Ash Development Association of Australia

COAL ASH matters

17 NOV

THIS ISSUE - NOV 2017

CCPs - *a valuable resource*

www.adaa.asn.au

IMAGE: Dr Liza O'Moore (University of Queensland) and Mr Craig Heidrich (Ash Development Association of Australia) receiving their Life Membership Awards at the Concrete 2017 Gala Dinner.

Ash Development Association of Australia

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Membership

COMPANY MEMBERS

A primary role of the ADAA is to bring together producers and marketers of coal combustion products (CCPs). Our activities cover research and development into CCP usage, advocacy and technical assistance to CCP producers and users, as well as a forum for the exchange and publication of CCP information.

For more information on the Association, visit us at **www.adaa.asn.au**

CURRENT MEMBERS

- BG&E Materials Technology
- Boral Quarries & Recycling
- Brickworks Ltd
- CS Energy
- Delta Electricity
- Golden Bay Cement (New Zealand)
- Heeleys Consulting
- Hyrock (NSW)
- Intergen (Millmerran)
- Latrobe Magnesium
- NRG Gladstone Power Station
- Origin Energy Eraring Power Station
- Sphere One
- Stanwell Corporation
- Synergy
- Vecor Australia

RECIPROCAL MEMBERSHIPS

- CSIRO www.cmit.csiro.au
- Association of Canadian Industries Recycling Coal Ash (CIRCA) www.circainfo.ca
- European Coal Combustion Products Association (ECOBA) www.ecoba.org
- UK Quality Ash Association www.ukqaa.org.uk
- American Coal Ash Association www.acaa-usa.org
- World Wide Coal Combustion Products Network (WWCCPN) www.wwccpn.org

Editorial

The Ash Development Association of Australia (ADAA) is pleased to showcase the latest coal combustion product (CCP) news from across Australia and the World for readers in this edition of Coal Ash Matters.

In review, it's been another productive year for the Ash Development Association of Australia (ADAA) and our members are continuing to advocate strongly for the use of coal combustion products (CCPs) in an ever-expanding range of applications. First up, the Concrete Institute of Australia has granted Life Membership to Craig Heidrich for his 20+ years support to the Concrete industry and the Institute.

In other good news, the Association's involvement in the Cooperative Research Centre for Low Carbon Living continues with the $3.1 million research project now producing multiple positive results throughout the variety of papers. Later we provide an update on CemAssure and its objectives to provide assurance to the industry and deliver quality products to the Australian market.

Also in this edition, we take a look at multiple projects currently underway in the U.S, including the American Coal Ash Association Educational Foundation (ACAAEF) Scholarship Program and the Coal Combustion & Gasification Products Journal (CCGP). The GGCP is an international peer-reviewed, online journal encompassing the science and technology of the production, sustainable utilisation, chemistry, and environmentally sound handling of all byproducts.

Each year, the ADAA conducts an annual survey for information regarding CCP production and sales by members and non-members for each calendar year to determine the utilisation of CCP's annually. Information provided by members and non-members is collated and then aggregated into a national set of results and include CCP production levels, and nominated uses for all CCP's. The results of the 2016 survey have been included in this edition of Coal Ash Matters for your consideration.

Educational events were also in abundance this year with a number of conferences available for Association members and industry stakeholders to attend. Conference reports are provided later in this edition for the Coal Ash Asia (CAA) Conference which the Association attended in some form.

Some time in November 2017, we will be relocating our office to **Unit 5, 41-47 Five Islands Road, Port Kembla, 2505 NSW**. The phone numbers and email addresses will remain the same at 02 4228 1389 and info@adaa.asn.au.

Finally, the Association would like to wish its members a safe and happy Christmas and New Year. We look forward to continuing our work with you in 2018 to further the use of Coal Combustion Products.

Best Regards,

Aiden Chilcott

CONCRETE 2017
ADVANCES IN CONCRETE MATERIALS AND STRUCTURES

The Concrete Institute of Australia's Biennial National Conference, Concrete 2017 was held at the Adelaide Convention Centre, from 22nd October, 25th October, 2017.

Craig, Carol and Aiden (HBM Group) travelled from Sydney to Adelaide on Sunday, proceeded to bump in at approximately 4pm, and were then ready for an early start on Monday morning. The exhibit included displays of sample materials, product/membership information, past editions of Coal Ash Matters as well as lollies and the famous USB man. An iPad was used to feature the Association's website and proved a useful tool in demonstrating to delegates how simple it was to find product, member and safety information online.

The Conference began with registrations at 8.00am with the plenary sessions underway by 9.00.am. The Ash Development Association of Australia booth was manned during all breakout sessions. Over the duration of the Conference, many domestic and international delegates were keen to ask technical questions in regard to the end uses of the products displayed.

Conference highlights included
- 8 keynote speakers
- 525+ registrants networking, including 140+ international delegates
- 59 exhibiting companies, 17 sponsors
- 158 technical papers

The theme of the conference, "Advances in Concrete Materials & Structures" covered topics such as materials, research, design, construction and innovation. The Conference provided a forum for the sharing of ideas and experience through the formal presentations, industry displays and contact between delegates. It was the concrete industry's pre-eminent technical and social event in the southern hemisphere for 2017.

The three-day conference included 4 parallel sessions each day, providing delegates with every opportunity to attend papers on topics related to their specialities or key areas of interest. The program included the following (but not limited to) themes and topics:

- Durability – a key focus with a number of international speakers from ICDC
- Case Studies & Major Projects
- Materials (incl. cement technology, SCM's, aggregates, geopolymers)
- Structures behaviour and design
- Reinforcement materials
- Repair and retrofit
- Constructability and concrete construction
- Innovations (incl. 3D printing, UHPC, recycled materials)
- Precast concrete
- Environmental and sustainability

At the conference, the Concrete Institute of Australia also announced that Concrete 2019 would be held in Sydney. Times flies... We'll see you there!

CRAIG HEIDRICH AWARDED **LIFE MEMBERSHIP OF CIA**

At the Concrete 2017 Gala Dinner, Craig Heidrich (CEO) was awarded life membership of the Concrete Institute of Australia. The Council of the Concrete Institute of Australia makes Awards for Life and Honorary Membership to recognise people who have made significant contributions to the Concrete Industry. **Well done Craig!**

AWARDS FOR EXCELLENCE 2017

Every two years, the Concrete Institute of Australia recognises excellence in the development of concrete technology and practice in Australia at its Biennial National Conference. Winners of state-based projects proceeded to the National Awards at Concrete 2017 'Advances in Concrete Materials'.

The Biennial Awards Scheme was established to not only recognise the many significant contributions to the development of concrete technology and practice in Australia, but to foster improvements in the standard of concrete construction and to publicize the many excellent examples of concrete structures erected in Australia!

The big winner on the night was the Song School, Submitted by SA Precast. The prefabricated concrete church is truly a magnificent sight.

The Awards events are an excellent opportunity for all Members of The Institute. For established professionals, it is an ideal platform to see the latest and greatest in concrete research, technology, design and application. For Student Members or recent Graduates, this is an extremely valuable opportunity to build your connections with the wider industry, and hear from high calibre industry experts.

The ADAA congratulates SA Precast and invites you and to join us to help celebrate excellence in the application of concrete and to meet those organisations who are developing, designing and delivering concrete solutions across Australia.

Read more: concrete2017.com.au

WORLD WIDE COAL COMBUSTION PRODUCTS NETWORK - THE GLOBAL OPERATING ENVIRONMENT

At the World of Coal Ash 2017 Conference in the United States, CEO Craig Heidrich presented the following report to a plenary of +1,100.

ABSTRACT

Whenever coal is burnt, coal combustion products are produced by the thermal transformation of the mineral matter present into amorphous inorganic oxides. Large-scale use of coal in power generation gives rise to significant quantities of coal combustion products from which important 'hard won' end use markets have been established.

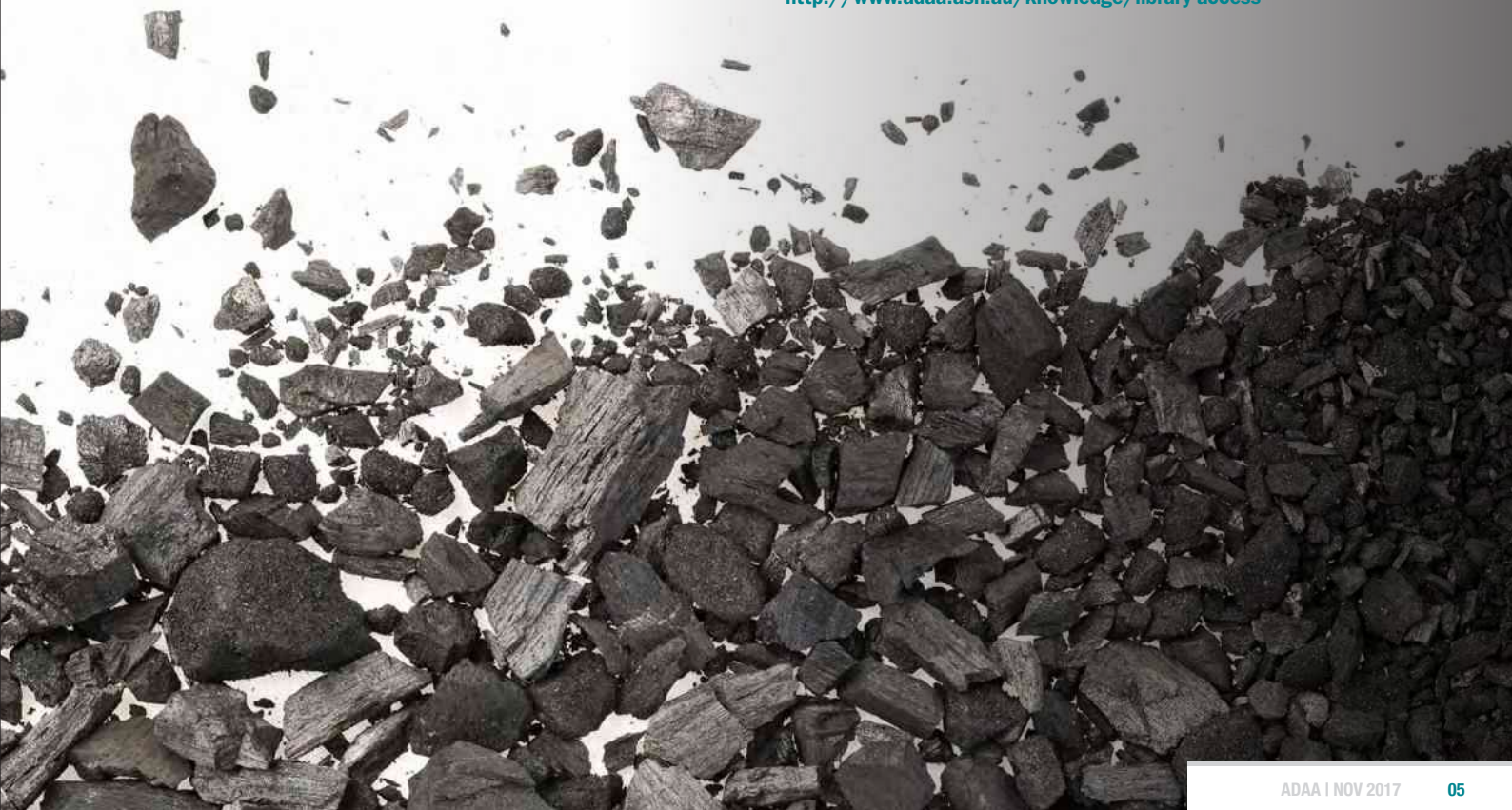
Existing and proposed end use markets for coal combustion products (CCPs) are not only of critical importance to the economics of power generation, but also to the established supply chain participants which have invested, researched, developed and promoted CCPs into various end use markets, for example the construction sector use large quantities. Globally, the continued growth in utilization of CCPs is dependent on many factors beyond the quality and characteristics. Appropriate legislation and regulation coupled with the development of international classification systems, standards and codes of practice are only a few of the important enablers for easing the way towards increasing utilization and securing the 'legal certainly' for continued investment.

The paper updates the 2013 report (Heidrich et al 2013) and discusses changes in the global operating environment for CCPs, the growing role of coal in energy production, changing environmental paradigms for emerging industrialized economies such as India and China. The paper updates global CCP production and utilization including volume and value of international trade. An overview of country-specific classification systems for CCPs will be discussed, moreover the important and emerging role of legislation in creating legal certainty for the ongoing investment in CCPs management and market development.

DETAILS

The paper has been jointly written by members of the World Wide Coal Combustion Products Network and is the result of an ongoing, international collaboration between respective country industry associations, being non-governmental organizations (NGO's), to inform the public, industry and governmental entities about the beneficial environmental, technical and commercial uses of CCPs.

Head to the ADAA Library to download the full paper:
http://www.adaa.asn.au/knowledge/library-access



NEW MEMBER - SPHERE ONE

Sphere One's goal is to always provide the highest quality products and services to our customers by establishing and reviewing quality objectives.

To accomplish this, they utilize Continuous Quality Improvement techniques to understand customer needs and requirements and continually improve the effectiveness of the quality management system.

Sphere One offers a number of CCPs, some of which are shown below.

Extendospheres®

Sphere One's lightweight Extendospheres® maintain low specific gravity without sacrificing strength. These low-density products allow the formulator to reduce their overall cost and the density of their finished goods.

Benefits:

- Reduced product cost
- Lower density
- Improved material flow
- Reduced shrinkage & warpage
- Impact resistance
- Improved sound and thermal insulation
- Environmentally friendly.

Solid Ceramic Spheres - Solospheres

Sphere One Solospheres are semi-solid ceramic microspheres. They are an excellent choice for applications requiring high strength, high temperature, and corrosion resistance. Solospheres spherical morphology are shear thinning in liquid applications allowing formulator to reduce the VOC's and increase filler loading. Solospheres can easily disperse in a high intensity mixing or dispersion system in plastics. Their unique nature makes them suitable for some applications such as; Corrosion and abrasion resistance, flame retardant, coatings, refractory castings and coatings, self-leveling cements, and many more applications.

Learn more about Sphere One here: http://www.sphereone.net

Coal Combustion and Gasification Products

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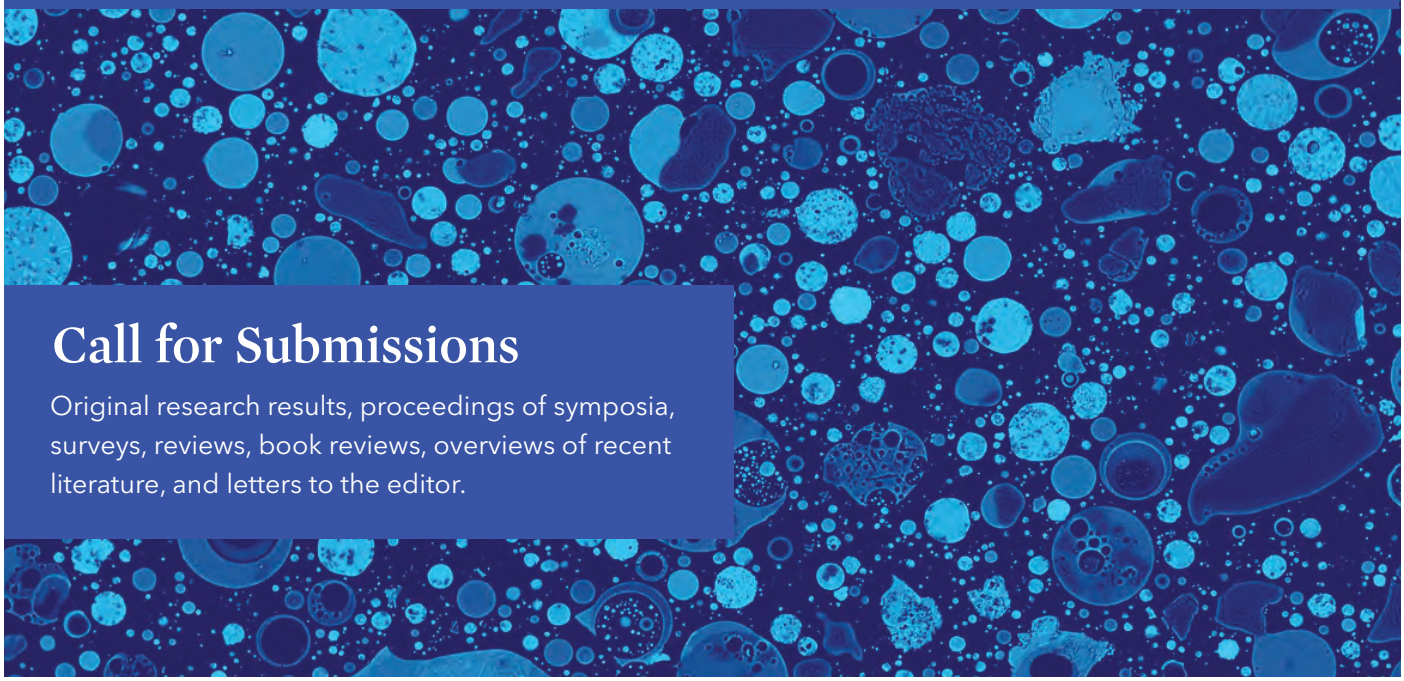
CCGP is a joint publication between the University of Kentucky Center for Applied Energy Research and the American Coal Ash Association.



Call for Submissions

Original research results, proceedings of symposia, surveys, reviews, book reviews, overviews of recent literature, and letters to the editor.

About CCGP

CCGP is an international peer-reviewed, online journal encompassing the science and technology of the production, sustainable utilization, chemistry, and environmentally sound handling of all byproducts.

The CCGP Journal is free to publish, and the journal is available online.

Topics of Interest

- Fly Ash
- Bottom Ash
- Boiler Slag
- Geotech
- FGD Products
- Ponds
- Beneficial Use
- Landfills
- Chemistry
- Regulations
- Gasification Residues
- Mining and Reclamation
- Cement and Concrete
- Construction Materials
- Disposal
- Aggregates
- Chemical Classification
- Rare Earth Elements
- Coal-Fuel Blend By-Products
- Groundwater and Environment

Website:
CoalCGP-Journal.org

Extended abstracts of all accepted papers are published in the ACAA online magazine Ash at Work:
https://www.acaa-usa.org/Publications/Ash-at-Work.

CEMASSURE™
THE CONFORMITY ASSESSMENT SCHEME

The cementitious products industry has a strong record of delivering quality products to the Australian construction industry for over 130 years.

The industry also recognises the need to provide knowledgeable and competent advice as to the properties and performance of its products. Therefore a conformity assessment scheme has been devised to utilise much of the existing product quality systems and provide an informed overview from skilled assessors as to the compliance of cementitious materials with prevailing Australian Standards.

CemAssure will be established as a not-for-profit company limited by guarantee for the purpose of providing third-party assessment of the conformity of dispatched product for cement, Fly Ash, Slag and Amorphous Silica products.

It is a Type 5 product certification scheme for tangible products as described in ISO/IEC 17067 Conformity assessment – Fundamentals of product certification and guidelines for product certification schemes. Further, it will be endorsed by JAS-ANZ conforming to AS/NZS ISO/IEC 17065 Conformity Assessment – Requirements for bodies certifying products, processes and services.

Conformity is assessed against the provisions of Australian Standard, AS 3972 – General purpose and blended cements and AS 3582 – Supplementary Cementitious Materials.

The conformity of products will be assessed quarterly by a Certified Assessment Body (CAB) engaged by the CemAssure Board and accredited to AS/NZS ISO/IEC 17065 Conformity Assessment – Requirements for bodies certifying products, processes and services.

The conformity of cementitious products will be assessed by inspection of test reports for individual products, laboratory accreditation reports and the results of a yearly coordinated material test program. Confirmation of sampling requirements for products under test will also be performed in the course of the audit visit.

The CemAssure scheme has been developed on the strong foundation of responsible cementitious materials supply in Australia. It draws in the existing practices utilised by material suppliers and then overlays a competent and informed review of product performance to ensure that all prescriptive and performance requirements are met.

For a supplier, it provides evidence that their nominated product has been competently assessed against the required material specifications by a third party. Therefore, in answer to an increasing demand for third part conformity assessment, the supplier can claim and produce proof of an independent review.

For more information contact Warren South at warren.south@ccaa.com.au

COAL ASH ASIA 2017

In July, CEO Craig Heidrich attended Coal Ash Asia in Beijing, China at the Sheraton Grand Beijing Dongcheng Hotel Beijing. The conference brought together global industry leaders to share knowledge and develop highest value solutions for managing and utilising Coal Combustion Products.

More than 600 attendees from 15+ countries attended the conference, exhibition and seminar series. Researchers, managers, technology providers, technology buyers, power producers and governments all gathered to develop a deeper understanding of industry best practices and discuss the challenges and emerging opportunities in the CCP utilisation industry.

Part of the conference included a visit to the world largest Coal fired power station located within Inner Mongolia which boast a very impressive coal ash resource reprocessing facility. In particular, the international delegation was given an up close tour of the alumina extraction operation. Built in 2012 the facility extracts alumina from coal ash to be used by the automotive manufacturing industry.

Mr Bill Martin, Bilmar Solutions, a regular attendee commented "anyone interested in learning more about global industry trends, technical developments or engaging with coal ash and construction material supply chains Coal Ash Asia is an excellent forum. I was very impressed by the number and diversity of the participants at Coal Ash Asia. There were hundreds of experts and executives from all aspects of industry, academia and government. The atmosphere and attitude were very friendly, with participants very focused on industry issues and actively engaged in discussion and exchange."

Conference Topics Included:

1 Metal extraction
- Aluminium Extraction
- Other metal extractions

2 FGD Gypsum Utilization
- Gypsum drying and Calcination
- Construction Applications: gypsum block, board, mortar
- Agricultural applications
- High Strength Gypsum, etc

3 Coal Ash Processing and Utilization
- Grinding, Classifying and Superfine grinding
- Cement, Concrete, Wall Materials and Geopolymer
- High-Value Utilizations: Ceramics, Cenospheres, Fillers
- Sulphoaluminate cement CalciumSulpho Aluminate

4 Coal Gangue and Coal Chemical Residue
- Processing and Utilization

Copies of the conference proceedings and selected published papers can be requested from the Association.

Read more: http://www.asiancoalash.org

GEOPOLYMER HANDBOOK

A Guide to Specification and Use of Geopolymer Concrete

Did You Know?

The manufacture of General Purpose Cement (GPC) is the second largest emitter of carbon emissions, globally. In Australia, GPC is responsible for 7.2 million tonnes of carbon emissions, according to industry data.

As these alarming figures increase, groups such as the ADAA and the Cooperative Research Centre for Low Carbon Living (CRC-LCL) are investigating ways in which concrete can be manufactured with low or even no carbon emissions. A promising method to achieve these targets is through the development of Geopolymer Concrete.

Geopolymer Concrete employs materials such as fly ash (FA) and iron and steel slags to replace large amounts of GPC in concrete, without reducing its performance as a building material. Using a range of activators and pozzolans, results continuously show that this altered formula of concrete is not only an effective way to reduce carbon emissions (approximately 80% carbon reduction) but it can also reduce costs.

Currently, there is believed to be a lack of knowledge within the construction industry concerning how Geopolymer Concrete can be functional in large-scale projects. The primary cause of this is the lack of publically available information about Geopolymer Concrete. To counter this, the Association (ADAA), in partnership with CRC-LCL and other like-minded organisations, have been working to publish a Geopolymer Concrete Handbook. The Handbook will be published through Standards Australia and designed to assist engineers and users about how to use Geopolymer Concrete with greater confidence and less risk. The Handbook will also build on other published information such as the Recommended Practice prepared by the Concrete Institute of Australia.

The Handbook “Guide to Specification and Use of Geopolymer Concrete” will include:

- Background
- Properties and applications
- Relevant standards
- Recommended performance test methods
- Case histories and long-term durability
- Performance-based specification

The production of the Handbook aims to remove major barriers to the use of low carbon Geopolymer Concretes and profoundly increase their use in the construction industry. Based on research previously conducted, having a standard specification is the highest priority to enable the industry to adopt Geopolymer Concrete in the near future.

The Geopolymer Handbook is expected to be completed in 2018.

AMERICAN COAL ASH ASSOCIATION

SCHOLARSHIPS AVAILABLE

ACAA

The American Coal Ash Association Educational Foundation (ACAAEF) has announced the 2017 - 2018 Scholarship Program for students who have an interest in advancing the beneficial use of coal combustion products.

The ACAAEF intends to award two individual scholarships: a one-time $5,000 award and a one-time $2,500 award to recognize outstanding students pursuing undergraduate or graduate degrees from an accredited program in the United States. The awards will be based on essays, coursework, academic credentials, recommendations and a demonstrated interest in the utilization of coal combustion products. Applications will be accepted from September 1, 2017, through October 23, 2017.

A third scholarship may be awarded at the ACAAEF discretion with a preference toward undergraduate students as an effort to increase awareness, experience and understanding of CCP management and utilization opportunities.

Information and application materials will be available on the ACAAEF website **(http://www.acaa-usa.org/About-ACAA/Educational-Foundation)** beginning August 14, 2017. Scholarship recipients will be invited to present at the 2018 ACAA Winter Meeting in January 2018 and have their essays published in Ash at Work magazine.

Scholarship application materials and instructions can be found on the ACAA website at: **www.acaa-usa.org/About-ACAA/Educational-Foundation.**

JAMIE NORTH - REMAINDER NO. 15

Remainder No.15 was created out of cement and blast furnace slag provided by ASMS, from which a mould was created and a bronze cast produced. This sculpture will form part of a larger commission of similar spheres for 105 Phillip Street, Parramatta, a new building that will have the NSW Department of Education as it's principal tenant.

For more information, visit: **http://jamienorth.com**

MEMBERSHIP SURVEY
CCP UTILISATION

The ADAA conducts an annual survey for information regarding CCP production and sales by members and non-members for each calendar year to determine the utilisation of CCP's annually. Information provided by members and non-members is collated and then aggregated into a national set of results and include CCP production levels, and nominated uses for all CCP's.

The survey results include all generators, marketers, (processing and marketing companies) and users for the total production and resulting sales for each end use.

The beneficial use of coal combustion products (CCPs) during 2016 resulted in 5.35 million tonnes or 43% being effectively utilised. The conservation of energy, finite natural resources, the reduction of carbon emissions and the effective recovery of mineral by-product resources that would otherwise be placed into long-term storage were all major benefits.

The survey results for CCP production and categorised end uses for the period January to December 2016 are shown in Table 1.

From the 12.3 million tonnes of all CCPs produced 43% of were effectively utilised within various civil and construction applications throughout Australia.

CCPs production has remained stable over the past 4 years, reversing the overall decline in the use of coal as a major energy source arising from wide ranging environmental reforms, renewable energy target and state government privatisation agenda over the past several years. CCP utilisation over the periods of 2010, 2011, 2012, 2013 2014 and 2015 have grown slightly with effective utilisation being 41%, 48%, 42%, 52%, 48% and 48% respectively.

Annual members and non-members were surveyed for CCPs generated, stored and sold during the reported period, which provides results for the calendar year, January to December 2016. Information provided by members and non-members was collated, compared with other data sources for verification purposes and then aggregated into national data set. The import and export of CCPs were included, however sources and destinations are not identified.

DISCUSSION OF RESULTS

Total CCP generation for the period has increased slightly from 12.1 (2015) million tonnes to 12.3 (2016) million tonnes. Some contributing factors are related to; the importation of CCPs from China and India, coupled with an uplift in based-load demand at site where CCPs can be captured, processed and removed for beneficiation.

The 5.35 million tonnes utilised during 2016 is partly a function of the continued demand within the supply chains for cement and concrete. The principle utilisation end uses continue to be attributable to 'graded' (See AS 3582.1 and AS 2758) materials used in cement and concrete, structural/ civil applications and mining applications such as mine site remediation, with growth in Category 2 and 3 sales for 'ungraded' materials.

Ongoing regulatory reform advocated by the Association focuses on new end use market opportunities for 'ungraded' material applications. Coupled with changes to AS3582.1 and AS 2758, these end use applications in 2017.

The use of CCPs such as fly ash has been proven to significantly contribute to further reducing the carbon footprint of the cement and concrete sector, but only where additional processing capacity can meet demand, coupled with supply chain inventory capacity and exploitation of large volumes of stored materials within ash dams to buffer the supply chain.

Demand for fine and coarse aggregate use in structural/civil applications continues to be closely tied to consumption or growth in the future development of infrastructure in both urban and regional Australia – estimated to be in excess of 160 million tonnes annually. Extractive resources are generally widespread and remain in adequate supply nationally, however, shortages in important large-scale markets (Sydney, Melbourne and Brisbane) are emerging, requiring additional logistics and associated costs. These are mainly attributed to unsuitable geology, conflicting or incompatible land uses and environmental problems caused by high rates of urban expansion. Natural sand and gravel resources are also being depleted leading to opportunities for substitution by ungraded CCPs.

There has been a considerable increase in interest from extractive industries to supplement natural sand and gravel resources with recovered resources such as CCPs, which is an area of considerable focus within the Association with the Cooperative Research Centre for Low Carbon Living research projects.

KEY RESULTS

The survey results include all generators, marketers and users for the total production and resulting sales for each end use. Where required, data was supplemented with importation data and other secondary data sources for accuracy purposes.

1. Approximately 12.3 Mt (million tonnes) of CCPs were produced within Australasia. On a per capita basis, this equates to approx 501 kg/person. (12.1Mt/24.13M population)

2. Some 5.35 Mt or 43% of CCPs produced have been effectively utilised in various value-added products or to some beneficial end over the period. On a per capita basis, this equates to approx 221 kg/person recycled or reused.

3. Approximately 1.8 Mt or 68% of effectively utilised coal ash was used in high value-added applications such as cementitious binders, concrete manufacture or mineral fillers.

4. About 0.48 Mt or 18% of effectively utilised coal ash was used in non-cementitious applications such as flowable fills, structural fills, road bases, coarse/fine aggregates and mine site remediation.

5. Some 2.3 Mt or 19% was used in projects offering some beneficial use (e.g. on site remediation, local haul roads etc.). These uses typically generate no economic return, that is, cost avoidance or recovery only.

6. Surplus CCPs of 9.4 Mt are typically placed into onsite storage ponds awaiting some future opportunity for economic reuse.

7. More than 47 Mt of CCPs [fly ash] have been used in cementitious applications or concrete manufacture from 1975 to 2016 [40 years].

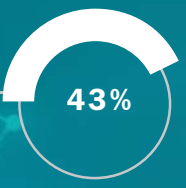
8. If all 47 Mt of CCPs was placed into 1 tonne bulker bags (84cm x84cm x 84cm) and placed in a straight line, the bags would circle the earth's circumference once.

In summary, the recovery and reuse of CCPs provide positive and significant environmental impacts, including resource conservation and in this case, the reduction of Greenhouse Gas emissions from the processing of virgin resources, resulting in the reduction of greenhouse gases.

The following table provides more detail for individual category sales of CCPs for the 2016 calendar year.

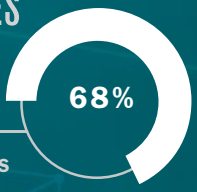
12.3 MILLION TONNES CCPS PRODUCED WITHIN AUSTRALASIA

5.35 MILLION TONNES OF CCP UTILISED
WITHIN VARIOUS CIVIL AND CONSTRUCTION APPLICATIONS



221KG PER PERSON RECYCLED OR REUSED

1.8 MILLION TONNES OF COAL ASH UTILISED
IN HIGH VALUE-ADDED APPLICATIONS



47 MILLION TONNES OF CPPS USED FROM 1975-2016
IN CEMENTITIOUS OR CONCRETE MANUFACTURE

ASH DEVELOPMENT ASSOCIATION OF AUSTRALIA
2016 MEMBERSHIP SURVEY - CCP PRODUCTION & USE SURVEY

Section A. Fuel or Coal Used	Tonnes Consumed	Avg % Ash Content	Ash (Auto-Calc)	Ash (Manual Calc)																
A1: Bituminous (Black Coal)	46,704,637	24%	11,340,328																	
A2: Sub-bituminous	12,310,444	18%	2,189,936																	
A3: Lignite (Brown Coal)	53,413,116	2%	1,071,413																	
Total Coal Burned (Auto-Calc)	112,428,197	13%	14,601,677																	
Section B. CCPs Beneficial Use Calculations (Tonnes)	Fly Ash	Furnace Bottom Ash	Cenospheres	Combined 2016		Combined 2015		Combined 2014		Combined 2013		Combined 2012		Combined 2011		Combined 2010		Combined 2009		Combined 2008	
B1. Total Produced (Jan-Dec)	10,960,982	1,335,998	50,481	12,347,461		12,418,366		12,384,140		12,264,395		12,797,331		13,680,219		14,076,233		13,755,682		14,638,323	
B2. Total not used [Stored]	8,472,478	882,177	9,058	9,363,714		9,601,852		8,634,847		8,276,419		9,755,479		9,421,266		10,365,700		9,053,178		12,246,852	
Total Production Used (Auto-Calc)	2,488,504	453,820	41,424	2,983,748		2,816,514		3,746,293		3,987,975		3,041,852		4,258,953		3,710,533		4,702,504		2,391,471	
B3. Amounts removed or diverted from storage	2,371,976	154	210	2,372,340	19%	2,322,908	18%	2,187,498	18%	2,365,284		2,343,291		2,368,626		2,101,983		2,037,200		2,192,625	
Total of All Used (Auto-Calc)*	4,860,479	453,975	41,634	5,356,087	43%	5,139,422	48%	5,933,701	48%	6,353,259	52%	5,385,143	42%	6,627,579	48%	5,812,516	41%	4,702,504	34%	4,584,096	31%
Section C. CCP Use (Tonnes)	Fly Ash	Furnace Bottom Ash	Cenospheres	Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)	
C1. Cement/Concrete Products/Grout	1,764,926	136,437	22,182	1,795,365		1,589,976		1,738,590		1,647,317		1,893,613		2,029,563		1,889,991		1,571,495		1,757,379	
C1. Cement/Raw Feed for Clinker	-	-	-	-		10,000		10,000		10,000		0		61,174		0		0		0	
C1. Mineral Fillers	-	-	20,000	20,000		23,023		70,000		25,000		10,000		35,879		0		0		30,000	
Category 1	1,764,926	136,437	42,182	1,815,365	68%	1,622,999	67%	1,818,590	67%	1,682,317	66%	1,903,613	79%	2,126,616	73%	1,889,991	77%	1,571,495	71%	1,787,379	79%
C2. Flowable Fill CLSM	-	71,337	-	71,337		80,000		9,000		0		0		180,715		35,000		22,180		215,000	
C2. Structural Fills/Embankments	-	69,847	-	69,847		39,000		129,108		135,813		123,108		95,515		103,505		12,820		227,821	
C2. Road Base/Sub Base	59,718	142,150	-	11,305		189,718		188,718		229,615		115,300		295,899		320,334		476,360		0	
C2. Soil Modification/Stabilisation	-	11,305	-	11,305		0		0		31,000		41,000		0		11,725		10,936		30,000	
C2. Mineral Filler in Asphalt	-	-	-	-		21,000		20,000		0		0		0		8,878		8,787		7,209	
C2. Agriculture	-	1,117	-	1,117		4,117		76,117		1,259		600		600		0		0		0	
C2. Aggregate	-	123,505	-	123,505		156,000		224,000		181,000		123,000		20,000		5,708		708		0	
Category 2	59,718	419,261	-	478,979	18%	489,835	24%	646,943	24%	578,687	23%	403,008	17%	592,729	20%	485,059	20%	531,791	24%	480,030	21%
C3. Mining Applications (e.g. Backfill)	134,000	99,807	-	233,807		134,000		153,615		166,979		81,000		166,775		83,000		107,500		275	
C3. Waste Stabilisation/Solidification	126,000	-	-	126,000		126,000		106,000		106,500		34,500		15,913		6,446		6,443		8,991	
C3. Miscellaneous/Other	1,000	-	-	1,000		1,000		1,500		1,500		2,000		0		1,500		0		0	
Category 3	261,000	99,807	-	360,807	14%	261,000	10%	261,115	10%	274,979	11%	117,500	5%	182,688	6%	90,946	4%	113,943	5%	9,266	0.4%
Total Use (C1, C2, C3)*(Auto-Calc)	2,085,644	655,505	42,182	2,655,151		2,373,834		2,726,648		2,535,983		2,424,121		2,902,033		2,465,996		2,217,229		2,276,675	
Section D. Summary Results	Fly Ash	Furnace Bottom Ash	Cenospheres	Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)		Combined (Auto-Calc)	
7. Total of All Sold (Auto-Calc)*	2,085,644	655,505	42,182	2,783,331		2,373,834		2,726,648		2,535,983		2,424,121		2,184,018		2,184,018		2,217,229		2,276,675	
6. Total of All Beneficially Used (Auto-Calc)*	4,860,476	453,975	41,634	5,356,087	37%	5,139,422		5,933,701		6,353,259		5,385,143		6,627,579		5,912,516		4,254,429		4,469,300	

TABLE 1 - 2016 CCP SALES AND PRODUCTION SURVEY†

†Data presented in this table is aggregated based on member and non-member responses. Where appropirate, estimates are given based on published public reports. Coverage of data represents all coal fired power stations currently operating.

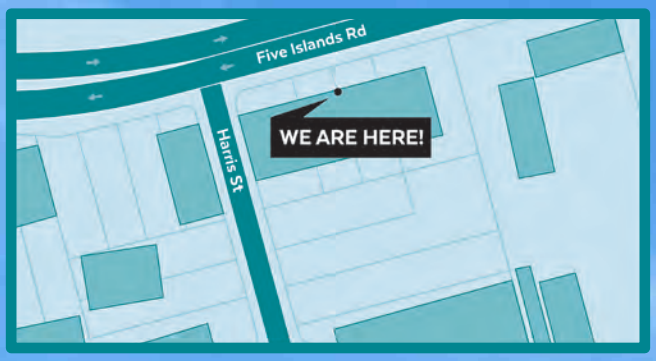
NEW HEADQUARTERS

It's with great anticipation and pleasure to let you know that in November 2017, the ADAA will relocate its office to Unit 5, 41-47 Five Islands Road, Port Kembla, 2505 NSW. The phone numbers and email addresses will remain the same at 02 4228 1389 and info@adaa.asn.au. The new location is close to the Wollongong CBD and will provide you with plenty of convenient parking.

Feel free to contact us with any questions you may have concerning the new location or our services. We look forward to hearing from you.

New Address:

Unit 5, 41-47 Five Islands Road,
Port Kembla, 2505, NSW.



COAL COMBUSTION *Products Factbook*

In May 2015 the ADAA FactBook went live on Apple, Google and Amazon platforms. The text offers readers a comprehensive understanding of the basics of fly ash and other important information about coal combustion products.

The FactBook employs a simple 'story telling' methodology to disseminate complex ideas. The eBook is available on mobile and tablet devices, meaning you will have all you need to know about CCPs right there in your pocket.

The FactBook covers the essential beginners pack to understanding CCPs including:

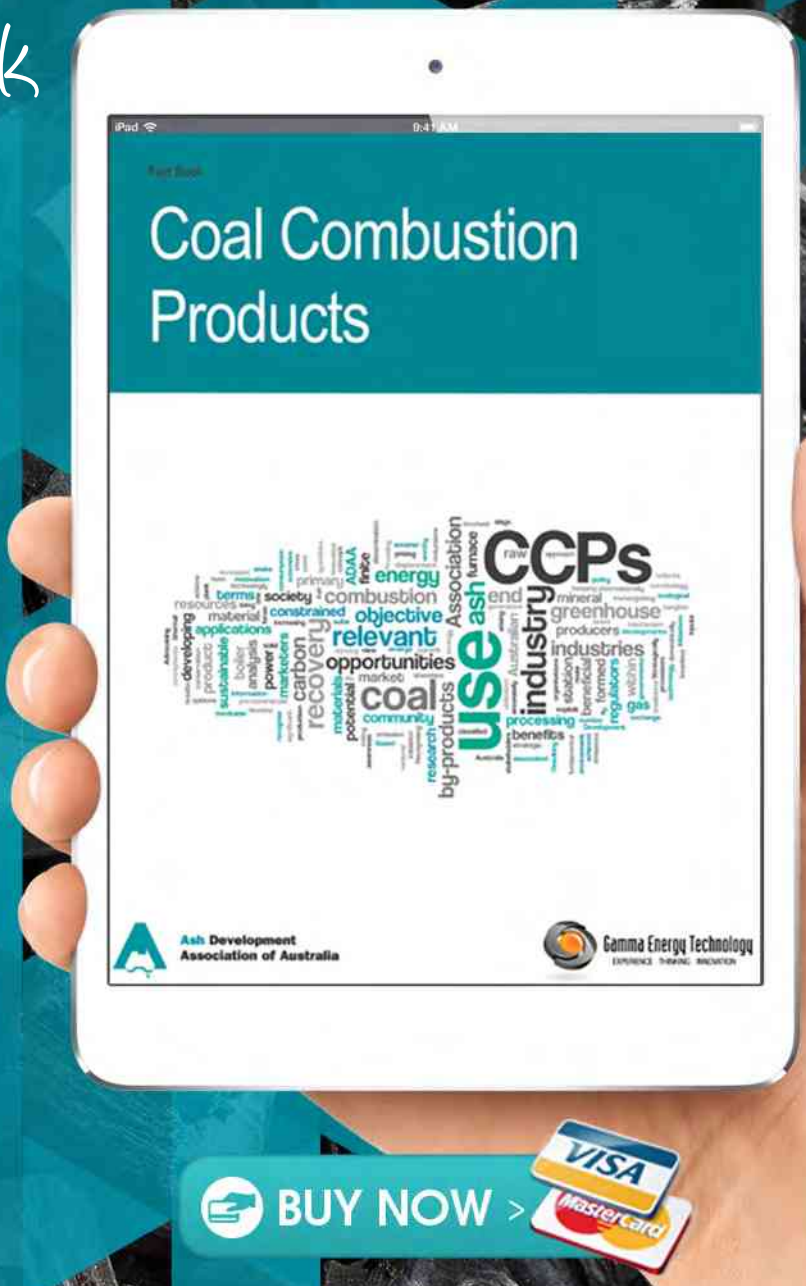
Coal Combustion Product Summary
"Australia produces approximately 13 million tonnes of coal combustion products annually. The majority of this material is not beneficially used despite a range of utilisation opportunities."

Coal Formation
"The quality, quantity and location of coal is not uniformly distributed and the nature of the mineral matter also varies significantly."

Coal Combustion Product Collection
"Fly ash constitutes up to 90% of the coal combustion products from a coal-fired power station."

Coal Combustion Product Use
"There are mature industries which utilise coal combustion products - some require simple transformation, others more elaborate processing."

Coal Combustion Product Volumes
"Of the 780 million tonnes of coal combustion products generated worldwide, some 49% was beneficially utilised in 2014."



FREQUENTLY ASKED QUESTIONS

Q. What is a FactBook?
A. It is a proven, simple 'story telling' methodology to communicate complex ideas to a broad range of audiences.

Q. How can the FactBook improve my understanding of coal combustion products?
A. The FactBook improves your understanding as the highly technical nature of the CCP industry is simplified and in some cases shown in a visual representation. The FactBook allows newcomers to the industry to grasp key words and concepts involved in all fly ash processes and applications.

Q. Who is the FactBook targeted at?
A. Anyone who feels as though their knowledge around the basics of fly ash could be improved in an easy to understand, visual method.

To buy or read more click here: http://www.adaa.asn.au/knowledge/ccp-factbook

Ash Development Association of Australia

USE OF FLY ASH TO ACHIEVE ENHANCED SUSTAINABILITY IN CONSTRUCTION

FLY ASH TECHNICAL NOTE NO. 11

2012

INTRODUCTION

Sustainability of our built environment has become one of the most promiment considerations in building design and construction. The definitions for sustainability itself take different forms and how sustainability may be rated is currently a developing science[1,2,3]. There are many rating systems that have been developed to measure environmental impact and drive sustainable development, one example being Green Star rating tools published by the Green Building Council of Australia (GBCA)[4].

This Technical Note has been produced by the Ash Development Association of Australia to provide guidance to architects, designers, engineers, contractors and infrastructure owners in understanding how best to use fly ash to achieve enhanced sustainability in construction.

The environmental impact of using concrete, the most commonly used construction material worldwide, is being debated along with its constituent materials in research and industry spheres. Fly ash, being a by-product of coal fired electricity generation prominent across Australia, has played a key role in this debate over the past 30 years and can potentially provide future solutions to problems faced in building and infrastructure projects when applied and used properly.

The use of fly ash as a supplementary cementitious material (SCM) in concrete is well recognised for its economic and performance advantages including improved workability, mix efficiency and durability[5,6,7]. Fly ash is also widely recognised, used and specified in standards covering SCMs[8] and General Purpose and Blended Cements[9]. More recently, the focus for the use of fly ash in concrete has shifted to quantifying benefits offered in enhancing concrete sustainability[10]. This Technical Note details the benefits fly ash can provide in producing sustainable concrete and how cement replacement with by products such as fly ash can directly contribute to sustainable development whilst maintaining other criteria including:-

- Engineering design aspects;
- Constructional aspects; and
- Economic advantages.

WHAT IS SUSTAINABLE DEVELOPMENT?

Sustainable development can be generally defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs[11]. It can be broken down into three components – environmental, economic and social[12,13]. Sustainability is said to be achieved when all three components are satisfied.

Concrete has a relatively low embodied energy when compared with other construction materials. It is a high quality, low cost material which is flexible, practical and durable and thus used extensively in construction. Used in such abundance worldwide,

its impact on sustainability when considered wholistically can be significant. There is currently significant debate regarding appropriate assessment criteria for measuring environmental impact in the use of concrete and component materials[14,15,16]. Key elements that could be considered to result in a more sustainable outcome when using concrete are:-

- Resource depletion,
- Emissions to air in the production of the material (or component materials (embodied energy),
- Water consumption, and
- Waste avoidance and reduction.

Fly ash has been proven to have a lower embodied energy compared with hydraulic cement as defined in AS3972[9,17,18]. Appropriate design and contruction considerations must be undertaken when using fly ash to exploit the lower embodied energy benefits and technical properties to achieve the required design and construction criteria. These issues are discussed in some detail in the Ash Development Association of Australia Technical Note 8[7].

GREEN STAR AND HOW TO ACHIEVE CREDITS

Green Star is a national, voluntary environmental rating system that evaluates the environmental design and construction of buildings[4]. It covers different categories that assess environmental impact, including the materials category which is further divided into different material credits. The concrete materials credit awards up to 3 points for the use of sustainable concrete[19]. The purpose of the credit is designed “to encourage and recognise the reduction in greenhouse gas emissions, resource use and waste impacts associated with the use of concrete”. The Mat-5 concrete credit was recently revised by the GBCA and with respect to cement replacement it awards 1 point where the cement content is reduced by 30% or 2 points where it is reduced by 40% for all concrete used in a project. Cement replacement with fly ash can therefore directly translate to Green Star credits if the use of fly ash results in this criteria being met. To evaluate reduction levels, Reference Case Portland cement contents for different strength grades are nominated in the credit[18].

THE BENEFITS OF USING FLY ASH FOR SUSTAINABLE CONCRETE

In the published technical literature some of the effective strategies to produce more sustainable concrete is to replace a portion of the cement component with one or more SCMs such as fly ash[7,12,16]. The benefits of the use of fly ash towards more sustainable construction materials include:-

- Reduction in CO_2 emissions and embodied energy;
- Reduction in resource use;
- Re-use of industrial by-products as alternative raw materials; and
- Sustainability achieved through efficient design and enhanced durability.

Reduction in CO_2 Emissions

The manufacture of Portland Cement is an energy intensive process that releases approximately 0.820 tonne of CO_2 emissions for each tonne of cement produced[16]. In a standard concrete mix, the cement component commonly accounts for approximately 70% to 80% of the embodied energy. Fly ash, being a by-product of coal fired electricity generation, has a relatively low embodied CO_2 content related to its manufacture, estimated at 0.027 kg of CO_2 emissions per tonne,[10,16,20] that is, 3% of Portland cement manufacture. In order to better illustrate the benefit of fly ash in CO_2 emission reduction, a comparison of CO_2 emissions for typical 25 MPa and 50 MPa concrete mixes with increasing proportions of fly ash are presented in Figures 1 and 2 repsectively (following references 17, 20 and 21). The results are also summarised in Table 1 to the right.

Reducing the cement content in concrete by incorporation of SCMs such as fly ash is arguably the most efficient and economical means of reducing CO_2 emissions and embodied energy in concrete. In doing this care is needed when undertaking this to ensure that other engineering design and constructional requirements are maintained as detailed in ADAA Technical Note 8 and other industry guides[6,7]. Other benefits of using fly ash, such as reducing water demand in concrete for particular workability requirements, can be factored in when using fly ash in concrete. For example recent research on post-tensioned slabs in buildings[21] and on pretensioned bridge girders[22] has shown that simple reduction of Portland cement in concrete does not necessarily result in lowering embodied energy of the structural element. The ADAA has published additional details in ADAA Reference Data Sheet 9[23]. Through efficient design, established structural and constructional performance criteria can be met along with achievement of reduced element embodied energy. Fly ash inclusions in the concrete enhance such solutions for structural, constructional and environmental benefit[20,21].

Typical Concret Mix Details	CO2 emissions (tCO_2-e/m^3)			
	GBCA Reference Case Portland Cement Mix	25% Fly Ash mix	30% Fly Ash mix	40% Fly Ash mix
Typical 25MPa mix	0.307	0.245	0.239	0.216
Reduction in CO_2 emissions for 25MPa mix compared to GBCA Reference Case (%)		19%	27%	38%
Typical 50MPa mix	0.496	0.385	0.365	0.324
Reduction in CO_2 emissions for 50MPa mix compared to GBCA Reference Case (%)		21%	32%	44%

Table 1: Summary of CO_2 emission reductions achievable with the use of Fly Ash.

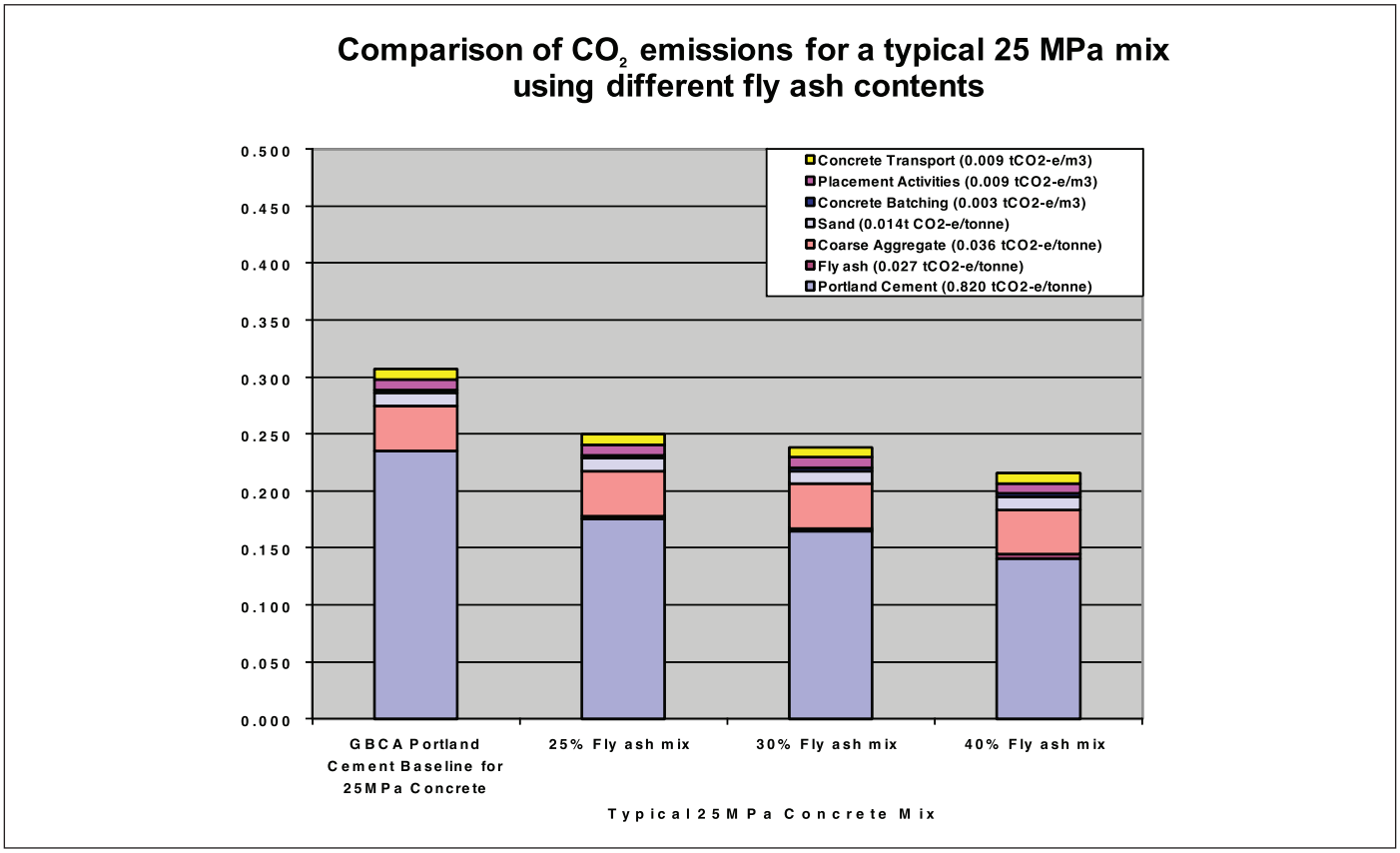


Figure 1 - Comparison of CO_2 Emissions for Typical 25 MPa Concretes With Varying Fly Ash Content (following references 17, 20 and 21)

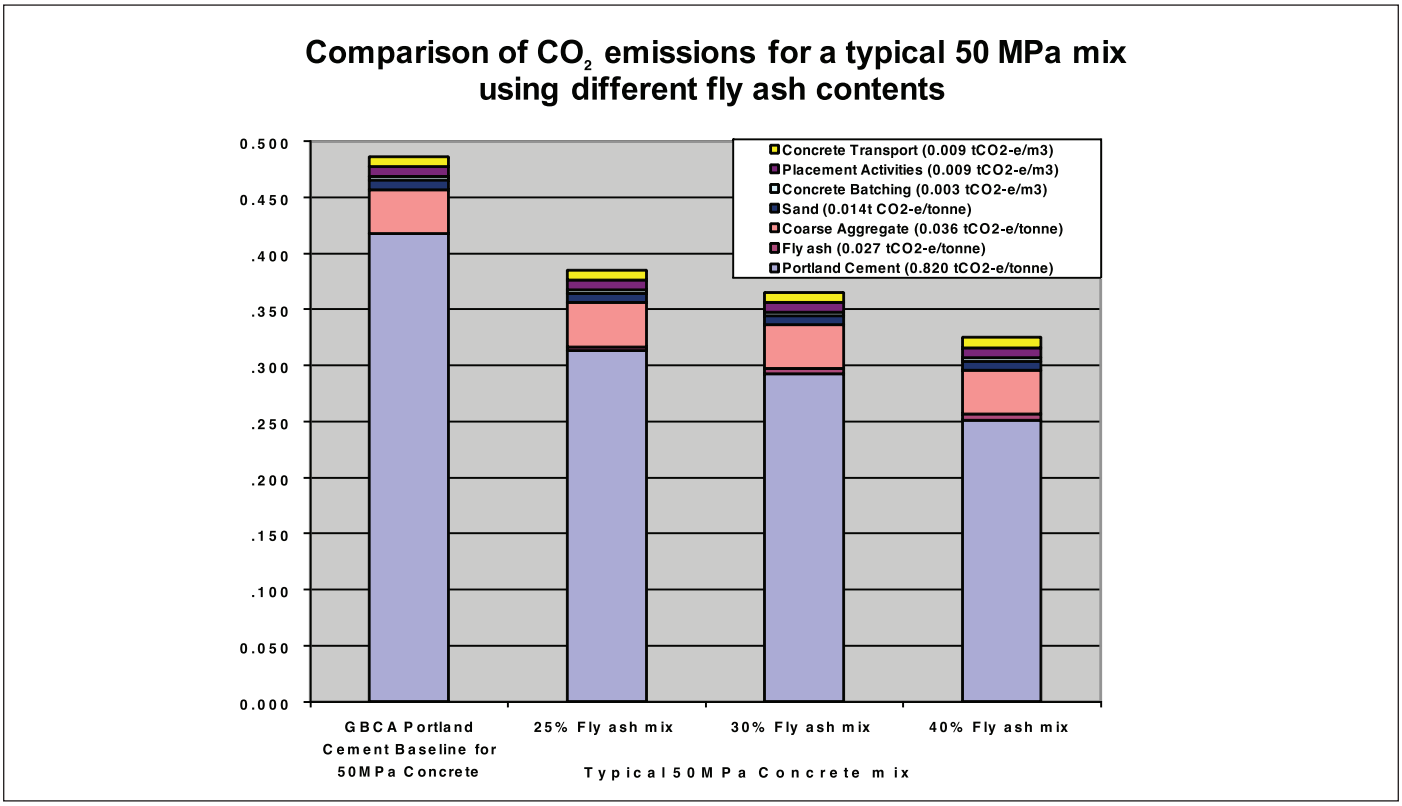


Figure 2 - Comparison of CO_2 Emissions for Typical 50 MPa Concretes With Varying Fly Ash Content (following references 17, 20 and 21)

By-Product Recovery and Reuse

In 2010, Australian coal fired power industry produced in excess of 14 million tonnes of coal combustion products, which includes fly ash, of which almost 1.9 million tonnes, or 14%, was used in concrete product manufacture[24]. Fly ash has great technical merit and is a valuable material with enormous potential for increased use in concrete. The reuse of fly ash and its diversion from long term storage ponds is highly economical as well as providing environmental and social benefits in line with the objective of concrete sustainability.

Reduction in Natural Resource Use

Cement production places a significant demand on our natural resources in terms of the processes involved in manufacture and inputs. It requires mining of natural raw materials including limestone, clay and shale as well as coal and gas for energy to drive the clinkering process. The use of fly ash as a partial cement replacement reduces the amount of cement required in concrete, this reducing this process in helping to preserve natural resources.

Durability and Service Life

The ability of fly ash to enhance the durability properties of concrete is well established[7]. More recently, the link between enhanced durability and sustainability has been explored[25]. Durable structures that are better designed to withstand chemical attack and physical stress have an increased service life and reduced need for maintenance. This maximises the return on the original capital as well as the natural resource use in the structure, translating into a higher level of sustainability measured over the life cycle of the concrete structure.

OPPORTUNITIES FOR THE USE OF FLY ASH IN SUSTAINABLE CONCRETE

The opportunities for using fly ash in the production of sustainable concrete are extensive and will continue to grow as concrete technology evolves, thus allowing the merits of fly ash to be commercially realised. With an understanding of the influences of fly ash on the early age and mechanical properties of concrete[7], it is possible to incorporate it in an appropriate proportion relevant to the design and construction requirements. Some applications and opportunities for fly ash are given below:

- Incorporation into Normal class concretes (defined in AS1379) where possible, to levels where minimum 7 day compressive strength requirements are achieved[26]. Typical proportions would be 15% to 25% for 20-32 MPa concrete and 25% to 35% for higher strength grades.
- Incorporation into Special class concretes[24] at a proportion where performance criteria can be achieved. This may vary from 15 to 30% for post-tensioned applications where early age criteria dominate, to values of 40% and over for applications where early strength is not required and acceptance age may be extended to 56 or 90 days.
- In the Green Star specification, achieving reductions in Portland cement contents in concrete relative to Reference Case levels in the concrete materials credit[4]. Specifically, reducing the Portland cement content by 30% to achieve 1 point or 40% cement reduction for 2 points.
- Up to 7.5% inclusion as a mineral addition in the manufacture of cement[27].
- As the main ingredient in alkali-activated cement, a technology based on using an alkaline solution to activate the polymerisation of fly ash (and/or slag) to produce an alternative to binders and concretes, one example being geopolymer based material. Much research is being undertaken in this area[28] and while products are not yet in common use, it is one technology that provides solutions for the future.

CONCLUSIONS

Fly ash can be crucial to achieving sustainable concrete. Fly ash when used appropriately can; reduce costs, cement contents and associated embodied CO_2 emissions, placing less demand on the use of natural resources when used in concrete. Its inclusion in concrete can also increase structure service life and reduce maintenance of concrete structures. These attributes are acknowledged by the GBCA using the Green Star rating tool where fly ash becomes a key strategy to reduce Portland cement levels in concrete by a defined 30% for 1 point and 40% for 2 points under the concrete materials credit.

While there is already awareness as to the benefits that fly ash can provide in the quest for sustainable concrete, given the volumes of fly ash being produced and technological advances in the concrete industry, much potential remains to further exploit its advantages. The challenge to achieve a sustainable concrete future will however require a paradigm shift by designers and builders from an accelerated construction schedule approach to a focus on increasing durability, service life and embodied energy, through the conservation of our natural resources using by-products where appropriate.

REFERENCES

1. Plank, R, "Sustainability Issues for Reinforced Concrete Construction", Concrete 2007 Proceedings, Concrete Institute of Australia, 23rd Biennial Conference, ISBN 0 909375 78 X, 2007.
2. Anderson, J.E. and Silman, R, "The Role of the Structural Engineer in Green Building:, The Structural Engineer, Vol. 87, No. 3, February, 2009.
3. The Concrete Centre, "Sustainable Concrete", The Environmental, Social and Economic Sustainability Credentials of Concrete, Report Reference TCC/05/03, ISBN: 1-904818-43-9, Available from http://www.concretecentre.com, 2007.
4. Green Building Council of Australia, "Green Star Rating Tool", Available from http://www.gbca.org.au, 2011.
5. Baweja, D. and Nelson, P., "Supplementary Cementing Materials: Their Acceptance in Australian Specifications", Sixth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, ACI SP 178-27, Bangkok, Thailand, June, 1998, pp. 475-492.
6. Concrete Institute of Australia, "Fly Ash and Its Use in Concrete", Current Practice Note No. 25, ISBN 0 909375 61 5, November 2003, 8p.
7. Ash Development Association of Australia (ADAA), "Australian Experience with Fly Ash in Concrete: Applications and Opportunities", Fly Ash Technical Note No. 8, , Available from http://www.adaa.asn.au/technicalnotes.htm, November, 2009, 4p.
8. Standards Australia, Australian Standard AS3582.1, "Supplementary Cementitious Materials for Use With Portland and Blended Cement – Part 1: Fly Ash", ISBN 0 7337 1688 1, Standards Australia International, 1998.
9. Standards Australia, Australian Standard AS3972, "General Purpose and Blended Cements", ISBN 978 0 7337 9698 2, Standards Australia International, 2010.
10. Malhotra, V.M., "Making Concrete Greener with Fly Ash", Concrete International, Vol. 21, No.5, May 1999.
11. Brundtland Commission (1987). UN World Commission on Environment and Development, United Nations: p. 318.
12. Cement ,Concrete and Aggregates Australia, "Sustainable Concrete Buildings", Concrete – The Responsible Choice, Briefing, ISSN 1447-199X, Available from http://www.ccaa.com.au, April, 2010.
13. Cement ,Concrete and Aggregates Australia, "Sustainable Concrete Materials", Concrete – The Responsible Choice, Briefing, ISSN 1447-199X, Available from http://www.ccaa.com.au, April, 2010.
14. Mehta, P.K., "Global Concrete Industry Sustainability: Tools for Moving Forward to Cut Carbon Emissions", American Concrete Institute, Concrete Instenational, February, 2009, pp 45-48.
15. Wilson, J.L. and Tagaza, E., "Green buildings in Australia: Drivers and Barriers", Australian Journal of Structural Engineering, Vol. 7, No. 1, Engineers Australia, R.E. Melchers Editor,2006, pp 57-63.
16. Wang, X., Nguyen, M., Stewart, M. G., Syme, M., Leitch, A., "Analysis of Climate Change Impacts on the Deterioration of Concrete Infrastructure – Synthesis Report", Published by CSIRO, Canberra. ISBN978 0 643 10364 1, 2010.
17. Heidrich, C., I. Hinczak, et al. (2005). Case study: CCP's potential to lower Greenhouse Gas emissions for Australia. World of Coal Ash 2005, Lexington, Kentucky, USA, American Coal Ash Association & University of Kentucky.
18. Flower, D., Sanjayan, J. and Baweja, D., "Environmental Impacts of Concrete Production and Construction", Proceedings, Concrete Institute of Australia Biennial Conference, Melbourne, Australia, 2005.
19. Green Building Council of Australia, Green Star Specification, Materials Category, "Mat-4 - Concrete", Revised Concrete Credit, Available from www.gbca.org.au, May, 2012.
20. Heidrich, C., Hinczak, I., and Ryan, B. "SCM's potential to lower Australia's greenhouse gas emissions profile." Iron and Steel Slag Products: A Significant Time of Scarcity, Australasian Slag Association Conference, March 2005 (papers published on CD), Sydney.
21. Jenkins, D., Baweja, D. and Portella, J., "Optimising Building Design for Sustainability Using High Performance Concrete", Proceedings, Concrete 2011, Concrete Institute of Australia Biennial Conference, Building a Sustainable Future, Perth, Australia, October, 2011.
22. Jenkins, D., Portella, J. and Baweja, D., "Optimising Precast Bridge Girders for Sustainability with the use of High Performance Concrete", AUSTROADS 8th Bridge Conference, Proceedings, Vol. 4, ISBN 978 1 921709 81 4, V. Ponnampalam, E Ancich and H Madrio Editors, Sydney, Australia, November, 2011, pp 124-134.
23. Ash Development Association of Australia (ADAA), "Post-Tensioned Structural Fly Ash Concrete", Fly Ash Reference Data Sheet No. 9, Available from http://www.adaa.asn.au/documents/Ref_Data_Sheet_9.pdf, April, 2009, 5p.
24. Ash Development Association of Australia, ADAA Annual Membership Survey Results http://www.adaa.com.au January – December 2010.
25. Mehta, P.K., "Durability – Critical Issues for the Future", Concrete International, Vol. 19, No. 7, July 1997, pp 27-33.
26. Standards Australia, Australian Standard AS1379, "Specification and Supply of Concrete", ISBN 0 7337 1468 4, Standards Australia International, 2007.
27. Standards Australia, Australian Standard AS3972, "General Purpose and Blended Cements", ISBN 978 0 7337 9698 2, Standards Australia International, 2010.
28. Concrete Institute of Australia, "Geopolymer Concrete", Recommended Practice Z16, ISBN 1 921093 56 0, September, 2011, 38p.

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