sustainability

Brief Report

Asbestos Stocks and Flows Legacy in Australia

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Abstract: Information about asbestos stocks and flows is paramount for effective legacy management, both for understanding potential asbestos exposure risks from the different product types remaining in the built environment and proactive resource planning for their safe decommissioning, removal and disposal. This paper provides an overview of the Australian Stocks and Flows Model for Asbestos, a national model that provides best estimates to examine asbestos legacy stocks remaining in the built environment and flows to waste, now and into the future in Australia. The model was updated in 2021 to reflect new information from literature and input from industry experts and includes a Monte Carlo analysis to better reflect the range in the value estimates, as well as allowing for input of data from asbestos removal programs. Australia's total asbestos stocks peaked at approximately 11 million tonnes in the 1980s. Over 95% of stocks comprise asbestos cement products, such as wall sheeting and water pipes. Australia's current remaining asbestos stocks in the built environment are estimated at 6.2 million tonnes, with just under half of total consumption estimated to have gone to landfill as waste. The model can continue to be used with updated information to help track how much of Australia's hazardous asbestos legacy is remaining and by how much it is reducing. The model can also be used to test scenarios and implications for predicted development trends and waste infrastructure needs. It is a valuable resource to assist with sustainable planning across a range of government departments that are responsible for managing asbestos waste in Australia.

Keywords: asbestos; asbestos waste; asbestos stocks; asbestos flows; stocks and flows model

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1. Introduction

Australia was one of the highest per capita users of asbestos in the world until the 1980s, leaving a hazardous legacy since its total ban in 2003. Asbestos is still present in the built environment, in homes, schools, hospitals, and in public and commercial buildings. It is estimated that 4000 Australians die annually from asbestos-related disease [1]. Understanding the volumes and types of asbestos containing materials (ACMs) remaining in the Australian built environment is critical for effective and sustainable legacy management.

1.1. Australia's Historical Use of Asbestos

Datasets available from Minerals UK [2] document the annual production, import and export of asbestos in Australia for all years from 1920 to 2003. It is understood that these data have been tested through significant court proceedings and found to be robust. Over this time, the total apparent Australian asbestos consumption was about 1.9 million tonnes, calculated as:

$$\text{apparent consumption} = \text{production} - \text{exports} + \text{imports}$$

Consumption peaked in 1975, then decreased rapidly until the early 1980s, where it remained at very low levels until its eventual ban in 2003. Based on consultation with an expert from Goulburn Valley Water [3], 34% of this asbestos was consumed in cement pipes. The earliest known use of asbestos in cement pipes was 1926, and continued until the 1980s; however, peak consumption occurred between 1957 and 1966.

The Asbestos Safety and Compensation Council [4] reported that 90% of raw asbestos was consumed in cement products. It is understood that, considering cement pipes as described above, the remaining 56% was used in asbestos cement sheeting in buildings. It was necessary to disaggregate the use of asbestos cement sheeting in buildings as commercial or domestic due to their different lifespans. The split was estimated based on the 'Value of Building Work' data set available from the Australian Bureau of Statistics [5], following a method used by the Allen Consulting Group [6]. It was estimated to be 60% domestic and 40% commercial. Various sources indicate that the use of asbestos cement sheeting in buildings in Australia ceased during the 1980s [4,7–9].

The next main uses of asbestos were flooring (3%), roofing (2%), friction products (1%) and lagging (0.4%) [10]. Although these values were originally taken from a U.S. source, they have recently been compared with data from the Victorian Asbestos Eradication Agency (VAEA) on asbestos in Government buildings [11]. The values agreed well for lagging and roofing but were somewhat different for flooring. However, this was likely due to the fact that VAEA data did not include domestic buildings, which consumed significant amounts of asbestos flooring. Friction products' main use was in vehicles rather than buildings; thus, they could not be considered in this comparison. The information on the timeline of asbestos cement sheeting was applied generally to asbestos in buildings, and therefore also includes flooring and roofing. Lagging is reported to have similarly ceased being used during the 1980s [12]. Friction products were used right up until the ban in 2003. The remaining 4% of asbestos consumed in Australia went into many different products, for example the VAEA lists 113 ACMs on their website. However, due to the small quantities consumed, these were grouped together (as 'other') for use in the model. Figure 1 summarises the percentage distribution of total asbestos consumption by product group in Australia.

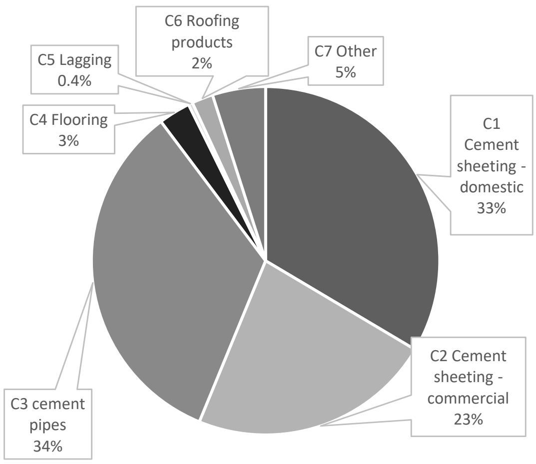

Figure 1. Percentage distribution of total asbestos consumption by product group (1920–2003).

1.2. Australia's Ageing Asbestos Products

Many asbestos containing products have been in the built environment between 40 to 100 years. However, levels of damage, disturbance and deterioration can vary. External ACMs, such as walls and roofing outside buildings, primarily are impacted by weathering. Internal ACMs, such as walls and flooring inside buildings, primarily are impacted by disturbance and damage such as abrasion and other direct contact. The release of fibres into air or soil or water, and transport of fibres creates a hazard as fibres become unbonded from their bulk matrix which may be Portland cement, or protective coatings such as paint.

A watchpoint to assess the deterioration of ageing stock will be its level of friability, or ability to crumble, and release loose fibres. Research by Gray et al. [13] into current and future risks of asbestos exposure in the Australian community concluded that a considerable amount of asbestos remains in situ in the Australian built environment. Potential current and future sources of asbestos exposure to the public are from asbestos-containing roofs and fences, unsafe asbestos removal practices, do-it-yourself home renovations and illegal disposal of asbestos. Further ASEA-commissioned research [14] identified four priority areas where ACMs may present a risk in Australia as: asbestos in the community (natural disaster zones, asbestos roofing, illegally disposed asbestos, residential, remote Indigenous community buildings); asbestos in commercial and government buildings (schools, hospitals, prisons, industrial premises, warehouses); asbestos contaminated land (development sites, naturally occurring asbestos); and imported goods that contain asbestos (building materials and friction products).

1.3. The Need for a Model to Estimate Asbestos Stocks and Flows to Waste

In line with National Priority 3 of the National Strategic Plan for Asbestos Awareness and Management, the *Australian Stocks and Flows Model for Asbestos* (stocks and flows model) was developed [15] and recently updated to support proactive planning for safe, prioritised asbestos removal and effective waste management [16,17]. The stocks and flows model provides estimates of legacy asbestos remaining in the built environment (stocks), and quantities of ACMs reaching the end of their productive life to waste or disuse (flows). It is designed as a national model to provide best estimate results that can examine asbestos stocks remaining in the built environment and flows to waste, now and into the future. It can also be used with jurisdictional-specific information should this be available and can support planning for asbestos waste infrastructure and workforce capacity.

The updated version includes additional information from industry experts and literature, and incorporated Monte Carlo range estimates for average product life span or end of life to increase the transparency of the model assumptions and uncertainties. The user interface was expanded to allow input of data relating to asbestos removal programs. This new feature can be used to improve estimates of remaining stocks where such removal programs have already occurred or to project the impact or assess feasibility of a future removal program.

This article provides an overview of Australia's hazardous asbestos legacy, and how the stocks and flows model can help us understand the legacy to plan for the future.

2. Methodology

Taking into consideration Australia's asbestos use profile and the age-related deterioration of in situ asbestos products as described above, the original stocks and flows model was developed in 2015. Details on the original model build and methodology are provided elsewhere [15], with key features summarised below. The original model estimated stocks and flows through reference to Australian asbestos consumption data from 1920 to 2003. Four 'critical parameters' were applied to the consumption data:

1. The proportion of consumed asbestos by decade that went into each of seven product groups.
2. The average proportion of the mass of each product group made up of asbestos.
3. The average lifespan of each product group in years (LAV).
4. The average number of years until only 10% of the initial stock of each product group remains (L10).

The updated asbestos stocks and flows model provides first-order estimates for the period of 1920– 2100:

- How much ACM was, is or will be in use?
- What proportion of the total asbestos consumed remains in stocks?
- What product groups contain this ACM?
- How much ACM was, is or will be reaching the end of its operational life?

Table 1 presents the inputs used to build the updated model. For each considered asbestos product group this includes the % total asbestos consumption, % asbestos in product, assumed mean lifespan and the assumed number of years to 90% removal. For the first two parameters some of the values are presented with a range in brackets. This range indicates uncertainty in the estimate. For the two lifespan parameters, the values are presented as a range, which is the range of values sampled from by Monte Carlo analysis. The references used to estimate the values are also shown.

Table 1. Summary of default settings for model parameters.

Product Group	C1 Cement Sheeting—Domestic	C2 Cement Sheeting—Commercial	C3 Cement Pipes	C4 Flooring	C5 Lagging	C6 Roofing Products	C7 Other
%total asbestos consumption	34% (25–35%)	23% (15–25%)	34%	3%	0.4%	2%	5%
Reference(s)		[4–6]	[3]	[10,18]	[18]	[10]	[10]
%asbestos in product	15% (10–50%)	15% (10–50%)	15% (10–20%)	20% (8–30%)	75% (55–100%)	20% (10–30%)	10% (1–85%)
Reference(s)		[19–21]	[6,22,23]	[19,24]	[25]	[19]	[19]
Assumed mean lifespan	35–65 years	40–60 years	60–75 years	10–25 years	40–60 years	40–60 years	5–50 years
Reference(s)	[26–29]	[6,27–29]	[3,30]	[31,32]		[6,27–29]	[26–28]
Assumed no. years to 90% removal	65–85 years	75–100 years	80–100 years	25–50 years	75–100 years	75–100 years	50–100 years
Reference(s)	[26–29]	[6,27–29]	[3,30,33]	[34]	[6,27–29]	[6,27–29]	[26–28]

Due to the high level of uncertainty for some of the model parameters, the updated model uses Monte Carlo analysis to generate a range of estimates. The parameters used in Monte Carlo analysis are the mean average lifespan of each product group and the number of years until only 10% of the product group remains in stocks. The model assumes that the 'true' value lies between the high and low estimates of these values with a normal probability distribution. Figure 2 illustrates the operation of the stocks and flows model.

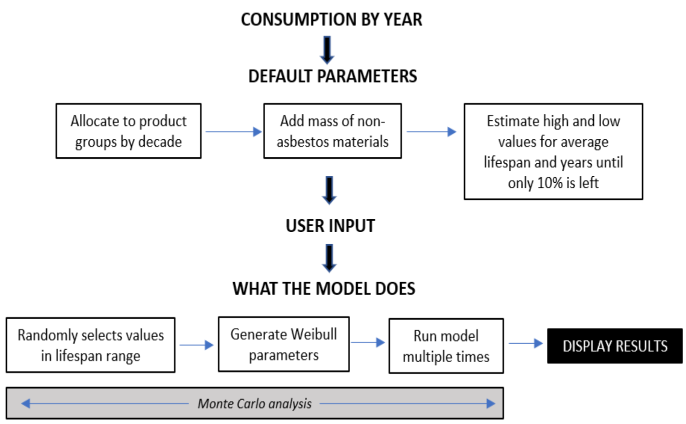

Figure 2. Graphic illustrating the operation of the stocks and flows model.

When the model is run, instead of generating a single set of results, 50 sets of results are generated, (however, this can be altered by the user for up to 100 runs. For each of these 50 runs a value is randomly selected from within the range of values for each of the parameters. The answer generated by the model is then the average of these 50 runs and is displayed with the 95% confidence interval to show the range of values within which the answer lies. The average results of the 50 Monte Carlo runs for each year are represented graphically as a black line, with vertical lines showing the 95% confidence interval (see Figures 3 and 4).

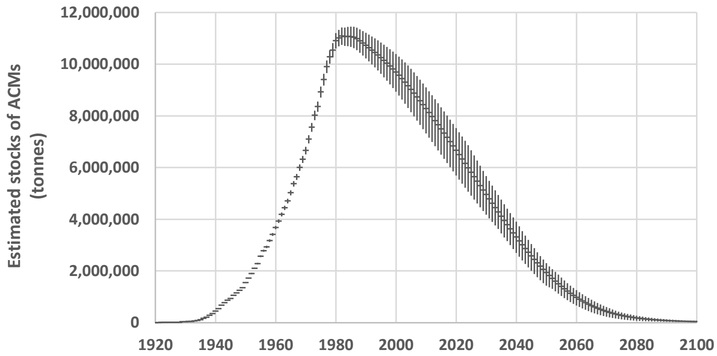

Figure 3. Estimated stocks of asbestos containing materials (tonnes).

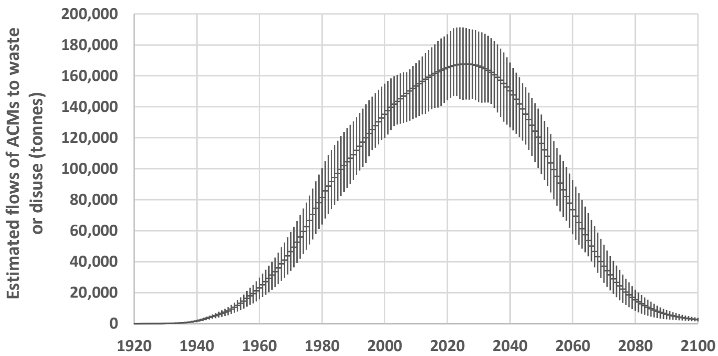

Figure 4. Estimated flows of asbestos containing materials to waste or disuse (tonnes).

3. Results

Australia's total stocks of ACMs peaked at approximately 10.9 million tonnes (range 10.4 to 11.2 million tonnes) in the 1980's. ACM stocks are predicted to decline at just above 10% per decade. ACM stocks are forecast at approximately 4.9 million tonnes (range 4.3– 5.5 million tonnes) in 2030, the time when waste flows are estimated to peak (see Figure 4). Looking forward, without significant intervention, ACM stocks will decline to around 1 million tonnes (0.7– 1.3 million tonnes) by 2060, with a long tail until at least 2100. The updated stocks and flows model can account for large-scale removal programs (proposed or actual), to better inform resourcing needs (e.g., workforce and infrastructure). This will ensure the capacity of the asbestos management system is considered proactively, and that such programs are sustainable, thereby maintaining appropriate risk management measures at all stages.

3.1. Asbestos Cement Products

Current asbestos stocks in the built environment are estimated at 6.2 million tonnes (5.5 to 7.1 million tonnes). The largest product groups estimates are for asbestos cement:

- 3.4 million tonnes (3.1 to 3.6 million tonnes) of asbestos cement pipes;
- 1.5 million tonnes (0.9 to 2.3 million tonnes) of asbestos cement sheeting (domestic);
- 1.0 million tonnes (0.7 to 1.3 million tonnes) of asbestos cement sheeting (commercial).

Together, asbestos cement pipes and commercial and domestic cement sheeting make up around 95% of the remaining legacy asbestos in the built environment in Australia. As percentages of the current stock remaining:

- Over 40% is estimated to be asbestos cement sheeting, in domestic and commercial buildings;
- Over 53% is estimated to be asbestos cement pipes.

Roofing products are largely cement based also. Current roofing is estimated as 0.08 million tonnes (0.06–0.1 million tonnes), or 1.2%.

The percentage of ACM product groups attributed to each jurisdiction in the national model is based on population. Although anecdotal evidence suggests that this is not always accurate [35], insufficient amounts of quantitative data were found to reasonably apportion it in any other way. However, the location of ACMs can be refined with updated regional input where this is known.

3.2. Asbestos Waste in Australia

The Hazardous Waste in Australia 2021 report notes Australia's two largest hazardous waste streams are contaminated soils and asbestos; it is estimated that about 21% of Australia's hazardous waste is asbestos [18].

Overall trends over the last ten years show reported asbestos waste volumes to be rising, which is linked with increased urban development and demolition. The amount of asbestos waste in Australia has increased nationally from approximately 315,000 tonnes in 2006–07, to approximately 1.42 million tonnes in 2020–21 [18]. Hence, asbestos constitutes one of the largest flows of hazardous waste in Australia.

Figure 4 illustrates the model's result for asbestos waste flows. Peak flows of ACM to waste are estimated for around 2030, at around 167,000 tonnes (145,000–185,000 tonnes).

3.3. Asbestos Flooring and Lagging

The current stocks estimate for flooring is 0.01 million tonnes (range 0.003– 0.02 million tonnes), or 0.2%, and for lagging is 0.004 million tonnes (range 0.003–0.005 million tonnes), or 0.1%.

Figure 5 below shows the composition of the estimated 6.2 million tonnes of Australia's asbestos legacy remaining in stocks, in ACM product groups.

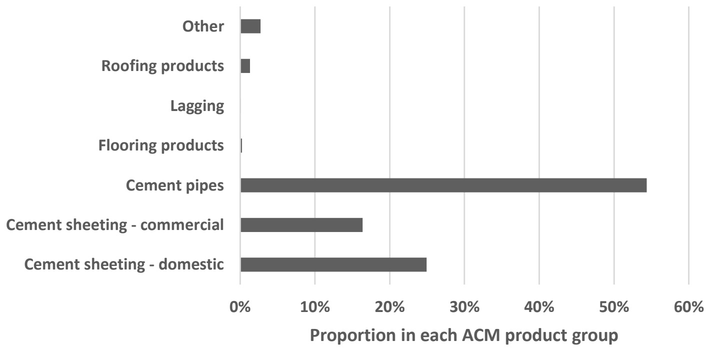

Figure 5. Estimated composition of Australia's remaining asbestos stocks in 2022.

4. Discussion

The *Australian Stocks and Flows Model for Asbestos* provides a national snapshot of the status of legacy asbestos in the built environment and its transition to asbestos waste. Current estimates indicate that there are approximately 6.2 million tonnes of legacy ACMs remaining in the built environment, and that with continued passive or reactive removal activities but no proactive intervention, there will still be approximately 1 million tonnes of ACMs remaining in 2060, with a long tail thereafter (Figure 3). These stocks currently comprise mainly asbestos cement pipes and sheeting (Figure 5), reflecting the asbestos consumption profile in Australia before asbestos was banned. Asbestos waste flows are estimated to peak in 2030 at 167,000 tonnes (Figure 4), with removed ACMs predominately sent to landfill.

It is worth noting that the quantities of reported asbestos waste greatly exceed the model estimates because reported 'asbestos waste' in most states and territory data has included soil and rubble contaminated with ACM. The stocks and flows model's estimated flows to waste do not include soil and rubble contaminated with ACMs, and so total recorded volumes differ to other waste reporting totals. Over time, it is hoped that the definition of asbestos waste is standardised in Australia; therefore, waste data are more meaningful and closer aligned with the model. In particular, there is a need for ACM to be distinguishable from soil and rubble contaminated with ACM. Efforts to achieve this have been ongoing for several years [36].

While the final destination for asbestos is generally landfill for most ACMs, when cement pipes are decommissioned, they are often left in situ in the ground. Managing cement pipes in this manner forms part of a hierarchy of methods, that are compliant with work health safety and environment protection laws, since they consider ongoing monitoring and management of asbestos exposure risks [37]. Even with a large proportion of legacy cement pipes not necessarily going to landfill, a challenge exists to manage the remaining product flows to waste anticipated in the future decades.

This challenge can be addressed in a variety of ways but depends on elements such as land availability and monetary considerations. Options include the creation of more space in landfills through, for example, improved waste resource and recovery efforts to divert other waste from landfills. The creation of new landfill infrastructure that accepts asbestos waste is another possibility. In both instances, regulatory requirements (licensing at minimum) apply to managing hazardous asbestos waste via deep burial in landfill. If stepping away from this policy alternative asbestos waste disposal methods, using emerging thermal, chemical, mechanical or biological technologies is another possibility, where these fulfil all regulatory requirements and other (e.g., economic and social) expectations [38].

Knowledge of the anticipated waste volumes, using the stocks and flows model, can inform such decisions. This new knowledge can help accelerate asbestos removal through safe, planned proactive actions. However, further research is needed on the implications of any ACM removal program on the entire asbestos management system.

5. Conclusions

In conclusion, the *Australian Stocks and Flows Model for Asbestos* provides an invaluable resource to support proactive planning for asbestos waste management, including prioritised removal and disposal. To our knowledge, there is no other such model available for tracking asbestos movements in and out of the built environment. With ongoing input from new or updated data sources (e.g., known regional-specific data on actual asbestos consumption, to reduce uncertainty based on assumptions that asbestos consumption was simply distributed on a per capita basis), the model will be able to predict volumes of asbestos stocks and flows with greater accuracy. On average, the current variability for the ranges of all estimates is approximately 25%. Nonetheless, the revised stocks and flows model continues to help track how much of Australia's hazardous asbestos legacy is remaining, and the rate at which it is reducing—critical information that aids in the long-term sustainable management of Australia's asbestos legacy.

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