The current demonstration plant kiln can process 12 tonnes each firing, whereas a full-scale kiln will denature up to 120 tonnes in each firing. To date, more than 80 tonnes of chrysotile-containing asbestos cement roof sheets have been processed, and the facility has a regulatory permit to treat 29,500 tonnes a year. The next phase involves opening a full-scale plant, with cooperation and support from the asbestos (removalist) industry. Extending the types and forms of asbestos that are denatured is also anticipated, based on the claims that this denaturing process can be used this way. Research is also currently underway to identify the best use for Calmag, with a focus on road building construction products such as blocks, bricks and pavers [30].

In 2021, Netherlands-based *Asbeter Holding* received EU funding for construction of an industrial plant to process asbestos cement sheets into a carbon-neutral building material. Using a patented alkaline minerals process (termed AC for the active and circular nature of the entire process), the company claim that they will be able to produce a highly sought-after alkali–silicate slurry, thereby reducing the need for raw building materials. Their technology involves an initial mechanical pre-treatment to increase the reactive surface area, followed by the addition of water and heat to create a slurry, and a final alkalinisation step to accelerate the reaction. The technique regains cementitious material for re-use but destroys asbestos fibres from asbestos cement sheet waste, as assessed by the absence of asbestos fibres using scanning electron microscopy. An indicative business plan suggests that the basic concept engineering is ready to be scaled-up, pending further financial investment which they are seeking from venture capitalists and banks. The logistics of the safe removal and transport of asbestos cement sheet waste is currently being considered and processing is expected to commence in 2025, with a 75,000 tonnes/year capacity at full scale in 2026 [31,32].

3.2. Non-Landfill Asbestos Waste Technologies in the Scoping or Experimental Phases

3.2.1. Thermo Chemical Conversion Technology (TCCT)

The Trustees for ARI Global Technologies Australasia Trust (trading as *EnviroMaster*) have the exclusive licence to use TCCT for asbestos waste management in the Australasian region covering Australia, New Zealand, Melanesia and New Guinea [33]. They have been exploring this in the Australian context since 2018, but despite government support via business investment and innovation grants [34,35], they have been unable to establish a pilot plant. The current concept facility for the Australian market is designed to process at least 100 tonnes of asbestos waste per day, although no specific trial has been undertaken here. Their technology has been trialled overseas through small-scale demonstration projects, converting just over 1000 tonnes of asbestos waste in over 25 years of development. The system works by using a concentrated chemical fluxing solution (sodium borate) and high temperature (1230 °C) to treat asbestos waste for 20 min, to destroy the original mineral structure. Plastic waste (non-chlorinated) is proposed as a fuel source to supplement the energy requirements of this process due to its high energy density. This process converts asbestos waste to a smaller (33% by mass and 73% by volume), inert (non-hazardous) end treated product with potential application in non-structural construction (e.g., earth and embankment fills, aggregate for road base, granular drains and filters, and aggregate for weaker concrete and flowable fills). *EnviroMaster* claim that the end-treated product is asbestos-free based on transmission electron microscopy, X-ray diffraction and optical analytical methods [33].

3.2.2. Biological Remediation

Micro-organisms (e.g., fungi and bacteria), as well as plants, can trigger degradation of asbestos fibres by accessing biological pathways that chelate metallic ions (e.g., iron and magnesium) from the asbestos mineral structure for their own nutritional use, thus reducing the carcinogenic potential of asbestos fibres.

An international consortium of researchers from three different countries (including Australia, New Zealand and the United States) is seeking to take advantage of bioremediation in practice, to manage legacy asbestos sites by creating 'activated landfills'. They propose to use controlled ecosystems that incorporate bacteria, fungi and plants in a systematic way, to define the optimal conditions that achieve remediation within a reasonable timeframe (e.g., five years). This novel approach is intended to offer protection to the community with any future use of or exposure to the legacy asbestos sites, above that which could be achieved by other methods such as capping, fencing and warning signs. Since it also represents a low-energy approach to managing asbestos, it offers a more sustainable approach to managing larger-scale asbestos-contaminated sites in the long-term, e.g., decommissioned asbestos mines or asbestos waste facilities sites that have reached capacity [36].

This approach has recently been echoed in research by an East Netherlands consortium of companies, water boards and knowledge institutions—including *Natural Soil Improvement BV* (Arnhem), *Grondslag* (Steenwijk), *KCPK* (Arnhem), *Drents Overijsselse Delta Water Board* (Zwolle), *KIWA BV* (Rijswijk), *Netherlands Institute of Ecology* (NIOO-KNAW, Wageningen). They received an EU subsidy (European Regional Development Fund grant) for the period 1 October 2018 to 31 December 2022, with co-financing from other public and private sources, to investigate bioremediation of asbestos [37]. The Fiber2Fiber project sought to determine whether a mixture of microorganisms, seeds and a patented combination of other organic substances, mainly from river sediments (known as 'Brickz'), would, when added to asbestos-contaminated soil, break down asbestos fibres and render them harmless [38,39]. The project concluded with a symposium in December 2022, which asserted that their goal had been achieved, with evidence of the conversion of asbestos fibres (using a combination of fungi and bacteria) into a biomass fibre that could be used as a raw material in the paper industry [40–42].

3.2.3. Other Developments

Another group also progressing an alternative asbestos waste management technology, but still in the early phases of development and with only limited information in the public domain, is *Environmental Decontamination Limited* (EDL). EDL is a New Zealand, UK, and Hong Kong based company, with a patented mechano-chemical destruction system (milling apparatus) for contaminants [43,44]. It claims that in recent trials investigating asbestos destruction in ACMs, temperatures did not exceed 180 °C and that the resulting by-product powder can be re-used as a high-grade cement additive [45].

4. Discussion: Assessing the Opportunity for Implementation

There are many factors to consider for the successful implementation of alternative asbestos waste technologies in Australia (or any market). Aspects such as commercial or economic feasibility, technological maturity, regulatory acceptance, as well as health and environmental sustainability have been considered in previous investigations [20–23]. The proposed European Commission study [24] will surely extend our understanding of these factors in the current global climate, as well as potentially highlight further technological developments not currently in the public arena. The below discussion of considerations highlighted in this viewpoint adds to this, and also points to opportunities or factors for further investigation that can lead to a wider deployment and use of alternative asbestos waste technologies in Australia.

In countries where alternative asbestos waste management technologies already exist, the use of multilateral environmental agreements for the legal transport of asbestos waste (i.e., the Basel Convention) represents a way to gain operational efficiencies that support long-term economic feasibility. In neighbouring European countries or regions, this has been demonstrated already [26,28]. These recent developments showcase the existing asbestos industry's resilience and capacity to safely accommodate changes to the typical asbestos disposal processes and demonstrates an already established and accepted path that can be replicated in the future.

Conversely, in countries such as Australia where alternative asbestos waste technologies are yet to be implemented, they are being explored in different ways. This includes directly, with the scoping activities described for TCCT in Section 3.2.1, and somewhat indirectly, with the 2016 investigation of thermal capacity opportunities for existing hazardous waste infrastructure. In this analysis, hazardous asbestos waste was not included in a list of suitable waste types for thermal treatment at these existing thermal facilities [46]; however, the presence of facilities including plasma arc furnaces (potentially similar to the *Inertam* and *Tectronics* technologies currently operating overseas) suggests that further exploration may be warranted.

Another critical commercial consideration is the early and coordinated identification of co-investment opportunities from multiple sources, as evidenced throughout the development process for most alternative asbestos waste facilities described in Section 3.1. All players in the asbestos management system (i.e., government and private sector alike) have overlapping roles and responsibilities to ensure effective asbestos management and sustainable action. In Australia, collaboration is an overarching aim of the Asbestos National Strategic Plan to ensure the efficient, effective and economical use of resources and the alignment of asbestos action plans to manage the harmful legacy [4]. The implementation of alternative asbestos waste technologies inevitably requires building a concerted and reciprocal relationship between all stakeholders. This is needed not only for financial feasibility, but to ensure that future resource planning (e.g., increasing the trained asbestos workforce to manage any increased flux through the asbestos management system from identification, through to removal and disposal) maintains the appropriate (and regulated) risk management measures to prevent asbestos exposure.

This leads to the perceived safety of alternative asbestos waste technologies and any resultant downstream by-products. The social acceptance of ACMs as a hazardous waste potentially entering the circular economy may be hindered by the historical distrust of the asbestos industry, which misled consumers about the supposed safety of ACMs and continues to use disinformation campaigns to target developing nations that have yet to ban asbestos [47], despite the clear detrimental health impacts [5,6]. Australian workplace health and safety laws, as well as environmental health laws, as with any similar laws around the world, prescribe the safety measures that must be adhered to in managing asbestos waste. A sound evidence base would be required for these laws to change to incorporate alternative asbestos waste technologies.

Finally, the potential areas of application of each technology (e.g., the asbestos fibre type that can be treated and the state the asbestos waste can be received) is another context-specific consideration, with varying needs depending on the asbestos legacy being managed. In Australia, the volumes and types of ACMs remaining have been characterized in order to facilitate effective and sustainable legacy management, particularly around disposal. Asbestos cement products (water/sewer pipes and sheeting) make up around 95% of the remaining legacy asbestos in Australia's built environment [3]. Any of the alternative asbestos waste technologies that have already been implemented internationally could be used to manage this legacy, provided the ACMs are proactively removed to remain intact.

Ultimately, there needs to be proof that alternative asbestos waste technologies can operate on an industrial level, a business case that demonstrates the technology is marketable and profitable, a clear pathway to the technology being licensable in a regulatory context, and evidence that that there is no or negligible risk to human health and the environment. To achieve this, the human health and environmental impact of improved ACM waste management through a circular economy approach may need to be further investigated using a balanced methodology that systematically considers a variety of factors. The World Health Organization has recently analysed assessment methods that are available for doing this and that are relevant to the different phases of the decision-making process. The organization supports a holistic approach, whereby different assessments are considered and integrated depending on scope [48]. In Australia, factors that influence the human health and environmental benefits arising from more proactive action in asbestos management are already the focus of current research (i.e., a socioeconomic analysis), as the Australian government begins to develop the next phase of the Asbestos National Strategic Plan. Information arising from this research can be leveraged and extended to inform the implementation of alternative asbestos waste technologies.

5. Conclusions

There are several asbestos waste technologies at varying stages in the research and development pipeline. While none have been implemented in the Australian market, plasma and other thermal technologies for managing asbestos waste are the frontrunners in Europe, with commercial treatment plants already in existence. Landfill does not destroy asbestos fibres, but this approach stabilises and contains them, and therefore provides a safe way of dealing with asbestos waste until alternative treatment options become more commonplace through uptake and use. Challenges associated with increasing volumes of asbestos waste and limited landfill capacity are key drivers for examining and implementing alternative asbestos waste treatment technologies. These additional alternatives could facilitate the proactive asbestos removal programs needed to sustainably manage legacy ACMs in the built environment, provided they continue to meet or exceed current standards in relation to workplace health and safety, public health, and the environment. Combined, such transformations in the Australian asbestos landscape will contribute to the overarching aim of the Asbestos National Strategic Plan—preventing exposure to asbestos fibres to eliminate asbestos-related diseases in Australia.

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