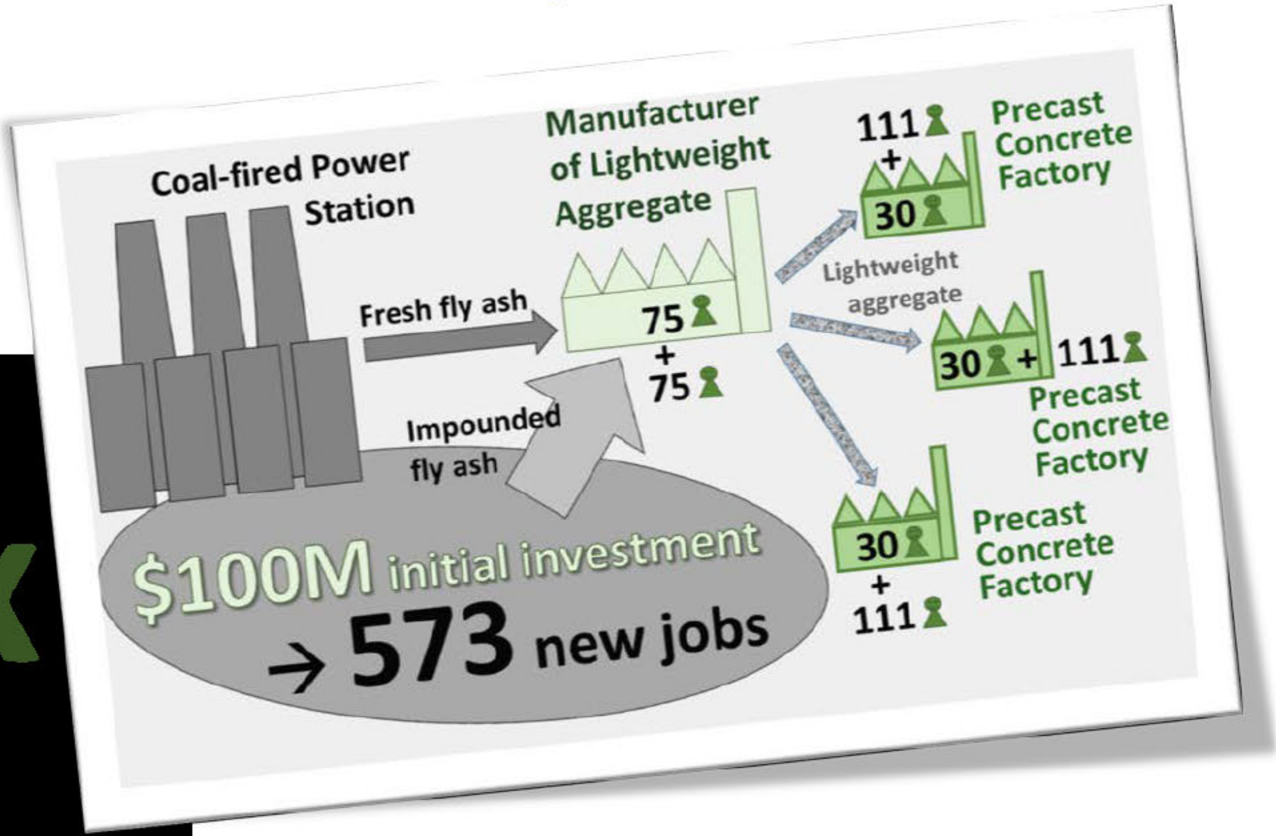
Load-based Levy for Coal-ash Boosts Regional Economies

Incentives for power stations to regulate the quality of the fly ash they produce and to make sure that the ash is actually sold and re-used

- Increased demand for Grade 1 fly ash from **road construction** (Transport for NSW, City of Sydney, Hunter Joint Organisation): can **increase by 50% within weeks**
- Joint investment (**power station** & **plant operators**) in processing plants for lightweight aggregate (levy avoided): can be shovel ready **within months**
- **Clusters of precast concrete factories** around each power station (Shepparton / Benalla model in Victoria): can be shovel ready **within a year**
- Structural **lightweight** aggregate **precast concrete products**: boost to **civil** and **buildings construction industries** (high-rise, warehouses, infrastructure – roads, airports, rail, tunnels, bridges, etc.): changes to project specifications can start now
- **2021 NSW Waste Management Strategy** with strong regional economic development effect from **Circular Economy** approach to **coal-ash reuse**
- **Government's contingent liability** for coal-ash dams **disappeared** before called on

REMPLAN Modelling: 3,000 Jobs

5x



Re-using coal-ash in New South Wales: Economic considerations

Report prepared for the Hunter Community Environment Centre
by Dr Ingrid Schraner

December 2020

Lilli Pilli Consulting

formulate a vision | make change happen | measure the difference

The Hunter Community Environment Centre is a not-for-profit community group funded by grants, donations and independent of government and corporate funding. We established in 2004 to encourage and facilitate environmental and social justice advocacy and education in the Hunter region, NSW, Australia.

The objectives of the Hunter Community Environment Centre are:

- To maintain a community environment information, resource and advocacy centre.
- To educate and inform the community about biodiversity and the need to protect it.
- To provide and promote the dissemination of information and views regarding environmental matters.
- To promote and assist cooperation, sharing of resources and coordination of activities amongst environment and community groups.
- To protect and conserve ecological processes, genetic diversity and the natural environment.

For further information on this report please contact

Johanna Lynch, Coordinator, Hunter Community Environment Centre

www.hcec.org.au

Produced & published by Hunter Community Environment Centre, ABN 40826463714

Publication date: 15 December 2020

Cover photo: Eraring ash dam seen from Lake Macquarie

Executive summary and recommendations

This report first outlines how the combination of supply-side incentives and the realisation of demand-side opportunities can almost immediately increase the amount of NSW fly ash used in environmentally safe ways by one third to at least 50% of all Grade 1 fly ash currently produced.

The report then describes how decisive steps to end the practice of contaminating ash dams with construction waste and to modify ash management practices in existing dams can secure the basis for the establishment of a long-term industry, which manufactures structural lightweight aggregates from both, freshly produced fly ash and fly ash impounded or stored in ash dams – until the coal-ash repositories have reduced to environmentally safe concentrations of pollutants, eliminating the government's rehabilitation liabilities.

This new industry can not only provide structural lightweight aggregate concrete for the high-rise and multi-storey building industry, it can also produce structural lightweight precast concrete products of superior flexural strength. This will give the civil and housing construction industries a significant boost, because projects that were previously marginal will become economically viable through the provision of cheaper building material of superior quality, lower transport costs and less production wastage.

Including decommissioned ash dams and other repositories there is currently a reservoir of over 200 million tonnes (Mt) of coal ash in NSW, to which the operational coal-fired power stations currently add some 3.8Mt every year. It has been estimated that without significant changes over 260Mt of coal ash waste will have accumulated once all five power stations retire. This means that even if the amount of fresh Grade 1 fly ash used in road construction dramatically increases, there is enough raw material for a structural lightweight aggregates industry to flourish in NSW, providing significant numbers of jobs of the future.

The aggregate manufacturing plants will be located next to power stations creating regional jobs. Highly specialised factories for precast concrete products made with structural lightweight aggregate will cluster around them providing further jobs for engineers with skill sets similar to those used in power stations. Based on conservative assumptions, initial REMPLAN modelling shows that some 3,000 ongoing jobs can be created in the Upper Hunter, around Lake Macquarie and in Lithgow.

Recommendations

1. Introduce a load-based levy for fly ash deposited in ash dams and other voids, calculated based on the coal burnt at the power station and on the weighbridge records of trucks leaving the power station with fly ash contracted for uses other than storage elsewhere (in order to create an effective incentive for the establishment of logistics and infrastructure that lead to significantly increased amounts of fly ash being re-used, the levy per tonne would need to be at least half the price of ready-mix concrete delivered to metropolitan markets, currently about $60/t).
2. Quickly increase the effective demand for NSW Grade 1 fly ash in road construction by immediately adjusting, where necessary, the procurement policies of Transport for NSW, Councils in the Greater Sydney Region and the Hunter Joint Organisation of Councils to ensure that all their contract specifications include the maximum amount of NSW Grade 1 fly ash currently allowable.
3. Instruct EPA to proactively prevent construction and demolition waste to be deposited in ash dams, in particular the practice of depositing asbestos in ash dams.
4. Require ash management plans at all NSW power stations to be modified so that current practices facilitate the later re-use of the impounded ash.
5. Include strong measures in the 2021 NSW Waste Management Strategy that can support the development of a structural lightweight aggregate industry that re-uses significant amounts of coal ash, both fresh and impounded.
6. Review the State government's infrastructure pipeline with a view of benefitting from a fly ash-led recovery that creates regional jobs by establishing a new industry, grows the civil and housing construction industries, attracts significant investment and grows the NSW economy.
7. Commission a report that charts a strategy how to best target government support for the development of the most promising high-tech coal ash applications into competitive markets.

Contents

Executive summary and recommendations 3
Contents 4
List of Tables 4

1. The magnitude of the coal ash issue in NSW 5

2. Readily actionable: Increasing Grade 1 fly ash in road construction 6
Supply-side incentive structure: the role of Flyash Australia 6
Demand-side opportunities: the role of public road construction 7

3. Processing coal-ash into structural lightweight aggregates 8
Sintered lightweight aggregates 8
Geopolymer lightweight aggregates 9
Structural versus lightweight aggregates in the current Australian markets 10

4. Markets for structural lightweight aggregates 11
Lightweight aggregates in structural concrete 11
Structural lightweight precast concrete products 13
Future opportunities in high-tech industries 14

5. Employment considerations 14

6. Conclusion 15

References 16

List of Tables

Table 1: Estimated amounts of coal ash in NSW in million tonnes (Mt) 5
Table 2: Density comparisons (kg/m3) 9
Table 3: Flexural strength (MPa) of concrete 9
Table 4: Cumulative forecast demand for extractive materials 2018 – 2036, GSR 10
Table 5: Cumulative forecast demand for concrete by raw material type 2018 – 2036, GSR 11
Table 6: Indicative savings from using structural lightweight aggregate concrete 12
Table 7: The context of concrete product manufacturing 13
Table 8: Cumulative forecast demand by manufacturing sector and direct to site 2018 – 2036, GSR 13

1. The magnitude of the coal ash issue in NSW

The five operating coal-fired power stations in NSW collectively generate about 4.8 million tonnes (Mt) of coal ash a year, of which they dump about 3.8 Mt each year into on-site ash dams, placement areas, or mine voids. Collectively they have accumulated about 160 Mt, to which the decommissioned Wallerawang and Tallawarra dams need to be added, as well as the contributions from Wangi power station to Eraring dam and from Munmorah and Vales Point A power stations to Vales Point ash dam. Altogether, the total amount of ash stored in NSW amounts to about 216 million tonnes.

Table 1: Estimated amounts of coal ash in NSW in million tonnes (Mt)

c	Annual ash production	Ash re-used per year	Ash disposed of per year	Accumulated ash to date
Vales Point B	0.68 Mt	0.18 Mt	0.5 Mt	61Mt
Vales Point A & Munmorah	--	--	--	
Eraring	1.22 Mt	0.42 Mt	0.8 Mt	40Mt
Wangi	--	--	--	
Bayswater – Pikes Gully/Ravensworth	1.53 Mt	0.23 Mt	1.3 Mt	45Mt
Liddell	0.80 Mt	--	0.8 Mt	39Mt
Mt Piper	0.57 Mt	0.17 Mt	0.4 Mt	15Mt
Wallerawang B & C	--	--	--	13Mt
Tallawarra A	--	--	--	3Mt
Total	**4.80** Mt	**1.00** Mt	**3.8** Mt	**216Mt**

Source: Paul Winn, Out of the Ashes II, p iv-v

A report prepared by the Hunter Community Environment Centre, *Out of the Ashes II*[1], estimated that from this accumulated ash waste every year 100 tonnes of leachate enter waterways in NSW, which contain heavy metals and metalloids. Heavy metal pollution represents a major threat to biodiversity and can alter the distribution and abundance of species through toxicological impacts, including deformities that impair reproductive success.

Lake Macquarie catchment is the region worst affected by coal-ash pollution in NSW, with an annual estimated amount of 45 tonnes of metals leaching that are reportable to the National Pollutant Inventory (NPI). The Central Hunter River Valley receives 40 tonnes of NPI reportable leached metals annually and the Upper Coxs River, which forms part of Sydney's drinking water catchment, receives an estimated 16 tonnes of NPI metals per annum.

According to the detailed calculations presented in *Out of the Ashes II,* the amount of approximately 45Mt of coal ash, which is expected to accumulate under a business-as-usual scenario between now and the retirement of coal-fired power stations, is estimated to leach 1,000 tonnes of NPI reportable metals. Distributed regionally, this additional ash means 460 tonnes of leachate in the Central Hunter Valley, 302 tonnes in Lake Macquarie, and 206 tonnes in the Upper Coxs River.

The liability for the pollution stemming from the ash produced prior to privatisation around 2015 lies with the State of NSW. Finding economically viable solutions for the safe re-use of the ash currently produced and impounded in dams, placement areas and mine voids is thus in the public interest.

[1] Winn 2020

2. Readily actionable: Increasing Grade 1 fly ash in road construction

Supply-side incentive structure: the role of Flyash Australia

According to their website,

> 'Flyash Australia Pty Ltd is a leading supplier of high quality fly ash products. We are a joint venture company, equally owned by Boral Limited and Cement Australia Pty Ltd, and our core business involves the collection, processing, storage and distribution of quality fly ash products. … Flyash Australia has operations within NSW, SA and WA and distributes its products throughout Australia.' (http://www.flyashaustralia.com.au/ accessed 30 November 2020)

Boral Ltd and Cement Australia Pty Ltd are arguably two major players in the NSW cement and concrete markets. High quality fly ash, i.e. Special Grade and Grade 1 qualities as specified in the Australian/New Zealand Standard™ for 'Supplementary cementitious materials, Part 1: Fly ash' (AS/NZS 3582.1) competes directly with cement. This means that the amount of fly ash, which the leading 'supplier' Flyash Australia brings to market, does not depend on how much fly ash is being produced in NSW's coal-fired power stations, but on the amount of cement substitutes that maximizes the profits of Boral and Cement Australia.

As long as it is basically free for power stations to deposit coal ash in ash dams, power stations have no particular interest in either forcing Flyash Australia Pty Ltd to market and sell at least all the high quality fly ash produced, or in facilitating actual users of fly ash to take up meaningful amounts of the coal ash produced.

And for as long as long as cement companies don't have a significant competitor that uses meaningful amounts of fly ash as a substitute for cement, there is no incentive for Flyash Australia as the leading marketer to develop the logistics that would allow high quality fly ash to become a serious competitor for cement sales on a scale that impacts on the amount of fly ash impounded.

The answers provided by Transport for NSW (TfNSW) to the Questions on Notice from the recent NSW Upper House 'Inquiry into the costs of remediation of sites containing coal ash repositories' provide strong evidence supporting various aspects of this point:

- Those marketing fly ash do not provide a continuous and reliable supply to the market[2]
- 'Sourcing of fly ash is a commercial matter between fly ash suppliers and cement producers'[3]
- The problem is not that Transport for NSW applies stricter standards than the relevant Australian standard AS3582.1 (2016), the problem is the variability of the unburnt carbon (measured as Loss on Ignition or LoI) in fly ash brought to the market, which has a direct impact on various performance aspects of concrete[4]

The level of pulverization of the coal fed into power stations' boilers is the most important factor in determining the LoI in Grade 1 fly ash leaving power stations. Each boiler has a ball mill that crushes the coal before it is blown into the boiler, which means the power stations are in full control of the key determinants of the LoI of the fly ash they produce[5]. It would appear that there is nothing stopping power stations from having the fly ash that leaves their premises certified to the levels required by Transport for NSW, and from ensuring the delivery in certified batches.

For the last two decades NSW power stations have based submissions to planning and environmental authorities on projections of increasing levels of coal ash re-use that have not materialised. There is an

---

[2] Transport for NSW in their Answer to Question 3: 'As recently as last September 2020, TfNSW were advised by industry of a shortage of fly ash.'

[3] Transport for NSW in their Answer to Question 5 about the supply chain and the point of origination of coal ash

[4] QA Specification 3211 Cementitious Materials, Binders and Fillers by Transport for NSW requires variability levels that ensure that the LoI in fly ash used by Transport for NSW remains lower than 4%.

[5] The only time when it is reasonable to expect a LoI that is not close to 1% is when a boiler is started up, and it is very easy not to use that particular batch together with the rest of Grade 1 fly ash. Other relevant considerations are discussed in Widmer et al. 2005

obvious need to establish a regulatory system that changes the perverse incentives that have prevented a significant increase in environmentally sound re-use of coal ash. Such a regulatory system has to ensure that those who are in control of the quality of the fly ash produced also have a strong incentive to meet the market demand and actually sell significant quantities into the existing market with the specifications and certifications demanded.

Recommendation 1: Introduce a **load-based levy for fly ash deposited** in ash dams and other voids, calculated based on the coal burnt at the power station and on the weighbridge records of trucks leaving the power station with fly ash contracted for uses other than storage elsewhere (in order to create an effective incentive for the establishment of logistics and infrastructure that lead to significantly increased amounts of fly ash being re-used, the levy per tonne would need to be **at least half the price of ready-mix concrete delivered to metropolitan markets**, currently about $60/t).

Demand-side opportunities: the role of public road construction

Trials undertaken at Eraring Power Station in NSW and Stanwell Power Station[6] in QLD show that 1,000t of fly ash used per kilometre of three-lane highway is used as the conservative base level of trials, i.e. without any changes to existing regulations and standards. According to Transport for NSW[7] the state has a network of 185,000km roads. The equivalent of 1.25% of this road network would consume, calculated as three-lane highways in the above examples, at least 2.3Mt of Grade 1 fly ash, or 50% of all the fly ash produced in NSW's five coal-fired power stations every year[8].

In the second of their answers to the Questions on Notice from the recent NSW Upper House 'Inquiry into the costs of remediation of sites containing coal ash repositories'[9], Transport for NSW estimated that for the 150km two-lane Pacific Highway section of the Woolgoolga to Ballina Bypass approximately 90,000 tonnes of Grade 1/Class F fly ash was used in the concrete pavement. Some 27,000 tonnes fly ash was sourced from Gladstone in Queensland and 63,000 tonnes from Eraring in NSW. Adjusting for the three-lane equivalent used above, this would roughly amount to 770t/km, or a potential to increase fly ash use by a little under a third.

This does require that the power stations address the issue of variability in the Loss on Ignition (LoI) of their fly ash and secure appropriate certification measures – a high enough load-based levy will provide a powerful incentive to those who are in control of these issues. Once these issues are successfully addressed, the demand for Grade 1 fly ash can increase by at least a third without any further change in specifications, while engineers can specify the maximum amount of local coal-ash allowable in their specifications for all roads they build.

Local government can also play an important role, and their collaboration with Transport for NSW is crucial[10]. The City of Sydney for example has adopted the use of the Green Building Council of Australia (GBCA)'s Green Star MAT-4 as a standard for all its building activities. In their manual 'Sydney Streets, Technical Specifications Version: 2019' they spell out 40% cement replacement as a requirement, specifically mentioning Ground Granulated Blast-Furnace Slag (GGBS) and fly ash at the top of the list.

---

[6] Details provided in personal communications and at the Regional CCPS (Virtual) Workshop & Stanwell Pavement Trial Site Tour, organized by the Ash Development Association of Australia.

[7] https://www.transport.nsw.gov.au/operations/logistics-network/nsw-road-network

[8] Assuming only 50% of fly ash produced being Grade1 or higher is very conservative, optimal harvesting and management practices would allow 70-80% of fly ash to be harvested as Grade 1 fly ash or better.
It also needs to be stressed that the trials discussed experiment with significantly higher levels of fly ash use, while our calculations only refer to their base case, i.e. the amounts of Grade 1 fly ash that could be used *without* changing current practices and regulations.

[9] Transport for NSW 2020b

[10] Lake Macquarie City Council confirmed in their Answers to Questions on Notice from the recent NSW Upper House Inquiry that 'Lake Macquarie City Council records indicate that neither Transport for NSW or the former Roads and Maritime Service have specifically consulted Lake Macquarie City Council staff about the use of flyash in road construction'.

Lake Macquarie City Council seems to be taking the lead on issues related to the development of a Circular Economy within the Hunter Joint Organisation of councils. Their submission to the Inquiry stresses the need to facilitate the use of coal ash stored in repositories as a valuable resource, rather than taking a cap and cover approach as a means of managing contingent liabilities by the State government[11].

Recommendation 2: Quickly **increase the effective demand** for NSW Grade 1 fly ash in road construction by immediately adjusting, where necessary, the **procurement policies** of Transport for NSW, Councils in the Greater Sydney Region and the Hunter Joint Organisation of Councils to ensure that **all their contract specifications** include the **maximum amount of NSW Grade 1 fly ash currently allowable**[12].

3. Processing coal-ash into structural lightweight aggregates

Processing coal-ash into structural lightweight aggregates fixes heavy metals and other trace elements into the matrix of the aggregate. When coal-ash is stored in ash dams or ponds, these chemicals become a problem due to their concentration and the fact that when coal-ash is stored in water, they leach into surrounding water bodies and ground water, where they bioaccumulate and over the course of five to seven decades reach levels that are hazardous to animal and human health[13].

When coal-ash is manufactured into aggregates it has the potential to transform an environmental liability, for which the State of NSW has retained legal liability when the coal-fired power stations were sold, into a potentially flourishing industry that enables the creation of a variety of downstream industries that can boost the civil and housing construction industry and create jobs at all levels of skill sets, from transport and construction workers to highly specialised engineers.

Sintered lightweight aggregates

In this process fly ash collected at coal-fired power stations undergoes four basic steps before it is ready to be used as a lightweight aggregate in the production of structural lightweight aggregate concrete (if impounded ash is processed, a preparatory step will need to be added):

1. **Mixing & Pelletizing**: The coal ash is mixed with a binder and then pellets are formed in a pelletiser.
2. **Drying**: Once pellets have reached the desired size, they are carried via conveyor to a dryer to remove the moisture content that had been added as binder.
3. **Sintering**: The ash pellets are heated to just before their melting point (around 1,100 – 1,400 degree Celsius) in a kiln or on sintering strands.
4. **Cooling**: The product then must be cooled before it moves on to shipping or storage to be used in the production of various concrete products.

This process has been around for half a century and is widely used overseas. The Swiss multinational LafargeHolcim Ltd for example not only owns Cement Australia, but also Aggregate Industries in the UK, which produces Lytag®[14] from impounded ash at Drax power station in Selby, North Yorkshire. Lytag® is one of the best-known structural lightweight aggregates[15].

[11] Lake Macquarie City Council 2020a and 2020b

[12] While the proposed supply-side mechanism ensures that the power stations maximize the amount of their Grade 1 fly ash made available to the market in consistent and certified qualities, early consideration should be given to incentives for the establishment of facilities to process impounded ash into Grade 1 ash, and to incentives for current ash repository management practices that facilitate the future re-use of impounded ash (see below Recommendations 3 & 4).

[13] See submissions to the recent Upper House Inquiry by Hunter Community Environment Centre, Environmental Justice Australia and others, but also Winn 2020.

[14] In the 1990s Lytag® was owned by Boral, which demerged its energy operations in 2000 into newly listed Origin Energy, which is now running Eraring Power Station on Lake Macquarie.

[15] Lightweight aggregates currently available in Australia are made of pumice, perlites or scoria, which are all soft products that produce a lightweight concrete that does not have the strengths required from structural concrete.

On 6 December 2016 the Builders Merchants' News announced that Aggregate Industries invested £15M into a new manufacturing facility within the grounds of Drax power station[16]. However, recent informal discussions with staff at Lytag itself indicated an overall cost for the whole facility of closer to £40M with the capacity to process 200,000t of ash per year.

Vecor Australia[17] holds a patent originally developed at University of NSW that allows them to produce a lightweight aggregate similar to Lytag®, which has successfully undergone wide-ranging laboratory tests and appears to be ready to be used in a pilot factory for commercial production in NSW.

Geopolymer lightweight aggregates[18]

The basics of this technology combine fly ash, either directly from the power station or after it has been stored in an ash dam, with a chemical balancing agent like white China clay (Kaolin) and caustic soda (Sodium Hydroxide) to produce lightweight aggregates of a variety of sizes. The process is relatively simple and uses existing technologies and equipment, which can be arranged in a modular way, so that production can be increased as markets for the products manufactured are developed[19].

While caustic soda needs to be handled with appropriate care, it is widely used in the manufacture of pulp and paper, alumina, soap and detergents, petroleum products and chemical production. The process can use a wide range of fly ash including graded fly ash (all grades), run-of-station fly ash as well as ash recovered from ash dams. This technology produces aggregates that make for lighter weight concrete, as can be seen in Table 2 below.

While the weight reduction is smallest in precast concrete, the higher flexural strength, which concrete made from geopolymer lightweight aggregates has demonstrated, makes this concrete particularly adept for use for pre-stressed structural concrete beams and slabs. This leads to less deflection and thus a lower propensity for the concrete element to crack when being transported and placed into a structure.

Table 2: Density comparisons (kg/m3)

	Geopolymer Lightweight Aggregate (LWA)	Crushed Granite Aggregate	
Aggregate	1,709 kg/m³	2,550 kg/m³	↓ 33%
In Premix Concrete	2,021 kg/m³	2,438kg/m³	↓ 17%
In Precast Concrete	2,075kg/m³	2,387kg/m³	↓ 13%

Source: Personal communication based on research at RMIT University in Melbourne

Geopolymer-based lightweight aggregate appears to be reactive with the cement mortar that surrounds the aggregate, forming a stronger interfacial bond between the aggregate and the cement mortar. Regular crushed rock aggregate is inert and does not have the same properties, giving concrete made with geopolymer aggregate a distinct advantage when in its bending moment. Results from tests at RMIT University are shown in Table 3 below.

Table 3: Flexural strength (MPa) of concrete

	Geopolymer lightweight aggregate (LWA)	Crushed granite	
7 days	3.95 MPa	3.11 MPa	↑ 27%
28 days	4.54 MPa	3.34 MPa	↑ 36%

Source: Personal communication based on research at RMIT University in Melbourne

[16] https://www.buildersmerchantsnews.co.uk/Aggregate-Industries-unveils-15m-lightweight-aggregate-facility/44122
[17] Vecor Australia Pty Limited 2020a and 2020b
[18] This is not to be confused with geopolymer cement and geopolymer concrete, where fly ash is used as a cement substitute, together with aggregates from hard rock and natural or manufactured sand.
[19] The submission by Polyagg Pty Ltd to the recent NSW Upper House Inquiry refers to a technology of this kind.

The tests at RMIT University are also reported to demonstrate that geopolymer-based lightweight aggregates exceed the requirements of Australian Standard for concrete aggregates AS2758.1: 2014.

The importance of less weight and more flexural strength combined can be illustrated when comparing precast concrete panels made from structural lightweight aggregates (LWA) with those made from crushed rock aggregates (CRA). Whilst the structural LWA costs more, the resultant precast concrete panels are 13% lighter due to the lower density of the aggregate, and 11% thinner due to the superior flexural strength of the concrete, which overall results in the structural LWA panels being 23% lighter at much the same cost. The higher flexural strength results not only in thinner panels, but also in panels that have an up to 30% better bending moment, which in turn results in less breakage waste in storing and transport. In addition, the lower weight and better bending moment also results in significantly lower transport costs.

We are aware of a consortium forming, which plans to bring this technology to the Australian market in an integrated way that shares the investment costs between power station and plant operator, but also includes building supply, precaster and construction groups. They are discussing building plant capacity and market penetration in a modular way over a number of years aiming at a capacity of processing 1Mt of fresh and impounded ash per year.

Structural versus lightweight aggregates in the current Australian markets

As mentioned in a footnote above, the only lightweight aggregates currently available in Australia are made of pumice, perlites or scoria, which are all soft products that produce a lightweight concrete that does not have the strengths required from structural concrete.

Structural concrete in Australia relies on aggregates made from sand and crushed hard rock, which for the Greater Sydney Region (GSR), by far the largest user of building products in NSW, comes from 17 quarries in four feeder areas to the North, West, Southwest and South[20]. Estimates on prices and quantities vary, but the most recent report for the Department of Planning, Industry and Environment prepared by R.W. Corkery & Co estimates the current and expected demand for extractive materials as follows:

Table 4: Cumulative forecast demand for extractive materials 2018 – 2036, GSR

Extractive material	2018	2018 – 36
Crushed rock	13.7Mt	265Mt
Natural sand	6.1Mt	118Mt
Total	**19.8Mt**	**383Mt**

Source: R.W. Corkery & Co, Supply and Demand Profile of Geological Construction Materials for the Greater Sydney Region, Table 3.9 p100

The overwhelming majority of these extractive materials are being used in concrete. The detailed breakdown for concrete raw materials is given in the same report as detailed below (the fact that the cumulative weight is also 383Mt is coincidental).

[20] It is important to note that the market size discussed here does not include aggregates (sand and gravel) used in non-structural applications, which in the Greater Sydney Region are covered to a large degree from substitute construction materials produced from recycled construction and demolition (C&D) waste and from sandstone virgin excavated natural material (VENM), mostly from tunnel spoil. The demand discussed here therefore only consists of the roughly 54% of overall demand for construction materials (quarry products and their substitutes), as the substitutes cannot be widely used for structural applications and thus do not compete with structural lightweight aggregates.

Table 5: Cumulative forecast demand for concrete by raw material type 2018 – 2036, GSR

Concrete raw material	Quantity	Share
Cement	44Mt	12%
Fly Ash	16Mt	4%
Ground Granulated Blast Furnace Slag (GGBFS)	3Mt	1%
Fine Aggregates – Natural Sand	91Mt	24%
Fine Aggregates – Manufactured Sand	51Mt	13%
Coarse Aggregates	178Mt	46%
Total	**383Mt**	**100%**

Source: R.W. Corkery & Co, Supply and Demand Profile of Geological Construction Materials for the Greater Sydney, Table 3.13 p104

A cumulative market demand for aggregates of 320Mt until 2036 in the Greater Sydney Region alone indicates a market size that has ample room for the establishment of a new industry that produces amounts of structural lightweight aggregates that can make a significant contribution to the re-use not only of the coal ash currently produced, but also of the coal ash impounded in ash dams. Technology exists and is successfully used overseas to prepare impounded ash to be processed into lightweight aggregates.

However, in order for the ash currently stored in ash dams to be useable in the production of structural lightweight aggregates, some of the current malpractices in ash dam management in NSW have to stop. While this might not be easy, it will enable the establishment of a circular economy that not only re-uses a valuable resource, but also transforms a looming environmental disaster into a flourishing industry.

Recommendation 3: Instruct **NSW EPA to proactively prevent construction and demolition waste** being **deposited in ash dams**, in particular the practice of depositing asbestos in ash dams.

Recommendation 4: Require **ash management plans** at all NSW power stations to be modified so that current practices **facilitate the later re-use** of the impounded ash.

4. Markets for structural lightweight aggregates

Lightweight aggregates in structural concrete

Both kinds of structural lightweight aggregates produce a lightweight concrete of exceptional strength that has the potential to make high-rise buildings economically viable, which otherwise would be marginal or not viable at all. Examples from the City of London include the 'Shard', the 'Walkie Talkie', and in particular the 'Cheesegrater', which was started during the Global Financial Crisis and had seven stories added to the original plans once the benefits of structural lightweight aggregate concrete became evident.

These benefits can be illustrated by the indicative calculations in Table 6, which show the percentage savings that can be achieved when using structural lightweight aggregate concrete compared with regular concrete.

Table 6: Indicative savings from using structural lightweight aggregate concrete

	6-storey apartment building (lightweight / regular concrete)	**15-storey office tower** (lightweight / regular concrete)
Dead load	- 31%	- 27%
Total concrete volume	- 17%	- 17%
Total reinforcement weight	- 9%	- 14%
Number of foundation piles	- 29%	- 24%
Total concrete savings (m^3)	349 m^3	1,396 m^3
Total reinforcement savings (t)	8t	282t
Total structural cost savings ($)	$2,000	$821,100
Total structural cost savings (%)	0%	11%

Source: personal communications, crosschecked with other engineers

While the direct financial advantages are obvious, the construction industry in Australia is not only inherently conservative, but the concrete industry in particular is also highly concentrated and vertically integrated. Informal discussions with representatives from Lytag showed that Lytag has a very pro-active marketing team of highly specialised engineers that engage 2-3 years prior to design process with building companies that consider high-rise buildings, in order to ensure that the building specifications encompass the benefits lightweight aggregate concrete can provide – and that the required volumes of aggregates are available at the time needed[21]. Structural lightweight aggregates, in particular when combined with cements that contain a high percentage of fly ash, produce a lightweight concrete that performs extremely well in a circular economy perspective and in greenhouse gas audits[22].

However, as long as there are no government requirements to undertake such audits or to seriously reduce Greenhouse gas emissions, this advantage cannot be harnessed fully in the development of a new industry.

Table 6 above also indicates another potential limitation for the successful use of lightweight aggregates in the structural concrete market, namely the fact that the savings increase with the number of storeys of the building, but the number of large high-rise buildings in NSW is still limited. Even in the UK, with the City of London being bigger than that of Sydney, it would appear that Lytag at Drax, which has the capacity to use 200,000Mtpa of ash, is currently only operating at about 100,000Mtpa, presumably in order to safeguard its high margin on lightweight aggregate. Rumour has it that lightweight aggregates not used in lightweight aggregate concrete are given away at cost to concrete block manufacturers to clear the yard at Drax.

However, once there are strong government incentives to foster a circular economy in the construction industry that include the valuable raw material the coal ash can become, lightweight structural aggregate will find it easier to compete with aggregates from virgin material, which have much lower production costs, and they can penetrate markets for structural applications other than high-rise buildings where weight is such a crucial factor.

Recommendation 5: Include strong measures in the **2021 NSW Waste Management Strategy** that can support the development of a **structural lightweight aggregate industry** that re-uses significant amounts of coal ash, both fresh and impounded.

[21] The Coal Combustion Products Handbook reports that

> In the 1970s the MLC Tower in Sydney was designed and constructed using a lightweight aggregate manufactured from expanded shale. Part way through the project the manufacturer ceased operating, and the building had to be completed using imported aggregate, at great expense.
> Ward, Heidrich & Yeatman 2014, p286

[22] Beyond Zero Emissions' *Zero Carbon Industry Plan: Rethinking Cement* (http://bze.org.au) provides evidence that the manufacturing of one tonne of cement in Australia causes about 0.82 tonnes of carbon dioxide (global average is 0.87 tonnes of CO_2 per tonne of cement produced)

Structural lightweight precast concrete products

Precast concrete products make part of the concrete product manufacturing industry, which includes products like pipes and box culverts, bricks and blocks, cement-based building boards, floor, wall and roofing tiles, and precast panels and posts. Australian Bureau of Statistics (ABS) data[23] captures Concrete product manufacturing (2034) as part of the Non-metallic mineral product manufacturing industry (20), which nationally employed more than 40,000 people and almost a third of them in NSW.

The figures calculated in Table 7 below for the four digit subcategories are assuming that the NSW and the national industries are distributed in a similar way. They show that in 2018-19 in NSW there were almost 3,000 jobs in ready-mix concrete manufacturing and almost 2,500 jobs in concrete product manufacturing. This means that if a plant manufactures precast concrete products from lightweight aggregates with 30 employees, they employ a little over 1% of the market for manufactured concrete products. Yet they are producing a distinct product that is likely to add to and grow the overall market rather than taking market shares from others.

Table 7: The context of concrete product manufacturing

	Employment at end June		Wages and salaries		Sales and service income	
NEW SOUTH WALES, 2018-19	no.	%	$m	%	$m	%
20 Non-metallic mineral product manufacturing	12,882		1,149		7,153	
2031 Cement and lime manufacturing	1,163	9%	135	12%	1,242	17%
2032 Plaster product manufacturing	520	4%	44	4%	332	5%
2033 Ready-mixed concrete manufacturing	2,841	22%	270	24%	2,084	29%
2034 Concrete product manufacturing	2,444	19%	197	17%	978	14%

Source: ABS 81550DO003_201819 Australian Industry, 2018-19

In terms of extractive materials used, the cumulative expected market size for concrete aggregates from crushed rock used in structural precast concrete products has been estimated as 74Mt in the years to 2036. Table 8 below shows this in the context of alternative uses for extractive materials.

Table 8: Cumulative forecast demand by manufacturing sector and direct to site 2018 – 2036, GSR

Manufacturing Sector / Direct to Site	Quantity	Share
Concrete Aggregates Pre-Mix	181Mt	48%
Concrete Aggregates Pre-Cast	74Mt	19%
Mortar Sand	4Mt	1%
Asphalt & Spray Seal Aggregates	28Mt	7%
Direct to Site (Roadbase, Other Aggregates, Broken/Sized Rock)	96Mt	25%
Total	**383Mt**	**100%**

Source: R.W. Corkery & Co, Supply and Demand Profile of Geological Construction Materials for the Greater Sydney Region, Table 3.16 p106

Unlike concrete that is poured on site, high quality precast concrete is produced in a controlled factory environment using advanced manufacturing techniques. Reinforcement is placed into reusable and adjustable moulds, and concrete is poured, vibrated and cured. The finished precast elements are then transported to site and craned into position[24].

The precast industry is a highly specialised one that produces to order and employs highly qualified engineers and design specialists – the perfect industry to be developed to absorb well-paid employees transitioning out of the energy sector. Given the highly specialised nature of the industry, precast concrete products made from

[23] 81550DO003_201819 Australian Industry, 2018-19, released 29 May 2020 (retrieved 2 December 2020 from https://www.abs.gov.au/statistics/industry/industry-overview/australian-industry/2018-19#data-download)

[24] For more information and some illustration see the National Precast Concrete Association Australia, https://nationalprecast.com.au/

geopolymer lightweight aggregate can command a price premium due to their advantageous performance characteristics of lower weight and higher flexural strength.

Precast concrete products made with lightweight aggregate can in principle fit into existing distribution channels as the lightweight aggregate can be sold via existing building materials bulk suppliers either to precasters or directly to builders. Yet it might be advantageous for lightweight aggregate producers to develop direct relationships with precasters to retain the price premium[25].

Given that currently no structural grade lightweight aggregates are available in Australia at all, precast concrete products made with them open two new employment frontiers: new projects will become technically possible to build, and other projects will have significantly reduced transport and installation costs. And in both groups the number of economically viable projects will increase. Lightweight aggregate concrete products will thus create their own industry and will boost the wider construction industry and create employment in both.

Recommendation 6: **Review the State government's infrastructure pipeline** with a view of benefitting from a fly ash-led recovery that creates regional jobs by establishing a new industry, grows the civil and housing construction industries, attracts significant investment and grows the NSW economy.

Future opportunities in high-tech industries

Fly ash can also be used in a wide range of high-tech applications, many of which have been successfully tested in research facilities. There is a sizeable and fast-growing academic literature reporting on potentially high value-added applications for fly ash including high performance glass-ceramic materials, building ceramics, insulation products, ceramic membranes and the recovery of rare earths and heavy metals.

Another opportunity for industrial use of fly ash is in the production of ceramic tiles, an industry that is well established in China[26] and is being developed in Italy. However, it is at this stage not yet clear how much fly ash would be taken up by such an industry and whether a market for such tiles could be successfully established in Australia based on the local production cost structure.

Recommendation 7: Commission a report that **charts a strategy** how to best target government support for the development of the most promising **high-tech coal ash applications** into competitive markets.

5. Employment considerations

The creation of manufacturing facilities for structural lightweight aggregates appears to be the most economically viable avenue to reduce the concentration of coal ash in legacy ash dams in the longer term. Creating the conditions for a market-based re-use of the stored coal ash as a valuable raw material in a circular economy framework could be an effective way to reduce the State government's contingent liabilities resulting from these dams, which the government owned and operated for nearly half a century.

Around each ash dam's aggregate manufacturing facility clusters of highly specialised factories for precast structural lightweight aggregate concrete products can be established with very little economic development support, which will also provide jobs for specialist engineers as the power stations wind down, while the new products boost existing civil and housing construction industries.

Based on conversations with interested industry representatives we ran some preliminary REMPLAN modelling. When $100M is invested in an aggregate factory that employs 75 people, the modelling shows that each job created generates at least one additional job. When an initial cluster of three specialised precasters forms around the aggregate factory with each precaster employing some 30 people, REMPLAN modelling shows that each of these 90 jobs creates on average another 3.7 jobs, which brings the total for

[25] The examples of Shepparton and Benalla in Victoria demonstrate how clusters of precast concrete product manufacturers can support each other in their specialisations.

[26] Vecor 2020b

one location to 573 full-time ongoing jobs. To this figure one would have to add the temporary jobs created in the construction of the four factories themselves in order to capture the full stimulatory effect of an initial investment of $100M to establish one aggregate factory.

The examples below illustrate the financial context of an investment of $100M in an aggregate factory at each of three selected power stations:

- AGL's **Bayswater Power Station** in the Upper Hunter Valley currently deposits 1.3 million tonnes of coal ash every year and has an ash augmentation project under review that is said to cost more than $50M. The documentation suggests a staged approach to the dam augmentation and efforts to develop re-use facilities for up to 1Mt of ash a year to minimise the need for augmentation.
  An early investment of $100M in an aggregate factory could avoid the cost of the ash augmentation project, enable a precast concrete cluster, provide a huge boost to the local economy and create over 500 jobs, and save almost $80M a year in load-based levy (set at half the price of N20 concrete delivered to Sydney CBD or around $60/t).
- Origin's **Eraring Power Station** on Lake Macquarie has received approval for an ash dam extension that is said to cost more than $100M and is expected to provide sufficient storage capacity until 2024 for the 800,000t of ash deposited per year. For a similar amount Eraring Power Station could initiate a whole new industry and create over 500 new jobs, generate operating income, start re-using some of their impounded ash, and avoid paying the load-based levy.
  The alternative would cost Eraring a similar amount for the ash dam extension (and more for a possible further extension past 2024), plus an ongoing $50M a year in load-based levy.
- Energy Australia's **Mt Piper Power Station** in Lithgow currently disposes of some 400,000t of coal-ash in a dry emplacement in an old mine creating dangerous issues with ground water that demand urgent attention.
  Rather than paying $25M a year in load-based levies to dispose of this coal ash every year, Mt Piper could create a new industry and over 500 new jobs, generate operating income and avoid the load based levy.

6. Conclusion

The combination of regulatory measures recommended in this report will allow the government of NSW to transform its liability for ash repositories into economic development measures that enable private industry to create some 3,000 long-term jobs in regional NSW.

The report shows that the suggested suite of regulatory measures does not need to unduly burden power station operators. They will be able to avoid the cost of infrastructure expenditure to store their ash as a waste product for the remaining life of their operation.

In collaboration with the building industry the power station operators can utilise their ash as a valuable raw material to produce a highly valued construction material and secure an ongoing income stream. This will secure the funding for the ongoing management of the ash dams until the ash is used up and any residual material is of a low enough concentration that it can be safely stabilised.

Implementing these seven recommendations together ensures that the environmental legacy of NSW's coal-fired power stations can be transformed into environmentally safe and useful products, and that the remediation costs for the heavy metals leaching into surface and ground water will be significantly reduced.

References

Ash Development Association of Australia, 2020, *Regional CCPS (Virtual) Workshop & Stanwell Pavement Trial Site Tour*, held online Wednesday, 19 August

Assi A, Bilo F, Zanoletti A, Ponti J, Valsesia A, La Spina R, Depero LE, and Bontempi E, 2020, Review of the Reuse Possibilities Concerning Ash Residues from Thermal Process in a Medium-Sized Urban System in Northern Italy, *Sustainability*, vol 12, 4193

Australian Bureau of Statistics, 2020, *Australian Industry 2018-19*, released 29 May 2020 (accessed 2 December 2020 via https://www.abs.gov.au/statistics/industry/industry-overview/australian-industry/2018-19#data-download)

Australian Standard, 2014, *Aggregates and rock for engineering purposes, Part 1: Concrete aggregates* (AS 2758.1:2014) (available from https://www.techstreet.com/sa/standards/as-2758-1-2014?product_id=2065959

Australian Standard, 2016, *Supplementary cementitious materials, Part 1: Fly ash (*AS/NZS 3582.1:2016) (available from https://www.techstreet.com/standards/as-nzs-3582-1-2016?product_id=2068643)

Beyond Zero Emissions, 2017, *Zero Carbon Industry Plan: Rethinking Cement*, (accessed 5 December 2020 via https://bze.org.au/)

Cement Industry Federation (CIF) 2020 *Australian Cement Report* (accessed 5 December 2020 via https://cement.org.au/)

City of Sydney, 2019, *Sydney Streets, Technical Specifications Version: 2019* (accessed on 5 December 2020 via https://www.cityofsydney.nsw.gov.au/design-codes-technical-specifications/sydney-streets)

Environmental Justice Australia, 2020, *Submission in response to New South Wales Public Works Committee Inquiry into the costs for remediation of sites containing coal ash repositories* (accessed on 6 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-submissions)

Haiping Chen, Xiangsheng Li, Jiadi Wei, Yijun Feng, and Dan Gao, 2019, Preparation and Properties of Coal Ash Ceramic Membranes for Water and Heat Recovery from Flue Gas, *Journal of Chemistry*, vol 2019, 10 pages (accessed on 6 December 2020 via https://doi.org/10.1155/2019/2403618)

Hossain SkS & Roy PK, 2020, Sustainable ceramics derived from solid wastes: a review, *Journal of Asian Ceramic Societies*, (accessed on 6 December 2020 via https://www.tandfonline.com/action/showCitFormats?doi=10.1080/21870764.2020.1815348)

Hunter Community Environment Centre, 2020, *Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories, Submission No 39* (accessed on 6 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-submissions)

Lake Macquarie City Council, 2020a, *Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories, Submission No 9* (accessed on 7 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-submissions)

Lake Macquarie City Council, 2020b, *Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories, Answers to Questions on Notice* (accessed on 7 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-otherdocuments)

Le Capitaine S & Carlson C, no date, *Fly Ash & the Lightweight Aggregate Market*, (accessed on 5 December 2020 via https://feeco.com/fly-ash-the-lightweight-aggregate-market/)

Mondal S, Ghar A, Satpati AK, Sinharoy P, Singh DK, Sharma N, Sreenivas T and Kain V, 2019, Recovery of rare earth elements from coal fly ash using TEHDGA impregnated resin, *Hydrometalurgy*, vol 185 (May) pp93-101

Pires dos Santos R, Martins J, Gadelha C, Cavada B, Albertini AV, Arruda F, Vasconcelos M, Teixeira E, Alves F, Filho JL, and Freire V, 2014, Coal Fly Ash Ceramics: Preparation, Characterization, and Use in the Hydrolysis of Sucrose, *The Scientific World Journal*, vol 2014 (7 pages) (accessed on 6 December 2020 via http://dx.doi.org/10.1155/2014/154651)

Polyagg Pty Ltd, 2020, *Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories, Submission No 84* (accessed on 7 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-submissions)

R.W. Corkery & Co Pty Limited, 2019, *Supply and Demand Profile of Geological Construction Materials for the Greater Sydney Region*. Report prepared for the NSW Department of Planning, Industry, and Environment

Shuming Wang, Caixing Zhang, & Jundan Chen, 2014, Utilization of Coal Fly Ash for The Production of Glass-ceramics with Unique Performances: A Brief Review, *Journal of Materials Science and Technology* – Shenyang, vol 30(12) 1208-1212 (accessed 6 December 2020 via https://DOI.org/10.1016/j.jmst.2014.10.005)

Transport for NSW, 2020a, *QA Specification 3211 Cementitious Materials, Binders and Fillers*, (accessed on 6 December 2020 via https://www.rms.nsw.gov.au/search-results.html?q=QA+SPECIFICATION+3211#gsc.tab=0&gsc.q=QA%20SPECIFICATION%203211&gsc.page=1)

Transport for NSW 2020b, *Responses to Post-hearing questions: Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories* (accessed on 6 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-otherdocuments)

Vecor Australia Pty Limited, 2020a, *Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories, Submission No 11* (accessed on 5 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-submissions)

Vecor Australia Pty Limited, 2020b, *Inquiry into Costs for Remediation of Sites Containing Coal Ash Repositories, Answers to Questions on Notice* (accessed on 5 December 2020 via https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2556#tab-otherdocuments)

Ward C, Heidrich C, and Yeatman O (eds), 2014, *Coal Combustion Products Handbook*, Ash Development Association of Australia (2nd edition)

Widmer NC, Gauthier PJ, Moyeda DK, Payne R, and Seeker WR, 2005, Combustion Tuning Systems for Control of Unburned Carbon, Paper presented at World Coal Ash (WOCA), Lexington, Kentucky, April 11-15 (accessed on 7 December 2020 via http://www.flyash.info/AshSymposium/AshLibraryAgenda.asp#2005)

Winn P, 2020, *Out of the Ashes II: NSW water pollution and our ageing coal-fired power stations,* Hunter Community Environment Centre (accessed on 6 December 2020 via https://www.hcec.org.au/out-of-the-ashes-ii)

Yliniemi J, Paiva H, Ferreira VM, Tiainen M, and Illikainen M, 2017, Development and incorporation of lightweight waste-based geopolymer aggregates in mortar and concrete, *Construction and Building Materials* vol 131 pp784-792

Zhang W, Noble A, Yang X, 2020, A Comprehensive Review of Rare Earth Elements Recovery from Coal-Related Materials, *Minerals*, vol 10(5), p451ff (Special Issue Leaching of Rare Earth Elements from Various Sources)

Zulkifli SNA, Mustafa A, Othman MHD, and Hubadillah SK, 2019, Characteristic properties of ceramic membrane derived from fly ash with different loadings and sintering temperature, *Malaysian Journal of Fundamental and Applied Sciences*, Vol. 15, No. 3 (2019) 414-420