PERSPECTIVES ON BROWN COAL
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BROWN COAL INNOVATION AUSTRALIA
Positioning brown coal for a brighter future

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In this issue:

SPOTLIGHT ON BCIA

CEO's Update

Expanding the horizons for coal research

Over the past five years of operations, BCIA has funded research projects that have led to over 30 students being enrolled in higher-degree research in brown-coal related areas. Many of these students are now writing up, or have recently completed their PhD studies, have recently taken up new jobs, or are currently seeking employment in the area.

In the Skills section on page 9 you can see brief status updates from some of our brown coal alumni, and in this issue we also feature three excellent projects being undertaken by PhD candidates.

Adam Rady provides an overview of his work on using brown coal in direct carbon fuel cells – and shows that Victorian coals work surprisingly well in this application.

David Stokie provides an update on recent progress in steam fluidised bed drying of brown coal – his investigations into the physical and chemical changes of coals that have been through a drying process may be interesting to companies seeking to establish new coal-to-products applications.

BCIA members will soon receive copies of our Research and Technology review for Oxygen Blown Gasification. In parallel to the development of this report, Sunaina Dayal has been working on a project with Monash University and Mitsubishi Heavy Industries in the area of coal gasification.

Sunaina reports on the work done on understanding brown coal slag viscosity under the conditions to be found in an oxygen-blown entrained flow gasifier. This has shown that some brown coal deposits are more suited than others for this application.

BCIA funds research with the aim of accelerating, de-risking and optimising the potential for environmentally sustainable uses of brown coal. An important aspect of this is to ensure that projects progress from the laboratory bench to demonstration and deployment.

While BCIA does not take an intellectual property or equity ownership position in the technologies we support, we are able to provide advice, assistance and introductions to potential partners that will help in moving technologies along the commercialisation pathway.

As such, we are delighted to announce that the UNO technology for CO2 capture – for which BCIA provided research funding – has been taken up by a new company; UNO Technologies Pty Ltd.

UNO was formed to commercialise a range of globally relevant CO2 capture technologies and services. On page 4, Barry Hooper provides an overview of how this company will contribute towards the transition to a carbon neutral future in the second half of this century.

BCIA's membership continues to grow, and in this edition of Perspectives, it is the turn of Greenpower Energy Limited to share with us their plans for conversion of brown coal to a range of chemical products.

In this issue of Perspectives you will also find information on how BCIA is developing an industry driven research agenda for the next four years, as well as details on our recent events and activities.

As always, I trust that you will enjoy this issue of Perspectives.

PAGE 2 and 3

UNO Technology Pty Ltd

By Barry Hooper, Director of UNO Technology P/L

UNO TECHNOLOGY
Towards a carbon neutral future

Since our inception in 2009, BCIA has funded a variety of carbon capture projects – and provides assistance to help these research activities turn into demonstration and deployment of novel low emissions uses of brown coal. We are delighted to report that a new company has been established to take forward one of the BCIA-funded technologies, together with a range of globally relevant CO_2 capture technologies derived from work done at both the University of Melbourne and Monash University through the CO2CRC. Barry Hooper explains.

In April this year a new Victorian company emerged in the Carbon Capture and Storage (CCS) space, through the signing of a deal between CO2CRC and UNO Technology Pty Ltd. Commercial deployment of CCS will be essential for the transition of fossil fuels to a carbon neutral future in the second half of the 21st century.

UNO Technology and its principals, who have been involved in and committed to, the drive for low emissions CCS solutions for many years, are enthusiastic at the opportunity to continue the next stage of developing and scaling up the technologies.

UNO Technology

The UNO Technology suite is based on potassium carbonate absorption/stripping solvent processes which have many benefits over current technologies applied in the coal and other fossil fuel industries. These include low cost, low energy usage, low environmental life cycle impacts and the potential for revenue from both by-products and valuable chemical commodities.

This world-leading research has produced seven international patents in the USA, Canada and Australia, with others pending. The work is founded on the need to drive down costs of capture and to do so across the three key themes of:

- providing novel capture processes
- equipment that is fit for purpose to the new world of bulk CO_2 removal, and
- the need for well integrated process designs.

The UNO Technology patents and ideas address each of these areas and details can be found at our website (www.unotech.com.au).

This work has developed over many years through basic research here in Victoria within the CO2CRC's partner universities and then on to lab and plant based trials which were also strongly supported by the BCIA and Victorian Government funding. UNO Technology has expertise in four key areas, outlined as follows.

Process 1: Liquid Potassium Carbonate Solvent Systems

The UNO MK 1 & 2 processes selectively remove carbon dioxide from both post and pre-combustion applications. Plant based trials have been completed in both applications demonstrating oxygen and high temperature tolerance, low volatility and minimal environmental impact. In particular the pre-combustion version of the technology takes the well proven potassium carbonate technology to new territory, providing improved thermodynamic separation efficiency and process integration opportunities previously unidentified in IGCC applications.

Process 2: Precipitating Potassium Carbonate Solvent System

UNO MK 3, the flagship of the UNO suite, selectively removes carbon dioxide from both post- and pre-combustion applications using a slurry form of the potassium carbonate process. Costs are anticipated to be 50 per cent less than the current best amine technologies due to the low energy of regeneration, low raw material cost, low solvent loss and replenishment requirements, smaller equipment, removal of pre-treatment equipment and multi-impurity capture of SO_X and NO_X. Preliminary work also suggests it can be beneficially applied to emerging power technologies such as DICE.

There are minimal health and safety risks associated with the UNO process as it uses a chemically benign solvent akin to baking soda. It exhibits low environment impact with low volatility, low emissions and low carbon footprint and performs better than amine-based solvents on a broad range of environmental indicators. Potassium can be diverted from the fertiliser production chain to the UNO MK 3 process for CO_2 capture and returned as potassium sulphates and nitrate fertilisers (see Figure 1).

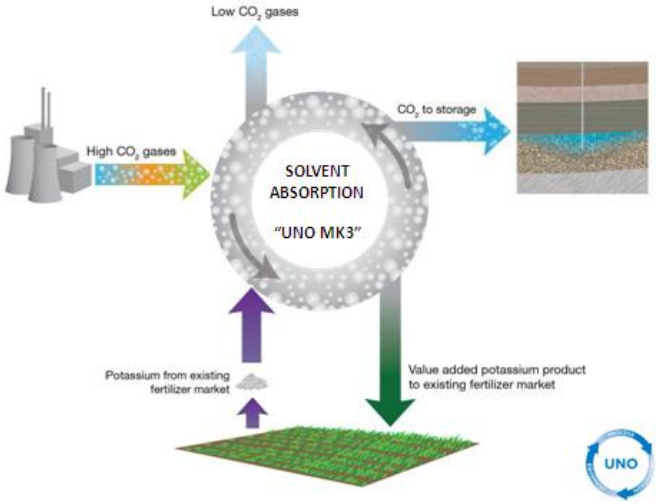


Figure 1. Diagram showing UNO technology's fit with the potassium supply chain
(Image courtesy of CO2CRC)

Equipment: Large Scale Single Stream Contacting Systems

Novel processes are key to driving down costs – but reducing equipment costs is no less important. UNO Technology has patented a novel contactor concept covering a range of configurations, including a large scale single stream concentric absorption/stripping column.

The concentric design is suitable for large scale implementation, with the potential for improved liquid and gas distribution, enhanced CO_2 absorption and reduced equipment size.

Capital cost can be reduced by as much as 50 per cent. Concrete construction will enable larger diameters than those available in steel, and facilitates on-site construction with lower cost material. Use of geo-polymers can reduce CO_2 emissions associated with producing cement construction material, with the potential to use on-site derived fly ash material. This innovation can be applied to all solvent capture processes.

Process and Heat Integration: Multi-objective Optimisation

This methodology and software provides a powerful tool for optimising energy usage and economic performance of retrofit and new-build CCS processes. As well as being an integral tool for low cost designs, multi-objective optimisation can help in developing retrofit pathways that may lead to accelerated uptake of CCS.

Development Pathway

The UNO technologies have moved progressively from ideas, to bench scale testing, plant based trials and large scale engineering designs. This has allowed the Technology Readiness Level (TRL) to build steadily. The company greatly appreciates the contributions of the CO2CRC, BCIA, the Victorian Government and industry who have supported this work over the years.

The next phase of development is to work with industry partners, collaborators and investors to take the UNO technologies to full commercial scale. Initial pathways for this development have been developed and we have commenced discussions with a number of interested parties both in Australia and overseas. We welcome the opportunity to discuss our ideas and solutions with companies who are keen to move towards a carbon neutral future.

Join with us in driving down the cost of CO2 capture (www.unotech.com.au).

Barry Hooper is the Director of UNO Technology P/L and well known in the CCS space. Until recently he was the Chief Technologist and formerly Capture Program Manager of the CO2CRC and was on the Executive from its inception in 2003. He is an A/Prof at The University of Melbourne and a Science Leader with ANLEC R&D.

PAGE 4

Why Direct Carbon Fuel Cells love Victorian Brown Coal

By Adam Rady, PhD Candidate at Monash University and CSIRO (Supervisors: Professor Sankar Bhattacharya, Assoc. Prof. Bradley Ladewig, Dr Giddey and Dr Badwal)

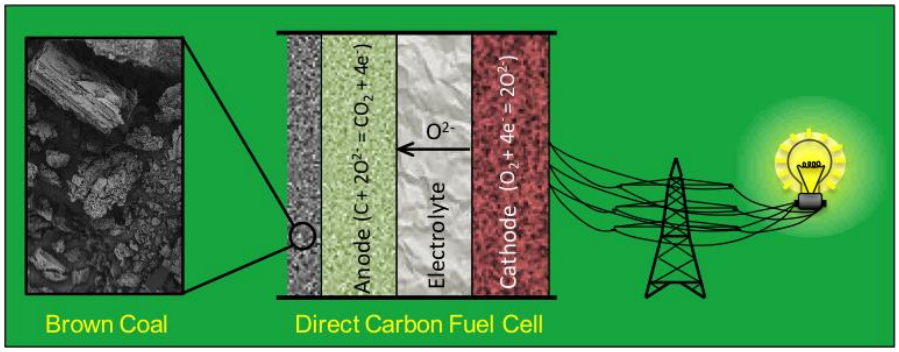
Direct Carbon Fuel Cells combine carbon and oxygen to produce energy, and provide the promise of producing highly efficient electricity generation together with a high purity CO2 stream suitable for geological sequestration. It turns out that Victorian brown coal is a highly suitable fuel for such fuel cells – as Adam Rady explains.

My PhD project started in 2011 as a collaboration between CSIRO and Monash University, to investigate Victorian brown coal as a viable fuel for DCFC. I started working at Monash University on coal preparation and characterisation.

This work was supervised by Prof Bhattacharya, and used Monash's extensive coal processing and characterisation facilities. I then performed most of the fuel cell testing work at CSIRO, where extensive infrastructure and facilities already existed.

CSIRO has been developing the direct carbon fuel cell (DCFC) technology since 2008 because of the advantages that direct carbon fuel cells offer over other power generation technologies. In general, fuel cells can efficiently convert the chemical potential in a fuel directly into electrical energy.

DCFC is the only fuel cell capable of operation on a solid fuel, and does so at the highest efficiency of any fuel cell type (>60 per cent total system efficiency), ie. roughly twice that of current coal-fired power stations. In addition, the resulting concentrated CO_2 product stream would dramatically reduce the energy penalties associated with CO_2 capture and storage (CCS).



Graphical Abstract from Rady AC, Giddey S, Kulkarni A, Badwal SPS, Bhattacharya S, Ladewig BP. Direct carbon fuel cell operation on brown coal. Appl Energy. 2014;120:56-64.

Much of the initial DCFC research by many groups had concentrated on using carbon black as the fuel to establish benchmark and technology feasibility. While carbon black provides a reliable and clean fuel for laboratory-based research and materials development studies, it is not a viable future fuel for the large-scale operation of a stationary power generation system.

It is therefore necessary to trial readily available 'real-world' fuels and understand how their properties affect important parameters of fuel cell operation. Filling this knowledge gap is a primary goal of my project.

Victorian brown coal is a particularly promising fuel for use in DCFCs due to the low ash content and the reactive nature of the coal. Laboratory scale testing of partially charred coals from the Morwell mine has produced exceptional results, out-performing the benchmark carbon black fuel.

What is it about Victorian brown coal then that DCFCs love so much?

- Low ash content (but what's there is the right stuff)
- High Boudouard gasification reactivity
- A surprisingly acceptable electrical conductivity

The contribution of inorganic matter in Morwell coal, namely Ca, Fe, and Mg, to Boudouard gasification catalysis is well documented. Since CO_2 is the primary product of carbon consumption in the cell and is produced at the anode in the presence of the carbon fuel, a reactive char will convert the CO_2 to CO in a timely manner.

This CO can then also be used by the cell as a fuel, generating additional current and CO_2, and setting up a cyclic mechanism in the gas phase. The parallel reactions of solid carbon consumption and gaseous CO consumption extend the fuel cell's performance to higher currents and power output.

Less reactive fuels such as carbon black aren't able to capitalise on the gas phase reactions of the fuel cell, instead relying on the reaction of solid carbon particles in direct contact with the anode.

A demineralised (acid washed) Morwell char was also produced and tested in the DCFC and performed similarly to the carbon black. The results of this study have been published in Applied Energy (http://dx.doi.org/10.1016/j.apenergy.2014.01.046).

CSIRO has developed the concept of using mixed ion electron conducting (MIEC) fuel electrode (anode) to shift the reaction zone from anode/electrolyte interface to anode/fuel interface specifically to cater for direct solid fuel reactions.

Thus a family of new electrode materials has been developed by CSIRO to produce practical power densities. One of the anode materials that performed well with clean carbon fuels, was found to be unstable with Morwell char, and as a result, new anode materials are now under development.

Work has also been performed at the Australian Synchrotron to investigate the stability of a range of anode materials in the presence of Morwell char, and a new family of materials has been identified for the improved stability of the anode in DCFC environment.

This project is in the write-up phase and experimental work is being finalised. This includes the testing of carbon black doped with common inorganic impurities found in Morwell char to further understand the contribution of these components to cell performance. This study exploring the use of brown coal in a DCFC has resulted in three journal papers, with more to follow.

PAGE 5 and 6

Steam Fluidized Bed Drying of Victorian Brown Coal

By David Stokie, PhD Student in Energy, Fuels and Reaction Engineering Group, Department of Chemical Engineering, Monash University

Brown coal represents a large resource for Victoria, with reserves sufficient for over 500 years at the current rate of consumption. However, the high moisture content of Victorian brown coal impedes its efficient utilisation. Current estimates show that the energy needed to dry the coal represents 20 – 25 per cent of the fuel's heat of combustion.

Coal drying is essential for improving the efficiency of brown coal power plants and processes. Many different drying technologies have been successfully commercialised or are in the late stages of development, however none have succeeded in completely addressing the environmental, economic and efficiency challenges inherent in power generation from moist, low rank coals.

The wide range of methods is due to the heterogeneous nature of low rank coals, which vary in moisture content and in physical and chemical composition. Due to the specific nature of the drying technologies, many of which have been developed with a particular fuel in mind, an ideal drying technology for one low rank coal may be inefficient and ineffective for another.

Steam fluidised bed drying (SFBD) was originally developed at Monash University by Professor Owen Potter in the 1970s. While the original process involved a single stage fluidised bed, many variations have been developed subsequently to increase the drying efficiency.

RWE in Germany has developed the internal waste heat utilisation system (WTA), which uses slightly superheated steam to dry the coal. Victorian brown coal power stations do not produce superheated steam, but it would be possible to integrate SFBD into a power station by using low grade steam, resulting in a cycle which has comparable or lower energy requirements for moisture removal.

Information on drying kinetics, chemical composition, physical changes, and the resultant combustion properties are not readily available. Investigating these factors will give a greater understanding of the practicality of steam fluidised bed drying for Victorian brown coal.

Such information is also required for scale up and eventual commercialisation of steam fluidised bed drying in Victoria. Investigation of steam fluidised bed drying at Monash University has involved the design and building of several small-scale fluidised beds (see Figure 1) and has been split into several objectives:

Analysis of the physical characteristics of fluidised bed dried Victorian brown coals

Changes in the internal structure of the coal particles during drying are not well understood. The surface area and porosity of the coal may affect the rate of moisture re-adsorption after drying.

Particle attrition of Victorian brown coal is a significant issue for the drying of brown coals. The vigorous nature of fluidisation, coupled with the comparatively weak structural strength of Victorian brown coals, has the capacity to cause a large amount of particle damage. The decreasing particle size increases elutriation loss and changes the fluidisation characteristics in the bed. Understanding how the particle size changes as a function of moisture content, particle size and residence time is imperative to better control of fluidised bed conditions.

Analysis of the chemical characteristics of fluidised bed dried Victorian brown coals

During the drying process, it is expected that Victorian brown coal will undergo a change in chemical composition, which may affect downstream processes. There is limited information available on the changes in chemical composition during drying, particularly to oxygen functional groups, and how this is affected by specific drying variables. We are working to develop a better understanding of these changes.

Another form of chemical analysis of the dried coal generated is the effect of drying conditions on the impact of combustion and gasification reactivity. Investigation of combustion and gasification at laboratory scale can be used as a measure of the effectiveness of the coal for power generation and production of value-added chemicals. Understanding and confirming the applicability of specific drying techniques is essential for use in an industrial implementation.

Analysis of the moisture re-adsorption of dried Victorian brown coals

Because of Victorian brown coal's strong hydroscopic potential, fully dried coal will very quickly re-adsorb moisture if left exposed to the atmosphere; however the impact of the drying method on the re-adsorption potential has not been examined. This is important because of the possibility of delays in combustion of the fuel. Any moisture which re-adsorbs will lower efficiency once it is combusted, so understanding the impact of drying methods may allow better control of the drying conditions.

Determination of the drying kinetics of Victorian brown coal with steam and hot gas as drying mediums

While drying kinetics have already been investigated through different drying technologies, coals and conditions, relatively little information is publicly available regarding using steam as a fluidising medium in conjunction with Victorian brown coal.

The influence of system parameters on the drying of coal is well-established; however, the relative change in drying ratios between similar properties at different fluidisation mediums has yet to be discussed. Using a laboratory scale fluidised bed, these aspects have been investigated and can be found in Figure 2 and Stokie et al. (2013).

Development of a drying model to predict drying rate in fluidised beds

While fluidised bed models of coal drying do exist, there are still gaps in current methods of calculation. We are working to develop a model that can capture the underlying kinetics and attrition of the dried coals, while being easy enough for engineering use. Once validated, the model will be expanded to include a particle set sized system instead of a single averaged particle diameter. Finally, the attrition results will be incorporated into the existing model, to increase the accuracy of the drying model.

This project is currently well advanced, and has enjoyed collaboration with international universities including the University of Science and Technology, Liaoning. For any further information on current work please feel free to contact Professor Sankar Bhattacharya (sankar.bhattacharya@monash.edu), David Stokie (david.stokie@monash.edu) or consult any recent publications:

- D. Stokie, J. Yu, A. Auxilio, S. Bhattacharya, Coal Drying and Dewatering for power generation – Current Status, Research and Development Needs, International Conference on Coal Science and Technology, International Conference on Coal Science & Technology Oviedo, Spain 2011
- D. Stokie, M.W. Woo, S. Bhattacharya, Comparison of Superheated Steam and Air Fluidized-Bed Drying Characteristics of Victorian Brown Coals, Energy & Fuels, 27 (2013) 6598-6606
- M.W. Woo, D. Stokie, W.L. Choo, S. Bhattacharya, Master curve behaviour in superheated steam drying of small porous particles, Applied Thermal Engineering, 52 (2013) 460-46
- D. Stokie, S. Bhattacharya, J. Tanner, Physical and Chemical Properties of Steam Fluidized Bed Dried Coal, The 38th International Technical Conference on Clean Coal & Fuel Systems Clearwater, Florida, USA, 2013, pp. 11
- Tahmasebi, Arash; Yu, Jianglong; Han, Yanna; Yin, Fengkui; Bhattacharya, Sankar; Stokie, David, Study of Chemical Structure Changes of Chinese Lignite upon Drying in Superheated Steam, Microwave and Hot Air, Energy & Fuels,
- D. Stokie, M.W. Woo, S. Bhattacharya, Attrition of Victorian Brown Coal in a Fluidized Bed Drier, In Submission.

Figure 1: Continuous fluidised bed

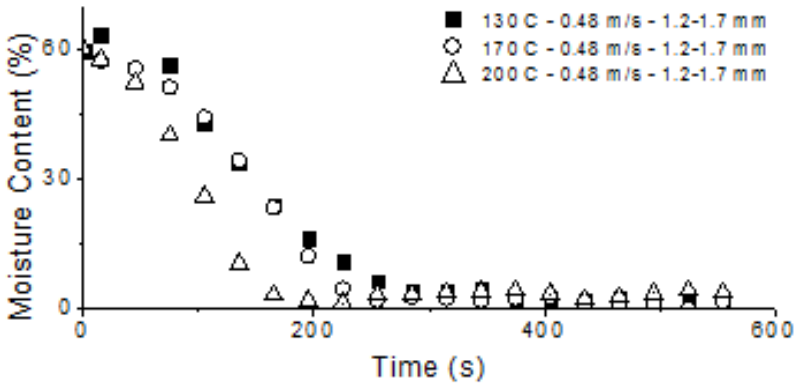


Figure 2: Typical steam fluidised bed drying kinetic data

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Slag behaviour during entrained flow gasification of Victorian brown coals and other lignites

Ms Sunaina Dayal, PhD Student in Energy, Fuels and Reaction Engineering Group, Department of Chemical Engineering, Monash University

Oxygen blow, entrained flow gasification of brown coal may be an important future route to low-emissions products. This technology utilises relatively high temperatures, meaning that the ash content of the coal melts to form a flowing slag. Sunaina Dayal reports on her PhD project to investigate the behaviour of brown coal under the conditions that would be encountered in an oxygen-blown gasifier, and her results including predicting and modifying slag viscosity with flux agents.

Victorian brown coal is an economical and important source of energy for the state of Victoria, accounting for approximately 85 per cent of all electricity generated. At the current rate of consumption, these brown coal reserves are expected to last for more than 500 years.

Conventional combustion of brown coal results in high CO2 emissions. However Victorian brown coal contains low levels of ash and is highly reactive once dried - attributes that make Victorian brown coal an ideal candidate for gasification, which can deliver a significantly lower CO2 footprint.

Gasification is a process where solid fuels like coal react with gases like air or oxygen, steam and carbon dioxide to produce fuel gas which can then be used directly for power generation, or as a raw material for manufacture of other chemicals or fuels.

Between 1992 and 2003, considerable research and development work was carried out on brown coal gasification at relatively low temperatures (around 900C) using pressurised fluidized beds and transport gasifiers. Due to the low temperatures, these processes suffer from low carbon conversion and agglomeration. An alternative process is entrained flow gasification process, where under higher temperatures (resulting in a high carbon conversion) the ash fuses to a molten state to form a flowing slag, avoiding agglomeration. The liquid slag viscosity should be low enough to enable slag to flow down the gasifier walls and drain out from the gasifier in molten form. The benchmark for continuous slag outflow is set by a maximum slag viscosity value of 25Pa·s (250 Poise).

Overall plant efficiency can be improved by lowering the ash flow temperature (AFT) below the operating temperature of slagging gasifiers (1400-1600^{o}C) – fluxing agents such as limestone and clay can be blended with coals in order to achieve this. Therefore, information on composition, viscosity and the change of viscosity with temperature for coal ash slags is essential for efficient operation of slagging gasifiers. Other assisting facets such as mineral phase transformations and trace element emissions also require further investigation.

My project aims to generate this information by focussing on the following aspects:

Design and construction of a viscosity measurement assembly

This assembly is constructed based on similar experiments previously conducted for high temperature viscometry. The key features of this specially designed assembly include a high temperature furnace, and a viscometer with a spindle and bob arrangement. This arrangement enables measurements of viscosity over a range of temperatures where the slag is expected to be in a molten state.

Examine applicability of existing viscosity models and development of a new model

Existing viscosity models developed for high-rank coals have been applied to Victorian brown coals to determine their suitability. The predictions varied wildly for the three coals that were tested and trends provided by experimental results also differed largely from those given by these models. Therefore, the next step was to conduct further systematic experimental work to develop new models to yield results specific to these coals.

Investigate trends for brown coal using a thermodynamic software package

Various modules of a commercial software are used for estimating different trends for the ashes. The percentage of liquid and solid content at different temperatures, the typical phase changes, and changes in viscosity with temperature are predicted using this software. Effects of flux addition on these properties can also be examined through these modules.

Characterisation of ash and slags

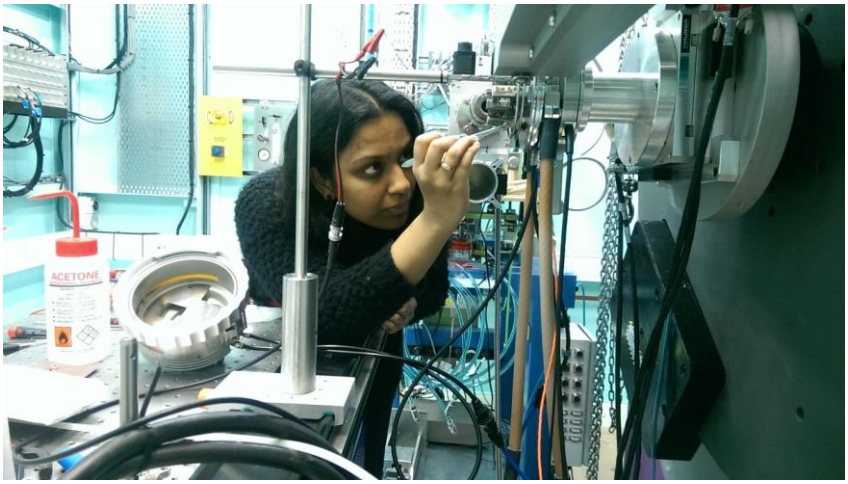
Various analytical techniques such as X-ray fluorescence, In-situ high temperature X-ray diffraction, room temperature X-ray Diffraction, Hot Stage Microscopy, Thermal Analysis, and Scanning Electron Microscopy are used to provide important information such as ash composition, ash fusion temperatures, phase changes in the slag at different temperatures, and trace element composition. This information along with the experimental and modelling work will allow the establishment of a temperature range for applying entrained flow gasification to Victorian brown coals. The lower the temperature that achieves full carbon conversion at an acceptable fuel gas quality, the better the overall efficiency.

Recently, a synchrotron application for high temperature in-situ x-ray diffraction was approved and experiments conducted for different ash samples including some with flux additives. These experiments will shed more light on the change of different mineral phases with increasing temperature in a CO_2 environment and this information will then be related to viscosity changes of the ash as it transforms into slag.

This is the first-ever research project on oxygen-blown entrained flow gasification of Victorian brown coal. The results so far indicate that one coal may not require any fluxing material, while two others will benefit from the addition of calcium based flux. The type of flux and its proportion is being established through this project.

This project has international partnership with Mitsubishi Heavy Industries (MHI), Japan and we have also formed collaboration with Julich in Germany. Both MHI and Julich provide valuable industrial and scientific input into the project, assist in several analyses and measurements, and provide standards for comparisons for our own results.

My project complements two other BCIA-funded projects on entrained flow brown coal gasification carried out by Ms Joanne Tanner and Mr Tao Xu. These research projects are also first-of-their kind on entrained flow gasification of Victorian brown coals and are also supervised by Professor Sankar Bhattacharya.



Above: Sunaina Dayal preparing for the experiments at the X-Ray Diffraction beamline at the Australian Synchtroton

PAGE 9

International Skills Development and Student Seminar

BCIA is committed to both skills development for new low-emissions brown coal technologies and the creation of new commercial opportunities for such technologies.

Our company seeks to support collaborative projects that help to create strong links with leading overseas organisations with brown coal expertise. One of the ways we do this is by supporting international exchanges and workshops, with the strong involvement of PhD students.

Previous newsletters have highlighted several examples of this. BCIA recently provided support for Joanne Tanner, a PhD student at Monash University, to travel to Germany to undertake experimental work at Karlsruhe Institute of Technology and Forschungszentrum Jülich GmbH (FZJ). This exchange has helped to build and strengthen the relationship with FZJ, providing Australian students with direct access to world-leading expertise in ash and slag chemistry.

Dr Lian Zhang's pilot-scale oxy-fuel combustion project has been an effective vehicle for building strong linkages with Shanghai Boiler Works Co Ltd (SBWL), the second-largest boiler manufacturer in China. Dr Zhang's project involves regular trips to Shanghai to participate in trials of oxy-fuel combustion of Victorian brown coal in SBWL's pilot boiler facility, including Dr Zhang himself, postdoctoral research fellow Dr Jian Zhang, and PhD students Baiqian Dai, Wirhan Prationo and Anthony De Girolamo. In return, SBWL has seconded three employees, Dr Xiaojiang Wu, Dr Kai Yan, and Dr Xueyuan Xu, to work at Monash University for a year each, with funding assistance from ATSE/JCG.

In a previous *Perspectives* newsletter issued in March, we reported on an *Australia-China Oxy-fuel Combustion Workshop* hosted by Dr Lian Zhang with ATSE/JCG support. This brought experts on oxy-fuel combustion from China, Australia, Germany, Japan, Sweden and the USA for two days of fruitful discussions. International exchanges and workshops such as these help to break down the barriers of distance and cultural differences, and build the cooperative and constructive relations that are needed to foster new commercial brown coal developments in Australia.

These international relationships are also incubated through the diverse multicultural backgrounds of the PhD students currently engaged in brown coal research. This was highlighted recently, when BCIA ran a one day seminar for early career researchers, '*Opportunities for higher degree students in low emissions coal technologies'*, which was followed by a networking event.

This provided an opportunity for early career researchers to showcase their projects to their peers, companies and research institutes involved in the brown coal industry. It also highlighted the growing number of international linkages that are being leveraged in local brown coal student projects, including companies and universities in both China and Japan.

Over 20 student presentations were delivered, and students had the opportunity to try their hand at chairing the sessions. The quality of presentations and the overall success of this seminar proves that the future of coal research is in good hands. Presentations provided on the day were:

- Kazi Bayzid Kabir, Monash University - Catalytic Gasification and Assessment of Dimethyl Ether Synthesis from Victorian Brown Coal
- Joanne Tanner, Monash University – Laboratory Techniques and Apparatus for Entrained Flow Gasification Studies
- Sunaina Dayal, Monash University - Slag Viscosity: Entrained Flow Gasification of Brown Coal
- Anthony De Girolamo, Monash University - Developing an Advanced Computer Modelling Program for the Prediction of Brown Coal Ash Slagging/Fouling Propensity under Oxy-Fuel Combustion Mode
- Kawnish Kirtania, Monash University - Entrained Flow Pyrolysis and Gasification of Selected Biomass - An Experimental and Modelling Study
- Tahereh Hosseini, Monash University - Investigating Leaching Behaviour of Fresh and Weathered Victorian Brown Coal Fly Ash using Hydrochloric Acid and Ammonium Chloride as Leaching Agents
- Anita D'Angelo, Monash University - Cerium Based Oxides as Oxygen Selective Sorbents
- Jinchen Ma, Monash University/Huazhong University of Science and Technology - Experiments of Cold Flow and Thermal Interconnected Fluidized Bed Reactor of Chemical Looping Combustion
- Sharmen Rajendran, Monash University - Chemical Looping Combustion of Victorian Brown Coal
- Baiqian Dai, Monash University - Enhanced Precipitation of Magnetic Iron from the Fly Ash Generated During the Combustion of Lignite Mixed with Silica Additive
- Christian Vogt, Monash University - Improvements in the Working Capacity of a MgO-Cs2CO3 Mixed Sorbent for Pre-Combustion CO2 Capture
- Alicia Reynolds, Monash University - Degradation of amine solvents during PCC of CO2 from a Victorian brown coal-fired power station
- David Stokie, Monash University - Steam Fluidized Bed Drying of Victorian Brown Coal
- Shah Taghavi, Monash University - Effect of Hydrothermal Dewatering of Morwell Brown Coal on Spontaneous Combustion Behaviour
- Mohammad Reza (Mehrdad) Parsa, Monash University - The Effect of Densification Process of Brown Coal on its Spontaneous Combustion Propensity
- Hirra Azher, University of Melbourne - Separation Performance of Polymeric Membranes for Water Separation from Brown Coal Flue Gases
- Manabendra Saha, University of Adelaide - Flameless/MILD Combustion of Solid Fuels
- Adam Rady, Monash University - Assessing the Performance of Victorian Brown Coal in Direct Carbon Fuel Cells (DCFCs)
- Karen Little, Monash University - The use of Commercial Brown Coal-Derived Amendments for Pasture Growth and Soil Health
- Mamun Mollah, Monash University - Attempted Production of Blast Furnace Coke from Victorian Brown Coal
- Rahmat Dirgantara, RMIT University - Victoria-Latrobe Valley Brown Coal Fly Ash Geopolymer Mortar

It was great to see strong interest from a range of executives in research and industry witnessing the showcase presentations. The subsequent networking event was kicked off with a number of short five minute presentations from industry and research representatives. The presentations provided an insight into how each individual started out in research and the workforce and the opportunities available within their current fields.

Perhaps one of the most useful outcomes of this event was the personal advice passed on from industry representatives to the early career researchers. The early career researchers were advised not to feel defined by their current research interests and specialist expertise. Rather, their strengths and attributes as researchers will make them valuable assets to a wide range of potential employers and they were encouraged to seek job opportunities that will expand their skill set and build valuable networks for the future.

BCIA supports this view and is confident that current research projects will create enthusiastic ambassadors for the Australian brown coal community and researchers who will continue to build cooperative relationships wherever their career takes them. In this way, the research scientists that we foster will create valuable new opportunities for brown coal in Australia. In the Skills section below, you can see information on where some of the students involved in brown coal over the past few years will be using their skills and expanding their careers.

BCIA Alumni Opportunity

Over the last few years, a number of early career researchers have been involved in BCIA funded projects and activities. We have tried to provide many opportunities to help them in furthering their education and networks within the brown coal area.

Many of these students are now writing up, or have recently completed their PhD projects, with some looking for their next job, and others may have recently started work in an academic or industry career.

We have included this section to update on what students who have worked on recent brown-coal projects are planning to do after their PhD. **Maybe you might have an opportunity that will be right for both of you!**

Sharmen Rajendran - Looking for opportunities to contribute my skills and knowledge to the energy industry.

Baiqian Dai - Looking for a job where I can use my knowledge on coal blending gasification and combustion

Hirra Azher - currently seeking a position in the water treatment or energy industry

Mamun Mollah – I am looking for a position within Blast Furnace Coke area.

Adam Rady - looking for graduate and/or post-doctoral positions with an industry focus in energy

Karen Little - looking for a post-doctoral position to further investigate the benefits of lignite coal to agriculture.

If you would like to make contact with any of our students listed above, please contact Kirstyn Krausz at kirstyn.krausz@bcinnovation.com.au for details.

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What's News at BCIA?

RESEARCH AND DEVELOPMENT

The R&D portfolio is currently in a transition phase, with most projects from the 2010 Funding Round either finished or winding up, and projects in the 2013 Funding Round just getting under way. PhD students are putting the finishing touches to thesis manuscripts prior to submission, while new students are beginning their literature reviews.

Some new projects, which are based on a strong existing base, are already making good progress. A good example is a project being led by HRL Technology, in which O2 and CO laser sensors have been installed in an air heater outlet at Yallourn W Power Station.

The aim of this project is to test whether the advanced laser sensors can provide more reliable and representative gas composition measurements than the standard sensors used throughout the industry. Having successfully installed the two test instruments, HRL Technology will now monitor and assess their performance over the next six months.

The advanced post-combustion capture (PCC) project, to be sited at Loy Yang A Power Station is also off to a good start. This project will involve the installation and operation of a new PCC process which is intended to significantly reduce the cost of capturing CO_2 from power station flue gas. The pilot plant will be designed and built by the Japanese technology company IHI, and operated in collaboration with CSIRO. The pilot plant must be designed to conform to both Japanese and Australian industrial and safety standards, which adds to the complexity of the task. However, good progress is being made, with the final design nearing completion.

The new oxy-fuel combustion project, being led by Monash University, builds on a successful project undertaken through the 2010 Funding Round. The feasibility of combusting Victorian brown coal under oxy-firing conditions has already been demonstrated at Shanghai Boiler Work's pilot test facility. The focus of current work is to further understand the nature of the chemical species produced during oxy-fuel combustion of brown coal, and their likely role in ash formation and metal corrosion. Reaction rate kinetics for evolution of sulphur-containing species are being studied, to improve the quality of the models being developed for the oxy-fuel process. Experimental investigations on ash reactions and tube corrosion are being conducted at Chubu University in Japan, using a specially-constructed horizontal furnace. The highly detailed nature of the work already under way is a direct result of the strong collaborations forged during the previous funding round.

These three projects, like the others in the 2013 Funding Round, are intended to accelerate the deployment of low-emissions power generation technologies in Victoria. Developing practical experience with such technologies will support the long-term sustainable utilisation of Victoria's brown coal resource.

COMMUNICATIONS AND STAKEHOLDER RELATIONS

During recent months, BCIA's 2013/14 Funding Round has generated significant positive media coverage of brown coal low-emissions technology innovation and R&D activity funded by the Victorian and Australian governments; the latter via BCIA's relationship agreement with ANLEC R&S.

In late April this year, an initial five projects awarded BCIA funding were announced by the Victorian Minister for Energy and Resources, Russell Northe, at the opening of the Third Low Rank Coal Symposium held in Melbourne.

Mr Northe told stakeholders at the symposium: "Victoria has a great opportunity to capitalise on projects such as this with its abundant reserves of brown coal which, with the right measures in place

for making brown coal an efficient and sustainable industry, has great potential for boosting the economy.

“That is why the Victorian Government is supporting and investing in projects that can deliver real outcomes for innovating the industry, creating jobs and delivering a sustainable energy source for future demand.”

Publicity of the initial five projects resulted in more than 30 media interviews and articles across radio, television and press including various specialist industry, trade and environmental publications.

In early August, BCIA announced the sixth project to be awarded funding via the 2013/14 Funding Round: Victoria’s first 24/7 capable CO_2 capture facility for brown coal power generation.

The $5M research project combines CSIRO CO_2 capture innovation with that of major Japanese technology vendor; IHI Corporation. The project is targeting a 40 per cent reduction in the energy usage of current plant post combustion capture (PCC) processes for Victorian brown coal-fired power plants.

Capturing CO_2 requires significant power and consequently increases energy costs. The project will see the installation of a $1M Japanese-built PCC pilot plant at AGL Loy Yang Power station; the first in Victoria to operate around the clock.

Announcement of the sixth successful project also generated significant news coverage across a range of mediums including radio, television, press and industry and trade publications. Links to news clippings, interviews and articles can be found at http://www.bcinnovation.com.au/BCIAbrowncoalresearchinthenews on BCIA’s website.

During August, BCIA published a special R&D funding edition of *Perspectives on Brown Coal,* focusing on BCIA’s 2013/14 funding round and an initial six projects awarded research funding.

The response to our call for new opportunities for low emissions brown coal power generation technologies was outstanding. BCIA received 18 research project applications, involving nearly 40 international and Australian based companies and research institutes.

BCIA is hosting a brown coal R&D roundtable forum on 15 October in the Latrobe Valley. The purpose of the forum will be to inform the development of an industry-led brown coal R&D agenda for Victoria that will support environmentally responsible coal development activity. For more information visit BCIA’s News and Events page.

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BCIA now LinkedIn and brown coal research in the news

About five months ago, BCIA developed a company page on the social media site; LinkedIn. The new page provides another way for BCIA stakeholders to connect and show their support for investment in brown coal low-emissions technology innovation.

The BCIA LinkedIn company page also provides another channel for sharing information about low-emissions brown coal research and development.

If you are already have a LinkedIn profile, you can use the link below to access and ‘follow’ BCIA’s company page:
http://www.linkedin.com/company/3700933?trk=tyah&trkInfo=tarId%3A1412128758064%2Ctas%3Abrown%20coal%2Cidx%3A2-1-7 or you can simply search for ‘Brown Coal Innovation Australia on the LinkedIn site.

As outlined in our Communications and Stakeholder Relations update, we have also added a page to our public website which provides links and pdfs of recent news clippings, interviews and articles. The new web page can be found at http://www.bcinnovation.com.au/BCIAbrowncoalresearchinthenews on BCIA's website.

We will be progressively adding to the web page as further news announcements are made, so make sure you check the page regularly or 'follow' our BCIA LinkedIn company page to keep informed.

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BCIA Membership

As a member-based company, BCIA undertakes a range of programs of interest to brown coal stakeholders including industry, research and education providers, governments and international coal technology organisations.

BCIA industry stakeholders encompass a broad range of sectors including coal-fired energy operators, original equipment manufacturers, companies involved in the conversion of brown coal to value-added products and services companies operating in the brown coal sector.

Membership enables BCIA's stakeholders to work with like-minded organisations to drive the future of the brown coal sector through active participation in our skills, networking and R&D programs.

On the next page, you can read about this edition's new member in the spotlight, Greenpower Energy Ltd.

For more information about BCIA membership, contact info@bcinnovation.com.au.

BCIA has updated our membership programs for 2014. Our current members include:

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SPOTLIGHT ON BCIA MEMBER

GREENPOWER ENERGY LIMITED
THE LOGICAL WAY TO USE VICTORIA'S BROWN COAL

Greenpower Energy Limited (GPP) develops processes that convert brown coal into valuable fuels and chemicals.

The Company is focussing on the development of a coal-to-liquids process (Oxidative Hydrothermal Dissolution 'OHD') that converts carbonaceous matter into useful low molecular weight organic chemicals. The process has zero greenhouse gas effects, zero net water consumption and relatively low capex, avoiding all the disadvantages of the Fischer-Tropsch process.

Greenpower, with Illinois-based Thermaquatica Inc., is preparing development of an OHD pilot plant sited in Victoria's Latrobe Valley that will use Victorian brown coal as feedstock. Thermaquatica Inc. is associated with the Southern Illinois University and is carrying out the day-to-day research and development. High level technical and techno/economic input is being supplied by an external specialty engineering firm with extensive experience in similar technologies.

Greenpower also holds a portfolio of coal and hydrocarbon assets in Victoria and Western Australia.

Greenpower also maintains an interest in an early start-up coal conversion technology which has as its output low API hydrocarbons as the main output.

Value Proposition: *When Victorian brown coal is processed by the OHD technology it completely converts to water soluble organic compounds [see photo]. One tonne of ROM (run of mine) brown coal produces over 400kg of these compounds of which 160kg can be applied to the manufacture of bio-degradable plastics, some to the production of transport fuels and also for use in agriculture. The cost of the input materials and the processing of lignite, oxygen and electricity are expected to be substantially less than the cost of sourcing these chemicals by conventional means.*

For more information, visit http://www.greenpowerenergy.com.au/
or call Gerard King on +61(0)418852700 or Alan Flavelle on +61(0)438599252
An additional useful link is: Thermaquatica at www.thermaquatica.com

VICTORIAN BROWN COAL AND OHD LIQUOR

Events Calendar

15-16 October 2014
All-Energy Australia Conference, Melbourne
All-Energy Australia is an annual, free-to-delegate, business-to-business conference and networking forum hosted alongside an impressive exhibition showcasing renewable energy, clean energy, sustainable transport and energy efficiency. Visit www.all-energy.com.au

18-20 November 2014
SD2014 – Science, Society & Sustainability, Adelaide, Australia
Held annually, the Minerals Council of Australia's Sustainable Development Conference is recognised as the leading minerals industry forum to discuss and debate sustainable development and its practical implementation. Visit http://sdconference.com.au/2014/

24-28 November 2014
Engineers Australia Convention 2014, Melbourne
This event expects 10,000 delegates, over 5 days, with 6 conferences in 1 convention. Call for abstracts is now open. For more information visit www.all-energy.com.au

3-5 December 2014
14th Indo-Coal 2014, Jakarta, Indonesia
Exploring and seizing the golden opportunities for a sustainable coal industry in Indonesia. Visit http://www.cdmc.org.cn/2014/ic/

27 Sept - 1 Oct 2015
2015 ICCS&T, MCEC Melbourne
The 15th International Conference on Coal Science & Technology will be visiting Australia for the first time. The conference aims to bring together academic, industrial, and government communities to exchange ideas, concepts and innovations for the shared purpose of facilitating coal research advances. Visit http://www.engineersaustralia.org.au/iccst-2015