Perspectives

ON BROWN COAL

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THE OFFICIAL NEWSLETTER OF BROWN COAL INNOVATION AUSTRALIA

BROWN COAL INNOVATION AUSTRALIA

Positioning brown coal for a low-emissions future

IN THIS ISSUE…

BCIA is proud to sponsor this year's ICCS&T Conference being held in Melbourne. Come visit us at our stand no. 7.

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Dr Phil Gurney
BCIA Chief Executive Officer

CEO'S UPDATE

Transforming ideas into innovation

This September edition of 'Perspectives' is timed to coincide with the International Conference on Coal Science and Technology (ICCS&T), which is being held in Melbourne for the first time. BCIA is the major sponsor of this conference. We look forward to welcoming the world leaders in coal science to our home town.

In this issue, we shine a light on some of the progressive research that BCIA has supported over the past five years, and also look forward to what is required to ensure a sustainable future for Australia's brown coal resources.

A key future role for coal will be to support the increasing penetration of intermittent renewable energy – so new power plants must combine fast start / stop / ramp times with significantly reduced emissions. DICE can potentially deliver all this and more, and Louis Wibberley reports on the latest developments.

Continuing the theme from last issue, David McManus explains the huge potential for agricultural products derived from brown coal, and the contribution of BCIA funded research. David also highlights a recent BCIA-supported report on CO_2 dispersion modelling, which will be made available soon to regulators and the general public.

Alan Chaffee provides a review of the work he has undertaken as BCIA Research Fellow, and provides some insights into the future uses of brown coal, from high-value manufacturing opportunities through to potential low-cost pathways to convert CO_2 into commodity chemicals.

The Australian Synchrotron has enabled fundamental research that would not otherwise be possible, and we feature an article on how this facility has added value to our research and development programme.

As always there is more going on than we can fit in to our newsletter 'Perspectives', so please visit our website for the latest updates, and if you are visiting Melbourne for ICCS&T 2015 conference, we welcome you to drop by our stand and learn more about how BCIA is transforming ideas into innovations that position brown coal for a low-emissions future.

NEWS

New opportunities for Victorian brown coal

While many in the community may think there is no future for brown coal, this is proving to be far from the truth…

Victoria's Latrobe Valley contains a vast resource of brown coal, approximately one quarter of the world's known reserves, of which 33 billion tonnes has economic potential. This resource contains about 14 billion tonnes of carbon, which is equivalent to about half the carbon content of Saudi Arabia's crude oil reserve. This coal contains very low impurities by world standards, but has a high moisture content.

The inefficient practice of burning wet coal to produce cheap electricity, with the attendant production of large quantities of CO_2, has led to the common misconception that brown coal is a "dirty" fuel. With the pressing need to sharply reduce global production of greenhouse gases, there is no question that the current fleet of brown coal boilers must be progressively phased out. However, it is unconscionable to think that the Latrobe Valley power industry could be forced or regulated to close down without a contingency plan to avoid causing damage to the local community.

While there are predictions that Victoria's brown coal will become a 'stranded asset', this does not have to be the case. Brown coal will have a viable future – provided that all future developments are both economically viable and have a low or zero CO_2 emission. Victoria has some of Australia's best geology for CO_2 sequestration in the Gippsland Basin, so it is feasible to achieve low-emission processing of Victorian brown coal, and BCIA sees the need to focus on three main areas to achieve a sustainable future for brown coal.

- Providing low-cost technology pathways for the transition from current methods of brown coal based electricity generation.
- Developing options for new uses and products for Victoria's carbon resources.
- Supporting economic growth and job creation via new manufacturing opportunities.

Brown Coal to Support Renewables

Wind and solar PV are the two main forms of renewable energy being installed in Australia; both are intermittent and vary seasonally and throughout the day. To ensure that the power generated matches the hour-by-hour demand, they must be partnered with some form of flexible power delivery system.

Brown coal power stations operate continuously, providing baseload power. To make up any shortfall from renewables, load following power plants (typically hydroelectric or gas turbine) are brought on and off line as needed, and so must be flexible enough to start up and shut down without losing efficiency.

The requirement for load following power will rise with increasing penetration of renewables. However, there is limited capacity to build new dams for hydroelectric power and gas prices are expected to rise sharply, so a lower-cost alternative will be needed.

50MW stationary diesel engine at Korea Midland Power.
(MAN Diesel & Turbo)

BCIA is supporting development of the Direct Injection Carbon Engine (DICE) (pages 5 and 6), a novel approach to power generation using water-based Micronised Refined Coal (MRC) fuel in large stationary diesel engines. CSIRO modelling indicates that MRC-DICE may be able to deliver electricity at double the efficiency of today's brown coal power stations.

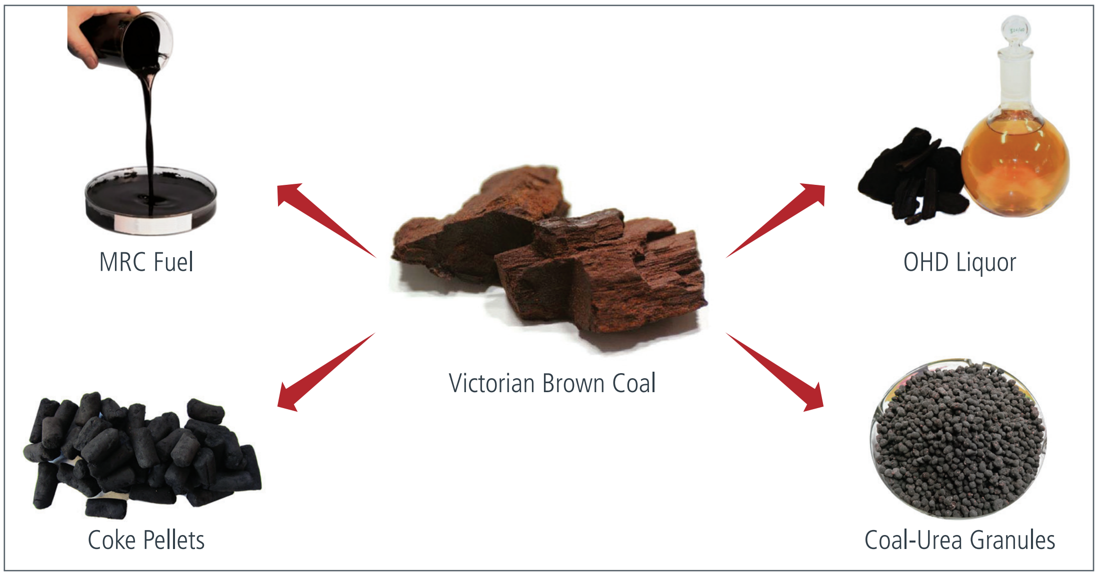
It is anticipated that brown coal MRC-DICE will be able to deliver load following power and be cost-competitive with gas. Rather than closing down the existing power stations, DICE technology could be installed progressively as modular units, changing the power generation capacity to a balance of both baseload and load following as renewable power sources are progressively introduced.

New Carbon Products

Beyond electricity production, the Victorian economy would benefit enormously if cost-effective low emissions processes can be developed to transform its massive carbon reserve into high value products.

A range of new technologies show promise for use with brown coal, including oxygen-blown entrained flow gasification, torrefaction, micronisation and advanced cleaning techniques, oxidative hydrothermal dissolution and densification. These technologies could potentially be used to transform brown coal into a wide range of products needed in a modern society, such as fuels, fertilisers, carbon fibres, industrial chemicals, plastics and metallurgical reductants.

Such products underpin a sustainable modern society. In the renewable energy sector alone, glass, steel, carbon fibre, plastics and hydrogen are essential and could be produced using brown coal (please refer to illustration on page 4). Increasing deployment of renewable energy will create an increased demand for these raw materials. These same materials are used in mobile phones, computers, aeroplanes, trains, etc. – in fact, all aspects of a modern society. There is a huge potential market for products manufactured either from or using Victorian brown coal.

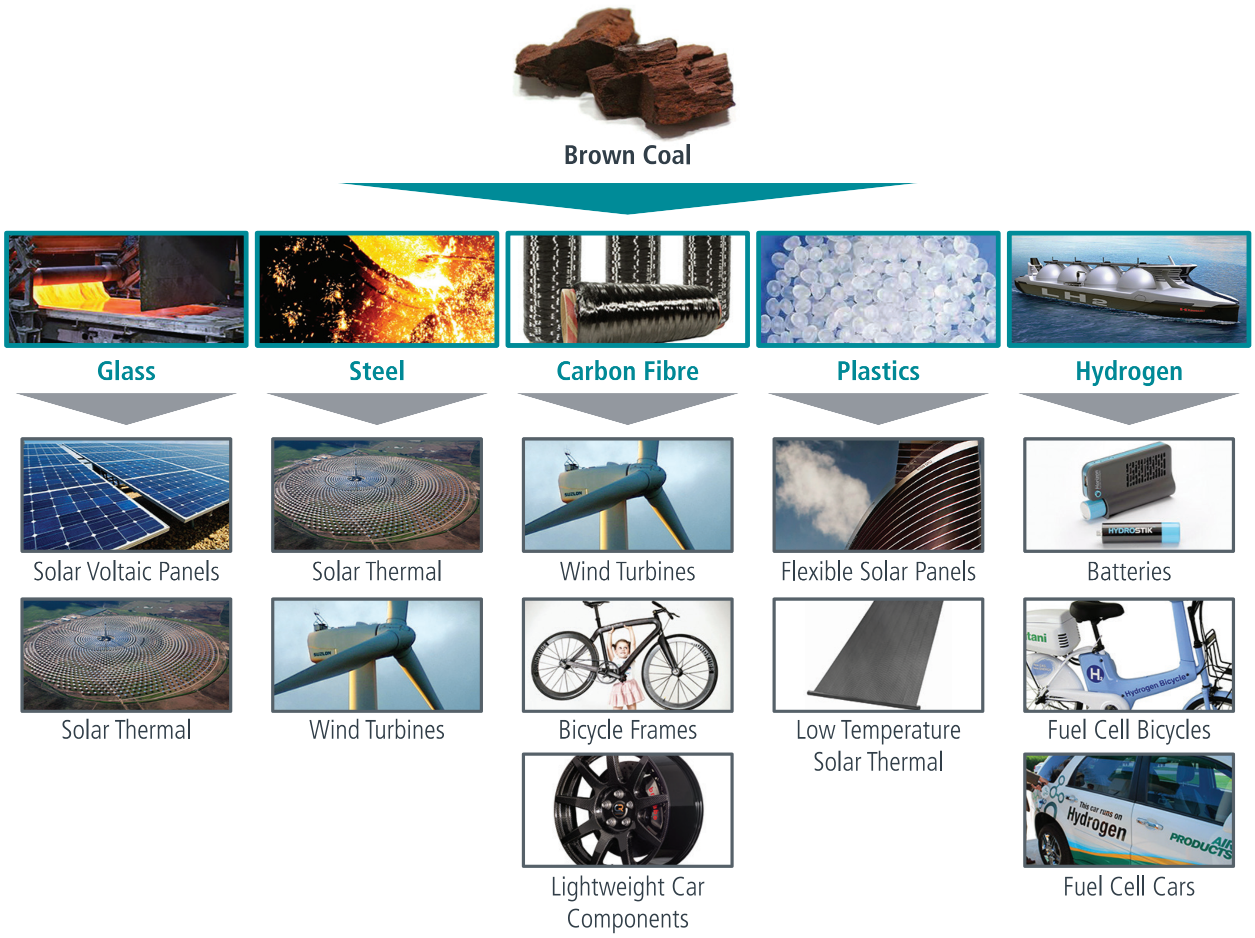


Some of the new products that have been produced from brown coal over the past five years.

NEWS

New opportunities for Victorian brown coal (cont'd)

Brown Coal Carbon Could Support New Manufacturing Industries in Victoria



Carbon Capture and Storage

Transformation of the Latrobe Valley into a low emissions power and manufacturing hub will necessarily require implementation of Carbon Capture and Storage (CCS) technologies, so that CO_2 emissions can be prevented from entering the atmosphere. The Latrobe Valley is already home to a strong oil and gas industry. The skills and expertise in this industry are directly applicable to new CCS installations, which will involve engineering design, project management, procurement and commissioning activities.

The installation of a pipeline to transport CO_2 for storage would create additional opportunities for such skills, and operation of the pipeline would create more highly paid jobs.

For CCS to be economically viable, it will be important to focus on high value products, supported by appropriate government policy settings.

A Sustainable Future for Brown Coal

There is no reason why Victoria should willingly convert its massive carbon reserve into a stranded asset, when opportunities to rejuvenate power stations with DICE technology and create new manufacturing industries for low-emissions carbon products have not yet been fully explored.

The Latrobe Valley has the potential to become a powerhouse of new low-emissions economic growth and commercial activity, while securing the jobs of the current coal workforce. Achieving this will require sustained investment in low-emissions coal technology development and innovation, and ongoing support for the most promising technologies from research and development through to commercial deployment.

Louis J Wibberley
Principal Technologist

DICE development with Victorian brown coal

By Louis J Wibberley, Leader, Advanced Carbon Power, CSIRO Energy Technology

The Direct Injection Carbon Engine (DICE) represents a major step towards a dispatchable power generation technology that has low capital cost, high efficiency, low greenhouse gas emissions and provides quick stop / start / ramp times. BCIA is providing funding to continue the development of this exciting technology – Louis Wibberley provides an update.

DICE can be used with any carbon-based fuel source, including both renewable and fossil fuels, and can provide back up for intermittent energy sources, such as solar and wind, or provide peaking power to complement fixed-load power stations. DICE also has the potential to provide a synergistic fit with carbon capture technologies.

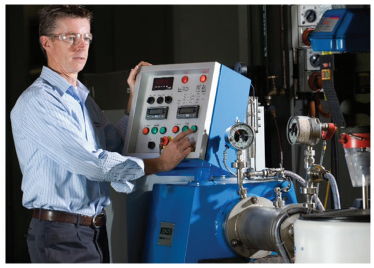
Victorian brown coal has proven to be an ideal fuel source for DICE, in the form of low ash coal-water slurry (a micronised refined carbon or MRC). CSIRO modelling suggests that brown coal MRC-DICE should be capable of fuel cycle efficiencies of 48%–50%. This is equivalent to the performance of the proposed next generation 'advanced ultra supercritical' steam boilers, which are expected to be much more expensive than DICE.

As part of its 2013 Funding Round, BCIA is providing partial funding for a joint national 'DICE Development programme', led by CSIRO Energy Technology. The joint programme is being undertaken collaboratively by the brown and black coal industries and the Commonwealth through ANLEC R&D, in conjunction with MAN Diesel & Turbo, the world's largest manufacturer of stationary diesel engines. The broad objectives of the national programme are as follows.

- Develop modified fuel handling and injection equipment to allow successful handling of MRC fuel slurry at small demonstration scale.
- Undertake proof-of-concept trials of both brown and black MRC fuels in a large test engine in Japan.
- Create sufficient data to allow an engine manufacturer to implement an engine development programme.
- Define the specification parameters and initial acceptable ranges for both brown and black coal derived MRC fuels.

DICE modified diesel engine at CSIRO Energy Technology, Newcastle NSW. (Murray McKean. Copyright © 2015 by CSIRO. Reprinted by permission.)

DICE development with Victorian brown coal (cont'd)



The brown coal-specific aspects of the programme will include preparation and characterisation of a brown coal MRC fuel that will remain stable during transport to Japan, small-scale engine testing to investigate possible fouling issues, investigation of the effects of coal ash components on atomiser wear and cylinder abrasive wear, and development of standardised specifications and testing protocols for MRC fuels.

While the ash content of Victorian brown coal is typically less than 2%, which is very low by world standards, the DICE application requires an ultra-low ash coal containing less than 1.5% mineral ash. The ash in Victorian brown coal typically has four components.

1. Coarse, abrasive minerals such as quartz (sand) and feldspar.
2. Finely-dispersed clay minerals.
3. Cations (e.g. Na, Ca, Mg and Fe) associated with the carboxylic acid groups in the coal structure.
4. Salts (mainly NaCl) dissolved in the in-seam water.

CSIRO has shown that the coarse, abrasive minerals can be effectively removed by milling the coal to ultra-fine sizes followed by size-density separation using conventional spirals technology. A large proportion of the ionic species can be removed during hydrothermal treatment (HTD) of the coal, which is essential for producing high quality brown coal MRC. Following such treatment, the main residual ash components are sodium and calcium ions.

Both sodium and calcium are known to cause problems of slag and ash fouling in existing brown coal pulverised fuel boilers. Since the temperature and pressure cycling in a diesel engine is quite different to the temperature profile in a conventional boiler, it was uncertain whether ash fouling is likely to be a problem for brown coal MRC-DICE. This is potentially a risk for the proposed demonstration-scale engine test in Japan.

In order to address this risk, CSIRO recently completed a test of engine grade brown coal fuel in a small 8 kW laboratory diesel engine. The test was designed to encourage engine fouling, by using brown coal briquettes containing 1.6% ash for the fuel, with a coarse particle size, operating in a small engine running at higher-than-normal combustion temperature. Despite these unfavourable conditions, the engine operation was stable over the 12-hour trial, exhibiting good fuel ignition and burnout. There were no carbonaceous deposits in the combustion chamber and no signs of adverse ash fouling.

This laboratory engine test, while preliminary, is a very encouraging result for brown coal MRC and has served to de-risk the proposed engine trial in Japan. The long-term potential for brown coal ash fouling in DICE remains uncertain, but this can only be properly investigated through much longer duration tests (thousands of hours) in a larger engine.

Successful completion of the DICE Development programme will confirm the technical feasibility and inform our understanding of the commercial viability of DICE, which has great promise as a low-emission power generation technology.

MRC made from Victorian LRC Yallourn.
(Copyright © 2014 by Wibberley and Wonhas)

CO_2 pipeline being laid in the US (1).

Dispersion modelling techniques for CO_2 pipelines in Australia

By Dr David McManus, Research Investment Manager, BCIA

Effective deployment of carbon capture and storage (CCS) infrastructure in Australia will require pipelines to transport compressed CO_2 from the point of capture to the point of storage. While Australians are generally familiar and comfortable with the presence of natural gas pipelines, pipelines for CO_2 are less well known locally. David McManus outlines BCIA's recent report on CO_2 dispersion modelling.

Although hundreds of miles of CO_2 pipelines have been built in the US, and planning for such infrastructure is well understood there, Australia has different regulations and to allow a pipeline to be built, strict risk assessments must be taken. The unplanned release of gas from a pipeline, and its subsequent dispersal into the atmosphere, is one of the major risks.

To assist in the planning of CO_2 pipelines in Australia, BCIA has supported the development of a report investigating the suitability of available gas dispersion modelling tools for use in Australian CO_2 pipeline permitting.

Natural gas pipelines in Australia must conform to the design and risk management approach set out in Australian Standard 2885 'Pipelines – Gas and liquid petroleum'. Any new CO_2 pipeline will also be designed using this Standard, but the methods for assessing the consequences of a gas release are not clearly specified.

One of the most important differences between natural gas and CO_2 is that natural gas is lighter than air, while CO_2 is heavier. In any event where gas is released from a pipeline, the dispersion of CO_2 into the atmosphere will be markedly different than the behaviour of natural gas.

Another important difference is that natural gas is highly flammable and explosive, while CO_2 is not. However, CO_2 is an acidic gas that can cause a pH imbalance in the bloodstream, with the physiological consequences depending on the dose and duration of the exposure.

These two key differences mean that the consequence analysis tools used for natural gas pipeline design are not applicable to CO_2 pipelines. In order for a CO_2 pipeline to be designed in accordance with Australian Standard 2885,

Dispersion modelling techniques for CO_2 pipelines in Australia (cont'd)

appropriate modelling tools need to be identified, especially for reliable simulation of release and dispersion of CO_2 into the atmosphere.

BCIA has supported a recently-completed project that investigated the application of CO_2 dispersion modelling in the context of new CO_2 pipeline infrastructure in Australia. The project was conducted in two stages, with the first led by Ramboll Environ Australia and the second by Sherpa Consulting.

Valuable international input was gained through technical contributions from Dr Stephen Hanna, an eminent expert in dense gas dispersion modelling, and through a critical review by Dr Simon Gant of the UK Health and Safety Laboratory, who was involved in recent European CO_2 release projects. Funding for the project was provided by the Victorian government through DEDJTR and by the Commonwealth through ANLEC R&D.

The investigation considered a series of modelling tools that may be regarded as 'fit for purpose' for simulating the dispersion characteristics of CO_2 gas. The assessment was based on a number of criteria.

- Availability, ease of use, access to technical support.
- Ability to calculate appropriate source terms for different CO_2 release scenarios.
- Validation history, particularly with CO_2.
- Ability to account for complex terrain and variable atmospheric conditions.
- Applicability to different stages of the design process.
- Acceptability to Australian regulators.

Modelling of a release of dense phase CO_2 from a pipeline requires consideration of a number of aspects, including transient pipeline depressurisation, multi-phase jet release, and dispersion of both dense and neutral gas. Appropriate models that can be used for each of these aspects were identified.

A range of dense gas dispersion models were investigated, including empirical correlations, integral models, Lagrangian particle and plume dispersion models and computational fluid dynamics (CFD) models. Selected models were reviewed and evaluated against the various criteria to determine if they could be considered 'fit for purpose'.

One of the main conclusions from this project was that sufficient information and modelling tools are available to allow a new CO_2 pipeline to be designed in accordance with Australian Standard 2885. The project deliverable was a comprehensive report that provides guidance on the current international best practice in modelling CO_2 dispersion, and identifies appropriate, fit-for-purpose modelling tools that can be used at different stages in the pipeline design process.

The final report [2] will be made available to the public and will be useful to both pipeline designers and regulatory authorities. The guidance provided in this report will allow the risks associated with new CO_2 pipelines to be reduced to as low as reasonably practicable, equivalent to the community expectations for natural gas pipelines.

New CO_2 pipeline construction in US [3].

(1) Ogeechee River Keeper, 2015 (http://ogeecheeriverkeeper.org/uncategorized/palmetto-pipeline-news/).
(2) Sherpa Consulting, 2015. Report will be available through the Global CCS Institute website (http://globalccsinstitute.com/).
(3) BlackHawk Construction, 2014 (http://blackhawkus.com/pipeline-construction/).

Dr David McManus
BCIA Research Investment Manager

Agricultural opportunities for brown coal

By Dr David McManus, Research Investment Manager, BCIA

Australian soils are among the least fertile in the world, and in order to maximise productivity, Australian agriculture is heavily dependent on the use of imported chemical fertilisers. Victoria's brown coal deposits represent a huge carbon resource, with significant potential for local manufacture of agricultural products derived from brown coal. David McManus overviews BCIA's research activities in this area.

While the use of chemical fertilisers is undoubtedly beneficial, it comes at a cost. Repeated applications of chemical fertilisers can alter the soil composition, increasing salinity and reducing organic carbon content. Whereas soil carbon levels of over 10% were recorded in Australia in the 1840s, levels are now often less than 1%. Soil structures have collapsed to the extent that much more horsepower is needed to cultivate them, and plant roots can no longer proliferate readily through them.

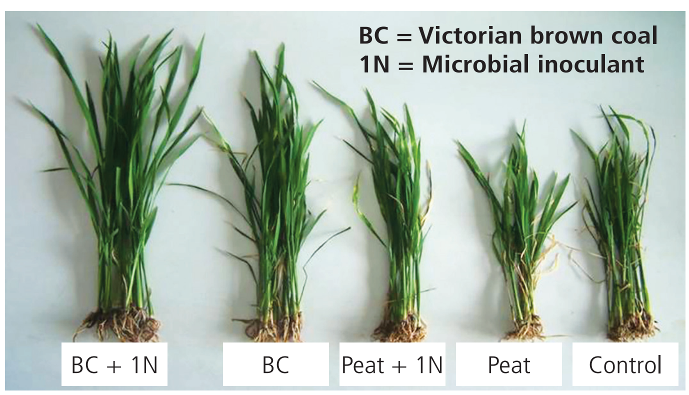
The majority of organic matter present in healthy soils is in the form of humic substances, formed by the breakdown of lignified plant tissue. Essentially the same humic substances are found in peat, compost and brown coal. While the majority of Australian soils are deficient in humic substances, Victoria has a huge supply of preserved organic matter in its brown coal deposits. Using brown coal as a soil supplement is potentially a simple way to rebuild soil carbon and thus rejuvenate degraded soils and improve agricultural productivity.

Sporadic research has been conducted on the agricultural potential of Victorian brown coal over many years, although the results were often inconclusive and not followed up. It is well established that brown coal has high water holding capacity and cation exchange capacity, both of which improve soil properties. Alkaline treatment of brown coal liberates a high proportion of humic substances, which are reputed to have plant growth-promoting properties.

In order to better understand the implications of using brown coal and humic substances as agricultural inputs, BCIA has supported research efforts at Monash University, led by Associate Professor Tony Patti. This has included funding for a three-year research project as well as PhD scholarship funding for Ms Karen Little, Mrs Azita Kargosha and Mr Biplob Saha.

These research efforts have led to a number of interesting and useful observations, including the following.

- Humic substances stimulate the proliferation of bacteria associated with nitrogen cycling in the soil.
- Beneficial plant growth-promoting bacteria were found to survive for up to 3 months when inoculated into brown coal.
- Humic substances are not rapidly decomposed by soil microbes and may be stable in the soil for many years (although this is yet to be confirmed).
- Brown coal can make phosphate fertilisers more bioavailable by complexing with calcium ions (which form insoluble precipitates with phosphate).
- Brown coal can improve the performance of urea by binding to ammonium ions, leading to reduced losses through leaching and nitrous oxide (a potent greenhouse gas) emissions and improved soil N retention.



Rice in glasshouse trial after 30 days.
(Copyright © 2015 by Monash University)

Agricultural opportunities for brown coal (cont'd)

Through the course of this research it has become apparent that the effectiveness of brown coal and humic substances on plant growth is dependent on complex interactions between the soil, plants and microbial species. The research to date has led to the development of sophisticated tools to help understand these interactions, but more research is necessary.

Even so, it is clear that there is commercial potential for the research already completed. This potential is beginning to be explored with the assistance of two local companies, Torreco and Feeco Australia. Torreco uses a torrefaction process to heat the brown coal briefly in an oxygen-deficient atmosphere, which makes the coal very dry and brittle, and thus easier to grind and granulate. Feeco Australia has expertise in granulation technology, and has produced experimental batches of granules containing blends of brown coal/humic substances and chemical fertilisers.

The granules that have been produced are hard and dense, and are suitable for direct injection into the soil using conventional agricultural equipment. These products have the potential to significantly improve fertiliser use efficiency and are suitable for use in low emissions no-till farming practices. To develop these products further, the manufacturing process needs to be scaled up, so that enough product can be made for testing in large-scale field trials.

Benalla pasture trial showing biomass effects.
(Copyright © 2015 by Australian Carbon Fertilisers Ltd.)

As reported in the June 2015 issue of 'Perspectives', Australian Carbon Fertilisers has been testing a similar product in field trials, observing yield increases of 27% in pasture and 38% in wheat. Increased plant yields require increased photosynthesis, which extracts more CO_2 from the atmosphere.

The use of brown coal blended with conventional fertilisers thus offers a number of environmental benefits.

- Reduced input of chemical fertilisers, through increased fertiliser use efficiency.
- Reduced greenhouse gas emissions from chemical fertiliser manufacture.
- Reduced leaching of fertilisers, preventing pollution of waterways.
- Reduced volatilisation of urea, with less production of NO_2, a potent greenhouse gas.
- Increased soil carbon levels, both directly through addition of coal to the soil and indirectly through increased root growth.
- Improved soil stability and structure, with better water retention and less tendency to blow away as dust.

Given that over 60% of Australia's rural landscape, i.e. more than 500 million hectares, has been affected by soil degradation, there is a huge potential market for agricultural products based on Victorian brown coal. The equipment needed to manufacture such products is relatively inexpensive, so this is one of the most prospective new manufacturing opportunities for the Latrobe Valley.

The costs involved for field trial validation are high. Chemical fertilisers such as urea and superphosphate, which are now universally used, were validated through government funded research and not by fertiliser companies. No single company would have funded this research, since the results would have been quickly utilised by the competition.

Exactly the same situation applies today with brown coal-based fertilisers. Further independetly-funded research is required to demonstrate efficacy and reproducibility in large-scale field trials. This will unlock the market for these products and open the door to a range of new manufacturing opportunities in the Latrobe Valley.

Professor Alan Chaffee

BCIA Research Leader Fellowship

By Prof. Alan Chaffee, School of Chemistry, Monash University

"I was delighted to have the opportunity to take up a BCIA Research Leader Fellowship and it provided an opportunity to pursue a number of research themes under the title 'New markets and greener approaches to brown coal use'."

BCIA Research Leader fellowships are awarded to outstanding researchers of international repute who can provide a significant leadership and mentoring role, and build Australia's internationally-competitive research capacity. With Alan Chaffee's fellowship now complete, he provides a review of the work undertaken.

The programme sought to address issues that impede the broader use of Victorian brown coal (VBC) and to facilitate its utilisation in new markets, along four major themes.

- Understanding spontaneous combustion.
- Transformation of brown coal into high value products.
- Coal and coal derived materials as adsorbents.
- CO_2 capture and utilisation.

The research focus was on 'applied science' – looking to generate outcomes that could be used in subsequent process development work by engineering groups. The programme also emphasised activities that offered improved environmental outcomes, including reduced energy consumption and the recovery or utilisation of associated CO_2 emissions. I have briefly described some of the highlights of the programme below.

Spontaneous Combustion

Although spontaneous combustion has been widely studied, the physico-chemical factors that influence its rate have been poorly characterised. Also, because VBC is heterogeneous, this has compromised comparisons between prior studies.

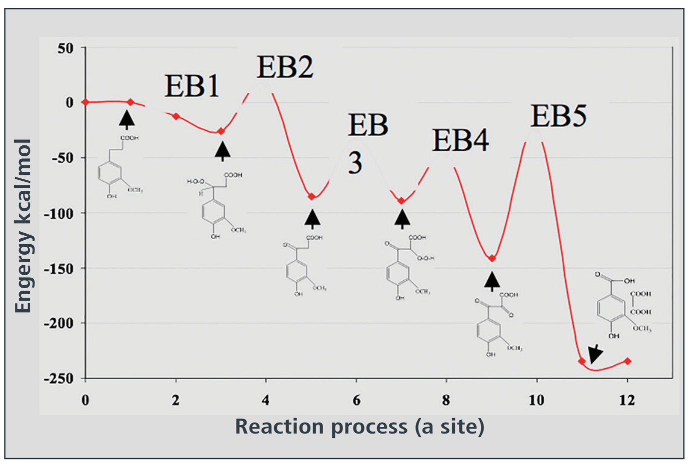
A significant new finding from our work was the identification of an inverse relationship between the volume of micropores present in the coal and the so-called critical ignition temperature, Tcr. Thus, when the micropore volume was reduced, for example by some dewatering methodologies, the propensity for spontaneous combustion was also reduced.

High-Value Products

VBC is potentially a low-cost carbonaceous precursor to a variety of higher value products. We have investigated methods for making materials, such as blast furnace coke substitute, active carbon products and also road bitumen. This work has been quite successful and has led to the development of valuable IP in the former two cases and we are looking to take this further. Studies of liquefaction of VBC in comparison with various forms of biomass led to new understanding about the chemical mechanisms involved.

In other work we identified a novel means of extracting coal using 'metastable' ionic liquids formed from the condensation of CO_2 and various low molecular weight amines. In certain cases these ionic liquids can extract as much as 70% of the coal.

The ionic liquid can be recovered as its constituent gases by simply heating the liquid to a mild temperature (~60C). This approach can be selective for specific types of molecular structures (such as triterpenoid components) under certain conditions. We are considering possible ways to take this forward.



Analysis of coal oxidation pathways.

BCIA Research Leader Fellowship (cont'd)

Adsorbents from Brown Coal

In a substantial programme on new materials for CO_2 capture we developed a composite amine/silica material that has also been patented. This material is prospective for adsorption based CO_2 capture from flue gas streams using a vacuum-swing adsorption (VSA) process configuration. Other materials were identified that have potential for CO_2 capture from synthesis gas at elevated temperatures in a pre-combustion context.

Active carbons prepared from VBC have abundant micropores and this makes them excellent adsorbents for small molecules. We have investigated their ability to store hydrogen and methane as well as CO_2. The electrical conductivity of carbons gives them a distinctive capability for use in a process configuration known electrical swing adsorption (ESA) and this is the subject of an on-going study with a consortium of European collaborators from industry and academia.

CO_2 Utilisation

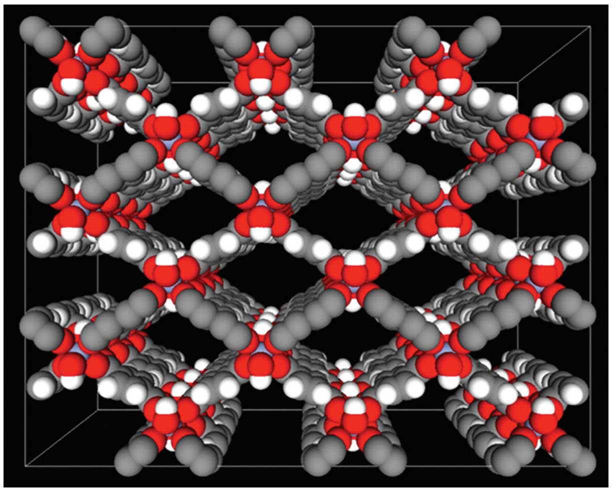
The direct conversion of CO_2 into commodity chemicals, such as methanol, by gas phase heterogeneous catalysis is also being investigated. In this study we are applying both conventional catalysts and novel ones based on a relatively new class of materials known as metal-organic frameworks (MOFs). MOFs are also prospective for CO_2 capture. This approach requires the use of hydrogen from a renewable source to assist the mitigation of CO_2 emissions associated with fossil fuel utilisation.

Collaboration

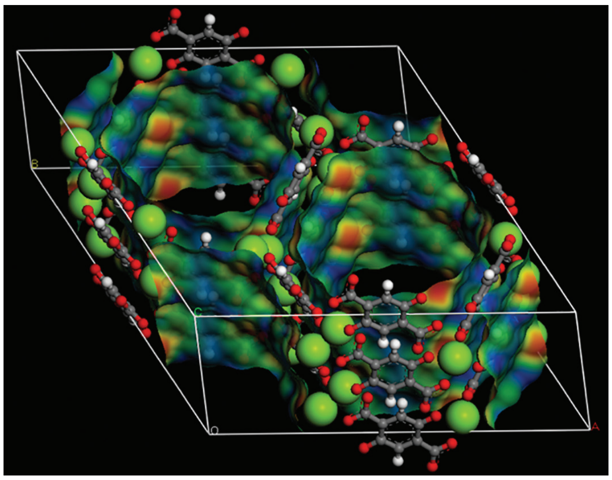
The fellowship provided the opportunity to collaborate with many groups both domestically and internationally. We hosted international exchange researchers from Canada, China, Germany, Japan and Spain who came here to learn of our approaches to utilising VBC.

There were several reciprocal visits by group members that provided opportunities to utilise unique facilities in overseas laboratories and to present our work at international conferences. The fellowship also provided a platform that helped foster funding from other sources. The programme was leveraged with funding from a range of industry and government sources.

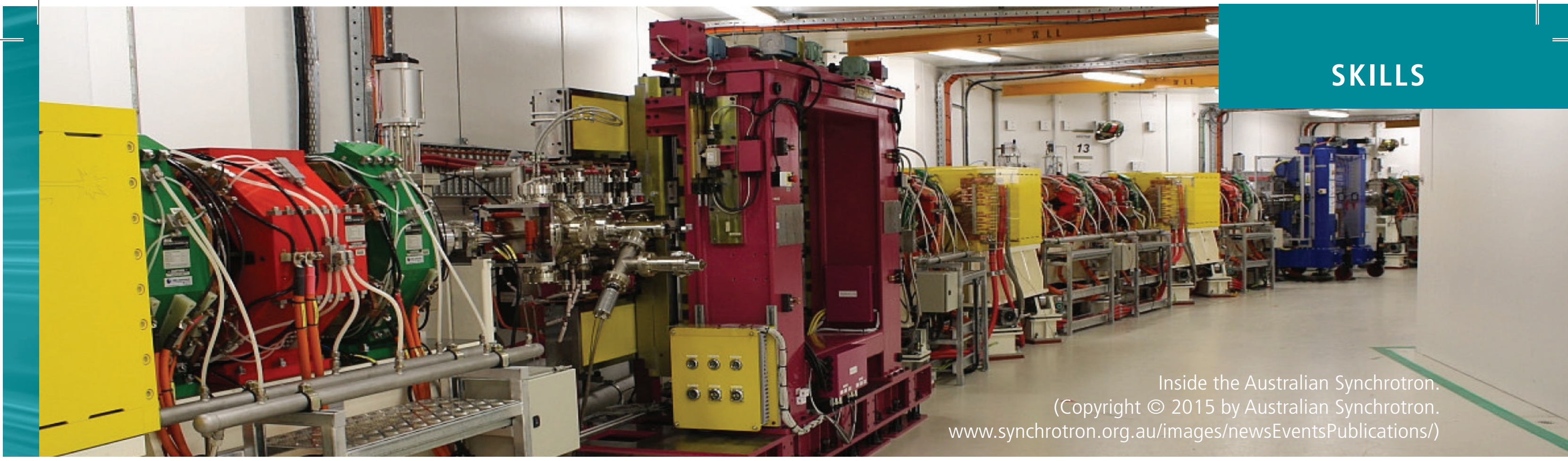
Although I will not name them here, I want to record my heartfelt appreciation to my collaborators, staff and students who worked with me through this period. It is their ideas, their enthusiasm and their hard work that has enabled the outcomes and advances we have made.



Molecular structure of MIL-53, a 'flexible' metal organic framework (MOF) material of interest for CO_2 capture. The pores of this MOF have the unusual ability to open or close in response to the gas atmosphere to which they are exposed.



This image displays the predicted electrostatic charge distribution over the internal surface of the porous metal organic framework (MOF) material known as 'Mg-MOF74'. Orange shading indicates areas of high positive electrostatic potential where CO_2 will selectively adsorb.



Inside the Australian Synchrotron.
(Copyright © 2015 by Australian Synchrotron.
www.synchrotron.org.au/images/newsEventsPublications/)

Australian Synchrotron

Adding value to brown coal research

By Dr David Cookson, Principal Scientist, Australian Synchrotron; and Prof. Sankar Bhattacharya and Prof. Alan Chaffee, Monash University

Australian Synchrotron
Turning bright ideas into brilliant outcomes

MONASH University

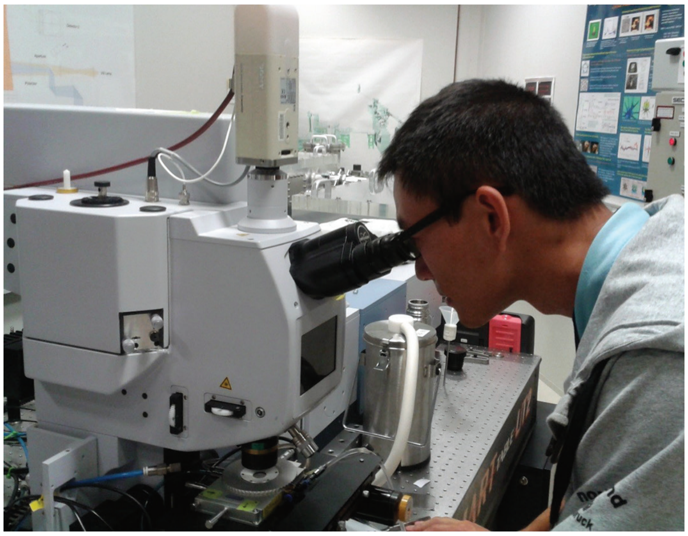
In recent years, Australian science has benefitted from access to the Synchrotron facility located in Melbourne. Dr David Cookson, Professor Sankar Bhattacharya and Professor Alan Chaffee outline some of the BCIA-funded research making use of this facility.

The Australian Synchrotron is one of Australia's most important pieces of scientific infrastructure, a state-of-the-art toolbox of research techniques, about the size of a football field, located in Clayton in Melbourne's south east. It contains a vast, circular network of interconnecting tunnels and high tech apparatus. To its users, who come from industry and academia across Australia and New Zealand, the Australian Synchrotron offers a highly intense and reliable source of malleable light, from infrared to hard X-rays, which is channelled and focused to provide new insight into the composition and behaviour of materials.

The light beams are produced by forcing high-energy electrons to travel in a circular orbit using strong magnetic fields. The interaction of the magnetic fields with the electrons, which travel at just under the speed of light (about 300,000 km per second), creates extremely bright synchrotron light, a million times brighter than the sun, which travels into one of ten experimental workstations, called beamlines. The characteristics of the light means synchrotron-based experiments are typically more accurate, more detailed, more specific and faster than those obtained using conventional laboratory equipment.

The Australian Synchrotron is a unique facility that allows experiments to be conducted that could not be performed anywhere else in the country. Since commencing operations in 2007, the Synchrotron has facilitated a huge diversity of research activities, ranging from medical and life sciences to advanced materials and engineering, and from earth and environmental sciences to accelerator science and synchrotron research methods. Data produced at the Australian Synchrotron has contributed to more than 2,000 publications in leading international peer-reviewed journals.

Access to 'beamtime' at the Australian Synchrotron is highly competitive. Reflecting their quality and that of their work, some of the students involved in BCIA-funded research projects have been awarded beamline access as merit users, due to the innovative nature of their research and its focus on practical outcomes. These include the following BCIA-funded projects supervised by professors Sankar Bhattacharya and Alan Chaffee.



PhD student Mr Tao Xu at the Department of Chemical Engineering at Monash University (funded by the BCIA and China Scholarship Council) using the Australian Synchrotron's Infrared Spectroscopy (IR) beamline examining the evolution of surface functional groups from brown coals with temperature.

Australian Synchrotron
Adding value to brown coal research (cont'd)

- **Entrained flow gasification of brown coals**
  Ms Joanne Tanner, Mr Tao Xu, Ms Sunaina Dayal, and Dr Srikanth Srivats
- **Catalytic synthesis of chemicals following gasification**
  Mr Bayzid Kabir
- **Electrode stability in the presence of brown coal for Direct Carbon Fuel Cell application**
  Dr Adam Rady
- **Chemical looping combustion**
  Dr Sharmen Rajendran and Mr Makarios Wong
- **Activated carbons from brown coal**
  Mr Lachlan Ciddor

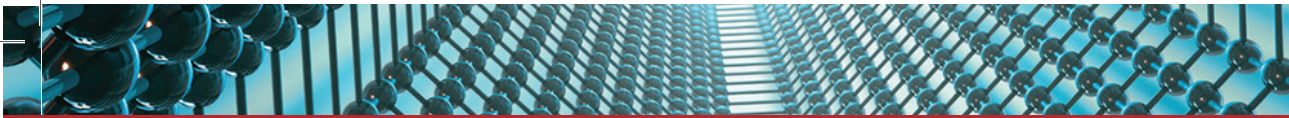
In the course of their research, the students have used four beamlines at the Australian Synchrotron for the following techniques.

- **Infrared Spectroscopy (IR)** – a non-destructive, highly sensitive technique for analysis of microscopic materials, providing information on surface chemistry at a scale of 3–8 μm.
- **Powder Diffraction (PD)** – for structural characterisation of powder or microcrystalline samples. The high brilliance of the synchrotron radiation makes it possible to observe changes in the pattern during chemical reactions, temperature ramps, changes in pressure, etc.
- **Soft X-ray Spectroscopy (SXR)** – featuring X-ray photoelectron spectroscopy, a widely used technique for determining the atomic configuration and chemistry at the surfaces of materials.
- **X-ray Absorption Spectroscopy (XAS)** – used to determine the 'nearest neighbour' environment seen by atoms of a specified element in a material.

Typically, these experiments run continuously for up to 72 hours. A successful outcome requires careful pre-planning and the participation of several researchers, along with their supervisor. The information gained from these experiments is combined with standard laboratory based analysis using Gas Chromatography-Mass Spectrometry, Thermogravimetric Analysis and Scanning Electron Microscopy.

The research topics that have been investigated include the following.

- The structural changes occurring inside coal or biomass during drying, pyrolysis or gasification under realistic operating conditions, and the implications for improved design of large scale gasifiers.
- Changes in coal ash behaviour and their relation to viscosity of slags during entrained flow gasification.
- The evolution of gaseous species and trace elements during pyrolysis and gasification, and the implications for the design of gas clean-up systems.
- Interactions between electrolytes and coal minerals under conditions representative of Direct Carbon Fuel Cell operation.
- Interactions between coal minerals and oxygen carriers under conditions representative of Chemical Looping combustion.
- Changes in catalysts during chemicals synthesis from fuel gas following gasification, providing insights into new catalyst design for improved working life.
- Changes in the surface chemistry of activated carbons as a result of different processing conditions.
- Determining the precise structure of new materials with CO_2 capture potential.
- In-situ observation of changes in the crystallinity of CO_2 adsorbents that develop during use.



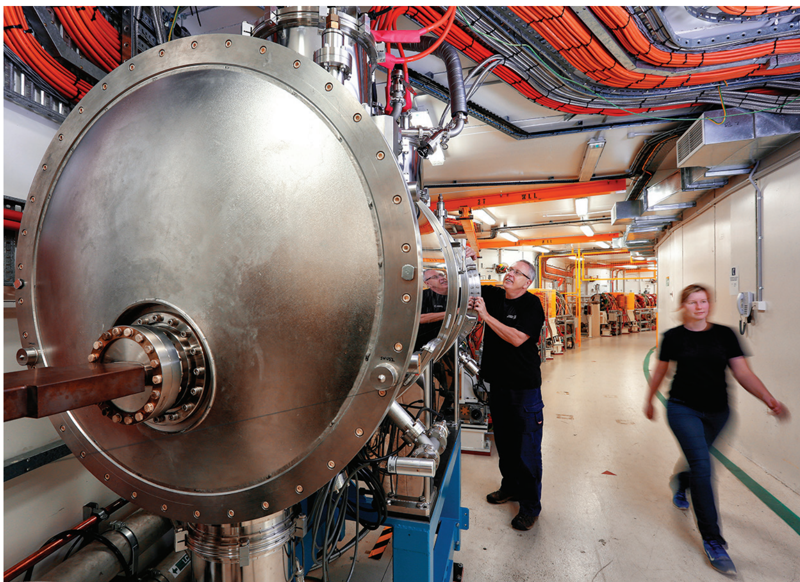
Access to the Australian Synchrotron has allowed brown coal researchers, including those at Monash University described above, to undertake detailed investigations that would otherwise not have been possible. The insights that have been achieved have contributed substantially to efforts to improve the applications of Victorian brown coal.

In addition, the students involved have gained invaluable training that will be of benefit to their careers. Two of the students are now working as scientists in the US and Sweden, and another will soon start work in Germany.

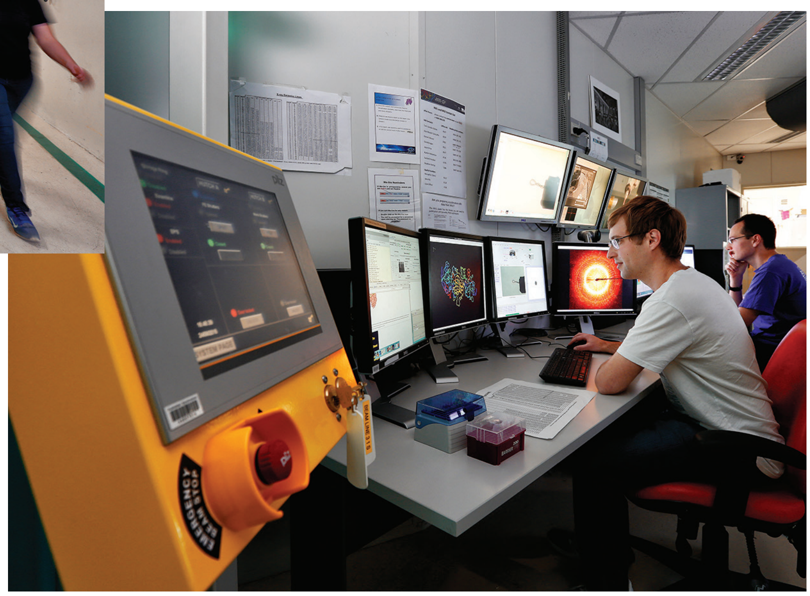
Australia's synchrotron: Open for international business

The Industry Support Team at the Australian Synchrotron is dedicated to supporting industrial users. By drawing on their own expertise and that of their Synchrotron colleagues, the team facilitates the design and execution of cutting-edge experiments and analysis to help solve pressing industrial problems, reduce technical risk and unlock the potential of new products and processes for industry clients.

Further information on how the Australian Synchrotron can effectively and confidentially support your industrial research, please visit Australia's Synchrotron website at industry.synchrotron.org.au.



Inside the Australian Synchrotron storage ring, where bunches of electrons travel at close to the speed of light. (Copyright © 2015 by Australian Synchrotron)



Researchers in a beamline station at the Australian Synchrotron. (Copyright © 2015 by Australian Synchrotron)

Australian Synchrotron
Turning bright ideas into brilliant outcomes

Advantages of a BCIA Membership

BCIA is committed to driving a low-emissions future for Australia's world-class brown coal resource. Being a member-based organisation, BCIA facilitates stakeholders to actively participate in the acceleration of technologies for emissions reduction and the development of high-value products derived from brown coal.

BCIA members encompass a broad range of stakeholders within industry, government, research and education, and international coal technology organisations, who are involved in the conversion of brown coal to value-added products and services operating in the brown coal sector.

BCIA membership enables stakeholders to work with like-minded organisations to drive the future of the brown coal sector through active participation in BCIA skills, networking and R&D programmes to ensure brown coal is heading for a sustainable future.

For more information about BCIA membership please visit bcinnovation.com.au/Membership. If you are interested in becoming a BCIA member, call us on +61 3 9653 9601 or email info@bcinnovation.com.au.

Key benefits of a BCIA membership

- **Commissioned Research Reports** including intelligence gathering and in-depth analysis of global activities and R&D.
- **Research Reports and Symposiums** with the ability to inform and identify focus areas for BCIA sponsored PhD projects.
- **Seminars and Published Reports** on BCIA's extensive research programme including development and demonstration projects.
- **Access to a Wide-ranging Expertise** in including access to our MEMBERS only web portal.
- **Participation in BCIA's Skills Development** activities, international linkages and networks and community forums.
- **Recognition** of each member organisation's commitment to a low-emissions future for brown coal with opportunity to promote member organisation through the BCIA newsletter 'Perspectives' and website.

BCIA MEMBER

Positioning brown coal for a low-emissions future

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