Perspectives
ON BROWN COAL

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Dr Phil Gurney
BCIA CEO & Director

International perspectives on coal R&D

The rhetoric around coal is changing once again. Here in Australia, last year's state-wide blackout in South Australia has been the driver for a review of energy security. The focus, at least at a Federal level, is now on how to build an energy system that can not only meet our commitments to reduce emissions, but is also reliable and lowest cost.

Our Prime Minister Malcolm Turnbull has confirmed that his Government will take a technology-neutral approach to reducing emissions. This will include not just wind and solar, but will examine how clean coal and CCS, together with technologies such as pumped hydro storage, can support grid stability and overcome the issues caused by intermittency.

But it is not just Australia that is focused on how technology development in coal and CCS can contribute to the global push towards lower costs and lower emissions. This issue of Perspectives takes in the views of the international community. Gianni Serra, from Sotocarbo, explains how Italy's focus on coal is changing, while Professor Zhenyu Liu of Beijing University looks at the clean coal technology R&D being supported by the 13th five year plan in China.

In America, it is clear that the new administration is taking a radically different approach to the previous one. While only time will tell how this will play out on a political level, Jason Laumb of the EERC in North Dakota presents a view from the technology perspective, looking primarily at the development of CCS in the northern states of the USA. As in many parts of the world, the Czech republic has considerable reserves of lignite. Stephen Mills of the IEA Clean Coal Centre looks at the R&D activities helping to build an environmentally sustainable future for coal in that region.

Our final article in the international perspectives series comes from Joanne Tanner of Monash University. Joanne, who is now a lecturer at Monash, was supported through her PhD by BCIA. The international links that she built through R&D collaborations, particularly with Germany, have helped to shape the successful start to her academic career. Joanne looks at some of the internationally linked R&D projects underway at Monash University, and the benefits to local researchers.

Finally, but by no means least, this issue features the R&D work at Federation University. Federation University has recently built an extensive analytical chemistry lab, located in the Latrobe Valley in Victoria. Rahul Chowdhury shares with us the progress on his work in looking at the effects of fly ash on carbon capture solvents.

As always, I trust that you will find the articles in this issue of Perspectives of interest. If you have a story on the work you are doing, please get in contact - we are always interested to hear from those undertaking work on brown coal developments, whether in Australia or internationally.

INTERNATIONAL PERSPECTIVES ON BROWN COAL R&D

ITALY

Sotacarbo: clean coal will have a say even in a low carbon world

By Gianni Serra, Director, Communications and International Relations, Sotacarbo S.p.A.

In the beginning, it was only coal. Nothing else. Nowadays coal is still there, on top of Sotacarbo's agenda, but not alone anymore. The development of clean coal technologies to reverse the fortunes of the declining coal industry in the Sulcis basin was Sotacarbo's original mission, as fixed by the Italian Parliament in 1985. Despite the imminent closure of the last Italian coal mine, coal research is still pursued and backed by the Italian government, who rates it strategically and of global interest. A very local and one-way perspective is replaced by a wider one.

Since 2014, the Company, spurred by the Ministry of Economic Development and the Sardinian Region, has expanded its range of study to develop various low carbon technologies, including CCS and CCT - the firm has become the largest national reference for both. Sotacarbo is now involved in a mainly three-way research program, which also includes renewable energy sources and energy efficiency.

"Sustainable energy research centre" describes not only Sotacarbo's central facility but also the company mission: *'to study and to develop new technologies able to link environmental and economic sustainability to energy*

production'. Sotacarbo's approach is very scientific, pragmatic, not ideological. No crusade for or against any source of energy but only the desire to explore new routes towards a balanced energy mix characterised by zero or near zero emissions. Through technologies like CCS or biomass co-firing, coal can be seen as a low-carbon energy source, which makes it a perfect fit in a low carbon scenario. Cleaner coal could have a decisive impact on the reduction of emissions because technological development is applicable everywhere and the benefit of an adjustment of the coal power fleet is potentially global - not only the Asian continent will benefit.

Sotacarbo has the know-how and the tools to develop technologies capable of tackling many of the climate change issues. Its modern research centre is located on the restored site of the former Serbariu coal mine in Carbonia (Sardinia, Italy). It comprises several laboratories: Carbon to new fuels; Gas and thermal analysis; CO_2 capture through GAIA plant; Ion chromatography.

The centre also has process plants, including a pilot plant equipped with an air-blown fixed-bed gasifier, fed with coal and/or biomass, integrated by some syngas treatment devices (gas washing, desulphurization, water-gas shift conversion and hydrogen purification), designed to combine power generation and CO_2-free hydrogen production. There is also a demonstration plant, which includes an air-blown fixed-bed gasifier fed with coal and/or biomass, a scrubber and a flare. The thermal power of the pilot plant is about 200kW, and the demonstration plant is about 5MW.

Sotacarbo is also studying the pressurised oxy-combustion process fed with coal slurry and is developing several research projects to optimise the pre-combustion and post-combustion CO_2 capture process through experimental tests on a very flexible gasification pilot platform and amine base solvents and membranes. Also underway is the designing of a trial site for CO_2 injection in an underground aquifer, with the aim to develop advanced drilling technologies and on-site monitoring techniques.

The lucky combination of many former coal mines and the unusual geology of the Sulcis basin provides a favourable condition to test where and how CO_2 storage technologies can be developed.

Consistent with a vision of problems and solutions that extend beyond its national borders is the willingness of Sotacarbo to establish partnership worldwide with the best actors in each of its line of research.

In fact, in 1989 the Italian government chose Sotacarbo, a limited public owned company, to represent the country in the IEA Clean Coal Research. This membership allows Italy to get firsthand the most unbiased data and information available in the world of coal - useful to provide competent inputs and advice to its shareholders, ENEA and Sardinia Regional Government. Being part of an independent international organisation of the highest calibre helps Sotacarbo also to boost its ambitious research and outreach programs.

In the last few years, Sotacarbo has developed several collaborations outside Europe, in China and the USA, with leading universities and state of the art research centres, through data sharing and researchers exchange programs. Sotacarbo hosted the 6th International Workshop on Cofiring biomass in September 2016 and will hold the 8th International Conference on Clean Coal Technologies in Italy in May 2017. Events like these are the ideal platform to expand the collaboration field for Sotacarbo and its guests too.

CHINA

Chinese perspective on priorities of research funding for coal, coal to chemicals and carbon capture and storage

By Professor Zhenyu Liu, State Key Laboratory of Chemical Resource Engineering, Beijing University of Chemical Technology

The 13th Five-Year Plan for Economic and Social Development of the People's Republic of China (the 13th Five-Year Plan of China) has set priorities on optimization of energy structure and protection of the environment. The main measures include making energetic efforts for clean coal, the deployment of technologies and actively responding to the global climate change.

The government funding is managed by various government branches, such as the Ministry of Science and Technology (MOST), the Natural Science Foundation of China (NSFC), and the Chinese Academy of Sciences (CAS). All these government branches fund projects on clean coal technology and carbon capture, utilization and storage (CCUS).

The funding by MOST is through the "National Key Research and Development Program of China" under the "Clean Coal Technology and Novel Energy Saving (Efficient) Technology". The funding totaled 460 million Yuan RMB in 2016 and the projects solicited are:

Category 1. Efficient coal based thermal power generation

- Novel power generation with supercritical CO_2 and CO_2/steam as working medium
- Development and demonstration of ultra-supercritical circulating fluidized bed boiler

Category 2. Clean coal conversion

- Fundamentals in direct conversion of low rank coals
- Key technologies in pyrolysis and gasification of coals
- Key technologies in waste water treatment and recycle

Category 3. Coal combustion emission control

- Technologies for emission control of PM2.5 and Hg
- Demonstration of integrated technologies for abatement of flue gas SO_2, NOx and PM

Category 4. CCUS

- Fundamentals in CO_2 reduction and geological sequestration
- Fundamentals in CO_2 conversion
- CO_2 capture technologies by microalgae

Category 5. Recovery of industrial residual energy

- Technology for residue heat recovery from particulates containing waste gas
- Technologies and equipment for low grade heat recovery

Category 6. Energy saving industrial processes and equipment

- Optimization and energy conservation of processing industry

- Energy conservation technology of industrial furnaces

Category 7. Energy conservation in data centers and public sectors

- Key energy saving technologies for data centers
- Development and demonstration of efficient energy system for public sectors

The following projects are being solicited for 2017:

Category 1. Efficient coal based thermal power generation

- Ultra-high parameters coal fired power generation
- Technologies of near zero CO_2 emission based on coal gasification
- Key technologies for clean combustion of ultra-low volatile fuel
- R&D and demonstration of thermal power unit with double reheat

Category 2. Clean coal conversion

- Novel catalysis and processes for fuels and chemicals from syngas
- Novel coal gasification technologies for clean fuel gas
- Technologies and processes for mild coal hydro-liquefaction for quality liquid fuels and chemicals
- Technologies of advanced indirect coal liquefaction
- Development and demonstration of large scale coal slurry gasification technology
- Development and demonstration of large scale pulverized coal gasification technology
- Development and demonstration of grading conversion and utilization technologies of low rank coals

Category 3. Coal combustion emission control

- Technologies for flue gas SO_2 abatement and utilization
- Technologies for ash utilization
- Novel technologies and demonstration of novel particulates emission control

Category 4. CCUS

- Advanced CO_2 capture sorbents/materials and technologies
- Membrane technologies and demonstration for CO_2 capture

Category 5. Recovery of industrial residual energy

- Technologies for heat recovery from high temperature solids
- Technologies for heat recovery from high temperature molten slag

Category 6. Energy saving industrial processes and equipment

- Energy efficient gas production technology
- Efficient and clean oxygen/oxygen-enriched metallurgy technology
- Efficient and clean combustion technology for industrial boilers

Category 7. Energy conservation in data centers and public sectors

- R&D of integrated energy saving technologies for public sectors

The MOST also support atmosphere pollution control projects. It funded 93 projects in 2016 with a total funding of 1.06 Billion Yuan RMB.

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CZECH REPUBLIC

European perspective on brown coal – the Czech Republic

By Dr Stephen Mills, Senior Consultant, IEA Clean Coal Centre, London

Coal is important to the Czech economy as it forms the country's only significant indigenous energy resource. Total confirmed resources remaining in place are around 16.3Gt of bituminous coal and 8.9Gt of brown coal. Of this, under current mining limits, only 169Mt of hard coal and 862Mt of brown coal can be mined, although this situation looks set to change.

Under legislation introduced in 1991, mining was restricted to certain geographical areas. However, in 2016, in a move welcomed by the brown coal sector, the Czech authorities decided to relax these limits. This will now make a further 120Mt/y of brown coal available at very competitive prices. Decisions on several other high quality deposits are awaited. Brown coal makes a large contribution in meeting primary energy demand. However, nearly all of the Republic's oil and natural gas is imported, and the greater, more efficient use of brown coal has been identified up as an important component in future energy supply.

For many decades, brown coal has been the most important primary energy source, in particular for electricity generation. However, in recent years, its share amongst primary sources has been decreasing, falling from 36.6% in 2000 to 28.9% in 2013. This has been due in part to the exhaustion of some reserves and a general decline in overall quality. However, it still accounts for >40% of gross electricity production and is also used widely for heating in large scale district heating schemes. Many power plants are based on conventional pulverised coal combustion technology. These have a total installed capacity of ~10.8GW and generate more than half of the country's electricity. In recent years, a number of the larger stations have been renovated in order to increase their efficiency and lifetime and reduce their environmental footprint. At around 6.5GW, ČEZ is the largest individual coal-based generator and the country's biggest coal consumer.

Above: Aerial photo of the Vresova IGCC plant, courtesy of SUAS

Alongside pulverised coal power stations, fluidized bed combustion (FBC) technology has also been embraced, with eight plants based on circulating FBC now in operation, mainly firing brown coal. The Czech Republic also hosts an integrated gasification combined cycle (IGCC) plant at Vresova. This comprises two 200MW gas turbines fired on syngas produced by 26 fixed bed gasifiers fueled with brown coal

supplied by Sokolovská Uhelná (SUAS).

For some time, production and consumption of brown coal has fallen steadily. However, in the past few years, annual consumption has stabilised at ~39Mt. The main brown coal deposit and the most important mining area is the 1400km^2 Northern Bohemian Brown Coal Basin, where coal seams are generally between 15 and 30 metres thick. The bulk of production comes from opencast sites although there is also a single deep mine producing brown coal. Most production passes through preparation plants where it is graded and pulverised, producing single purpose products for household and commercial heating, and centralised heating facilities. Industrial heating blends are also produced and supplied to various power and cogeneration plants.

R&D Activities

Czech energy policy covering the period up to 2040 is focused mainly on security of energy supplies, competitiveness of the energy sector, and sustainable development. R&D to support these aims is viewed as crucial and is being aided in a number of ways that include state support via National Research Programmes. These have provided support for topics such as 'Energy and non-energy uses of coal and carbonaceous materials'. Financial aid also comes from European resources and is administered by a number of mostly national institutions that include the Czech Science Foundation, Technology Agency, and a number of ministries. Support has come from European Union Framework Programmes as well as the European Research Fund for Coal and Steel (RFCS). Various Czech organisations have contributed to a number of such major multi-partner projects.

Above: Entrained flow gasifier added to the Vresova site in 2006 to gasify generator tars and other liquid by-products from the fixed bed gasifiers, courtesy of SUAS

Founded in 1953, the main focus for Czech R&D activities remains the Brown Coal Research Institute (VUHU - Výzkumný ústav pro hnědé uhlí a.s) in Most. In recent years, VUHU has concentrated on developing novel techniques aimed at minimising the environmental impact of brown coal production, treatment and use. This includes an interest in coal-to-liquids processes in general and the conversion of brown coal-derived materials into liquid and gaseous hydrocarbons. Related areas have included reducing its propensity for spontaneous combustion, and the development of new advanced technologies for the production of heat and electricity.

As part of its efforts aimed at reducing the environmental impacts of brown coal mining and use, VUHU has developed applications for the by-products and wastes of combustion and desulphurisation. Mining aspects addressed have included the control of dust emissions from surface mines, as well as practical improvements to coal handling systems, and the development of new engineering solutions for surface mining in general. There has also been a strong focus on the reclamation of depleted coal production sites. This has encompassed studies on the effects on air and water quality associated with remedial efforts. VUHU operates a number of dedicated accredited testing laboratories and business innovation and environmental centres. Laboratories cover topics such as geotechnics and hydrology, and technological processes and diagnostics.

Universities and R&D areas

Alongside VUHU, a number of Czech universities are also active in various brown coal-related areas. Areas of interest range from combustion-related effects, through the utilisation of combustion by-products, to the remediation of depleted mines sites. For example, the Czech Technical University (CTU) in Prague maintains an interest in the fluidized bed combustion (and co-combustion with biomass) of brown coal, resultant emissions, and the use of wastes generated; Brno University of Technology and the University of West Bohemia have been active in brown coal gasification; and the Institute of Chemical Process Fundamentals was a partner in the RFCS-funded 'HUGE' and 'HUGE 2' projects that examined the underground gasification of brown coal for hydrogen production - the institute is also active in areas such as fluidised bed and entrained flow gasification/co-gasification, and CO_2 capture. Mining-

related activities are handled mainly by The Technical University of Ostrava (VŠB –TUO) (via several of its institutes), CTU, Charles University, and the universities of Pardubice, Olomouc, and Masaryk.

There is also sometimes collaboration between coal companies and universities. For example, Sokolovská uhelná produces brown coal and operates the Vresova IGCC plant. It has partnered with academia to examine topics such as the production of liquid and chemical by-products generated from brown coal gasification at Vresova.

CCS-related projects have involved organisations such as the Czech Nuclear Research Institute, CTU, VŠB –TUO, and the Czech Geological Survey. Several of these have contributed towards major EU projects focused on CO_2 capture and storage from the country's fossil fuel fired power plants. For example, recent studies examined ammonia-based post-combustion capture from brown coal-fired power plants, as well as flue gas cleaning and oxycombustion concepts. As part of this, CTU undertook a series of pilot plant trials.

A €5 million collaborative programme between the Czech Republic and Norway ('Pilot Studies and Surveys on CCS Technology') was launched mid-2015. This is addressing topics that include a pilot scale project on geological storage in the Czech Republic, a feasibility study of CCS pilot technologies for coal-fired power plants, assessment of the potential for CCS deployment in country, and CO_2 capture via high temperature absorption from flue gas (via carbonate looping). Czech involvement includes the Geological Survey, VŠB-TUO, ÚJV Řež, a.s., Miligal, s.r.o., Centrum výzkumu Řež, s.r.o., and the Masaryk University in Brno.

AMERICA

Brown Coal R&D – A North American perspective

By Jason D. Laumb, Principal Engineer, Coal Utilization Group Lead, John P. Kay, Principal Engineer, Emissions and Carbon Capture Group Lead, Joshua J. Stanislowski, Principal Process Engineer, Energy Systems Development and Edward N. Steadman, Vice President for Research, Energy & Environmental Research Center, University of North Dakota

The recent focus on brown coal research in North America has been on managing carbon dioxide emissions. This focus has created several opportunities for the development of new power cycles and implementation of existing technologies for the coal power fleet.

SaskPower has implemented post-combustion CO_2 capture technology at Unit 3 of its Boundary Dam Plant in Estevan, Saskatchewan. This is a first-of-its-kind undertaking that leads the way in providing lessons for future commercial applications. Information will be gained on many aspects of technology implementation, such as unexpected costs and savings, performance results, operational challenges, and regional impacts.

As SaskPower proceeds with this commercial application of carbon capture and storage (CCS), it is important to capture critical information that can serve to identify areas where cost savings and operational improvements can be realized in future installations. In addition, the information available from the Boundary Dam facility will provide a better understanding of the current state of the art and the next research and development needs to further improve commercial implementation of CCS technologies.

The focus on CO_2 capture in the United States has provided the research community with challenges and concomitant opportunities to explore advanced power cycles, and rare-earth element extraction from coal and coal by-products, coupled with renewable power and coal beneficiation.

One opportunity of specific interest is in the northern Great Plains region, where there is synergistic incentive to develop and implement CCS technologies. Regional industry partners are actively seeking options that can cost-effectively improve the efficiency of power production while coproducing CO_2 for use in enhanced oil recovery (EOR)

applications. The region has a current demand for CO_2 as a commodity for EOR in conventional oil fields and a strong forecast for increased electricity demand because of regional oil and gas activity.

The Energy & Environmental Research Center's (EERC's) Plains CO_2 Reduction (PCOR) Partnership, one of the U.S. Department of Energy's (DOE's) Regional Carbon Sequestration Partnerships, estimates that approximately 1 billion metric tons of CO_2 opportunity exists for the top conventional oil fields in the plains region. The initial estimates for the Bakken shale oil EOR (unconventional) opportunity are for an additional 2 billion to 3.2 billion metric tons. These commodity markets for CO_2 create the opportunity to offset the capture and first-of-a-kind costs while developing higher-efficiency, cost-effective technologies that reach broader applications and meet the future needs for coal-fired power in other regions.

> *Specific technologies to meet the projected CO_2 and power market demands that are being considered are advanced power cycles that use CO_2 as the working fluid to generate power. These indirect-fired supercritical CO_2 technologies can provide electricity at a high efficiency (>40%) while also supplying an injection-ready stream of CO_2.*

The future of coal research in the United States will be focused on developing and implementing new technologies for the existing fleet, as well as new installations.

One can see many positive impacts on federal funding being made available for advanced technologies utilizing coal. Positive industry sentiments, in some regions, certainly will open the door for expanded coal mining and gas and oil extraction in the United States.

Hurdles may become more relaxed for permitting a coal plant in the United States, but reduced regulations on oil and gas extraction will also help to keep natural gas prices low. Utilities will continue to look for the lowest-cost sources for generation, and new natural gas facilities may be favored over coal facilities because of the low price of natural gas. However, limited natural gas pipeline infrastructure in some areas and recent concerns with permitting of pipelines may encourage utilities to take a closer look at coal plants, especially advanced cycles.

It is easy to assume that DOE's interest in advanced coal cycles will remain strong into the foreseeable future. It is expected that the time frame for implementation of advanced technologies becomes more achievable with the current investments by state, federal, and industry sources. Undoubtedly, a long-term plan for managing CO_2 from fossil fuels is necessary to maintain reliable electric power in the United States.

Above: EERC Researcher Engineer Nathan Fiala monitors a CO_2 absorber during a recent test.

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MONASH UNIVERSITY

The benefits of international linkages for brown coal research at Monash

By Dr Joanne Tanner, Lecturer and Postdoctoral Researcher, Department of Chemical Engineering, Monash University

International linkages are the key to collaborative research, and paramount to ensuring the spread and uptake of new knowledge and ideas across the globe. Brown coal research is no exception, and Monash University researchers have initiated and maintain many strong international connections in this field, as Joanne Tanner explains.

The Department of Chemical Engineering at Monash University, Clayton is home to several internationally recognised brown coal researchers and innovators, who form part of the Energy, Fuels, Biorefining, and Sustainable Processing Group. Many of their projects in the brown coal innovation space involve international partners, including collaborators from industry and academic institutes in Belgium, China, Germany, India, Japan, Taiwan, and the USA, among others.

To date, four academics, three postdoctoral fellows and 15 young researchers at Monash University have been directly involved in brown coal experimental and modelling projects with international partners. The benefits of such collaborative projects are obvious – the sharing of knowledge and experience from different countries and different backgrounds leads to more relevant outcomes and a richer understanding of the answers to the underlying research questions than could be achieved by the research partners alone.

I myself was a beneficiary of several international collaboration and research opportunities at Monash through my BCIA sponsored PhD in brown coal research. I was co-supervised by Professor Klaus Hein from Stuttgart University (Germany), a BCIA Research Fellow at Monash from 2010-2013, and Professor Sankar Bhattacharya, a leading brown coal researcher at Monash with a background in industrial research. Professors Hein and Bhattacharya organised an international collaboration for my project with Forschungszentrum (FZ) Jülich (Germany), and this partnership was co-funded by a Go8-DAAD grant.

As a result, I spent three months in Germany over two years, working closely with expert researchers in the Thermochemistry Division at FZ Jülich on various aspects of high temperature gasification. Our collaborative research into the effect of temperature and gasification atmosphere on the release of inorganic species from this process resulted in four joint journal publications and two international conference presentations, not to mention the successful completion of my PhD thesis. I also went on to work as a postdoctoral researcher at Jülich in 2015 to extend the original research scope. This collaboration with FZ Jülich is ongoing.

This work could not have been completed without the involvement of both sides of the collaboration. The German side provided the specialist equipment required for the measurement of the gas phase inorganic species (molecular beam mass spectrometry), and the Monash side of the partnership provided expertise from the high temperature gasification side. Hence the benefits of international collaboration!

And I am just one of many researchers involved in international linkages in the area of brown coal innovation at Monash…

Professor Bhattacharya, who leads the Energy, Fuels and Reaction Engineering Group, has a long history of establishing international partnerships to facilitate innovative coal research projects with industry and academia alike. For example, my PhD project under his supervision was just a small part of his ongoing pioneering work in the area of entrained flow gasification of Victorian brown coal. His international partners in this field include Mitsubishi Heavy Industries (MHI), who contribute technical expertise and represent the potential industrial applications of the research, and Penn State University, with whom equipment and expertise is shared in both directions to extend the scope of the research to new techniques and different coals (e.g., US lignites).

These collaborations have already delivered proof of concept of the technical feasibility of entrained flow (EF) gasification of Victorian brown coal and US lignites. The ability to extend the research to non-Australian coals is also important, as it proves the universality of the process. EF gasification of these low rank coals resulted in high carbon conversion and fuel gas quality, and appropriate gasification and slag process temperatures have been established. The results compare favourably with fluidised bed gasification technologies, and joint publications with the international partners are in preparation. This project has also attracted the interest of fuel companies in India and Japan, and negotiations for collaborative projects with these new international partners are underway.

Professor Bhattacharya is also leading an ongoing series of projects which started with the first ever investigation of chemical looping combustion of Victorian brown coal. This body of work involves partnerships with Alstom (Germany), VITO (Belgium), Southeast University (China) and Huazhong University of Science and Technology (China). Alstom and VITO are involved with Monash through Professor Bhattacharya in collaborative experimental work and techno-economical process assessments, and joint publications based on these results are in progress. The collaborative activities with the two Chinese university partners predominantly involve the reciprocal exchange of researchers for experimental work, which has resulted in eight joint publications and three conference presentations to date.

Dr Lian Zhang, a senior lecturer in the Department of Chemical Engineering at Monash, is also very active on the international stage of collaborative brown coal research. Dr Zhang is an alumnus of Chubu University Japan, where he began his career in advanced clean energy technologies. His extensive list of international linkages includes the deployment of oxy-fuel combustion technology for Victorian brown coal with Chubu University (Japan), Jiaotong University (China) and Shanghai Boiler Works Co Ltd (SBWL, China), who are an industrial partner on the project. While oxy-fuel combustion of brown coal has previously been investigated academically, the linkage between research and industry partners is paramount to its successful deployment for direct power generation and for cement rotary kilns in the construction industry. The collaboration has led to a total of 15 journal papers, one conference paper and one book chapter.

Also related to the development of brown coal products for the cement industry, Dr Zhang is working in conjunction with China Huadian Electric Research Institute (CHDER) and ICOG Australia on the extraction of high purity MgO from brown coal fly ash for use in the production of MgO board and cement additives, another industrial application and potential export market for our local resources. A total of 10 papers have been published in this area, and now a provisional patent has been lodged.

As well as working on the advancement of coal-only processes, Dr Zhang is very active in the field of fuel blending. For example, he has assembled researchers from Chubu University, Gifu University (Japan), Beijing University of Chemical Technology (BUCT), Zhengzhou Zhongneng Metallurgy Co Ltd (China), Coal Energy Australia (CEA), Gippsland Clean Energy (GCE) and SBWL to investigate the potential for increasing the value of Victorian brown coal and other low rank coals by blending with biomass and industrial wastes. This project targets the production of export-grade semi-coke from low rank coal to supplement or replace coking coals in metallurgical processes. A total of five journal papers have been published, and a provisional patent will be lodged shortly.

Dr Zhang's semi-coke investigations extend to a related international partnership with aims to determine the efficacy of brown coal semi-coke and high rank coal blends in mitigating the undesirable behaviour of each individual fuel. The use of entrained flow gasification technology to utilise these fuel blends may open up a market for brown coal semi-coke, leading to a new export product. This project involves Kailuan Coal R&D Centre (China), Hubei Yihua Group Co Ltd (China), and CEA, who all work together on the research, technical and market aspects of the project. Also in conjunction with Hubei Yihua Group Co Ltd, Dr Zhang is advancing the development of a novel de-ashing process to selectively remove sodium and calcium from coal. This simplifies the waste discharge from coal-fired boilers and other applications, and mitigates downstream corrosion and harmful environmental emissions, which are known complications of these elements. A patent has been filed for coal de-ashing, and one conference paper was published in this area.

In summary, the international linkages developed and maintained by the brown coal researchers at Monash University are paramount to the success of their projects. They provide invaluable support, experience and specialist equipment, without which it would not be possible to conduct our research to the high standard for which we are known. In fact, I don't think it is overstating the case to say that the flow-on effects in terms of meeting new partners through these networks and projects, and the endless potential for new ideas and applications makes international linkages the very lifeblood of modern research.

RESEARCH PROJECT UPDATES

The effect of Victorian brown coal fly-ash on Solvent Degradation during Post-Combustion Capture of CO_2

By Rahul Reza Chowdhury, PhD Student, Carbon Technology Research Centre, Federation University

Rahul Reza Chowdhury joined the Carbon Technology Research Centre in March 2015 as a PhD student. Before joining CTRC, he had a diverse research experience in the field of Solid Oxide Fuel Cell and Particle-laden flow. His PhD project focuses on heterogeneous reactions in amine absorbents during Post-combustion capture of CO_2.

Post combustion capture (PCC) of CO_2 is a major focus for mitigating greenhouse gas emissions. Acid-gas scrubbing with aqueous amines is the most mature technology for PCC from fossil fuel combustion flue gases. Power stations in the Latrobe Valley use electrostatic precipitators to remove fly ash from flue gases, but these are not completely effective. There is a concern that fugitive ultrafine fly ash will contaminate any amine solvents used for PCC, potentially leading to reduced solvent life and increased operating expenses.

My PhD project, which is supported by both BCIA and CSIRO, aims to understand the effects of fly ash on amine solvent degradation, which can occur via chemical reactions in solution and via reactions and interactions with metal surfaces. Solvent degradation has been linked to fly ash contamination in PCC plants overseas, but has not yet been investigated in Australia. The fly ash from Victorian brown coal has distinctly different properties from other coal ashes, so its role in solvent degradation merits further research.

My project involves characterisation of the degradative impact of fly ash by determining the identity and yield of water soluble organic and inorganic ions with respect to degradation time. The correlation between the formation of both soluble (e.g. metal ions, organic anions) and insoluble (e.g. metallic materials, metals adsorbed into mineral surfaces) products will enable further understanding of the heterogeneous reactions occurring during PCC operation. These interactions are being investigated using the advanced analytical technologies available at the new Carbon Technology Research Centre at Federation University in Churchill.

A detailed physicochemical characterization of Victorian brown coal fly ash samples collected from the CSIRO PCC pilot plant at AGL Loy Yang power station has already been completed. Scanning electron microscopy (SEM) revealed the ash samples contain very small particles of porous unburnt char, with morphologies associated with their botanical and microbial origins (Fig. 1A) and (Fig. 1B). These char particles have a relatively high surface area compared with the mineral components of the ash. They could potentially increase the rate of solvent degradation by facilitating degradation reactions, or inhibit it by removing deleterious compounds by adsorption.

SEM investigations have also been conducted on the surface corrosion of aged 316SS packing materials retrieved from the same plant. These packing materials experienced grain boundary corrosion and accumulated particles (Fig. 1C) and depletion of metals (Fig. 1D) during PCC operation. Interestingly, the corrosion in the absorber columns has not been found to correlate with temperature, CO_2 loading in the liquid phase or CO_2 loading in the gas phase. Further work is under way to investigate the physical and chemical processes that may be affecting corrosion within the PCC equipment.

Degradation of aqueous amine solvents is a critical area of research because it is the main source of environmentally sensitive compounds in PCC. Understanding and controlling this issue is necessary to support the "social licence to operate" for PCC in the Latrobe Valley.

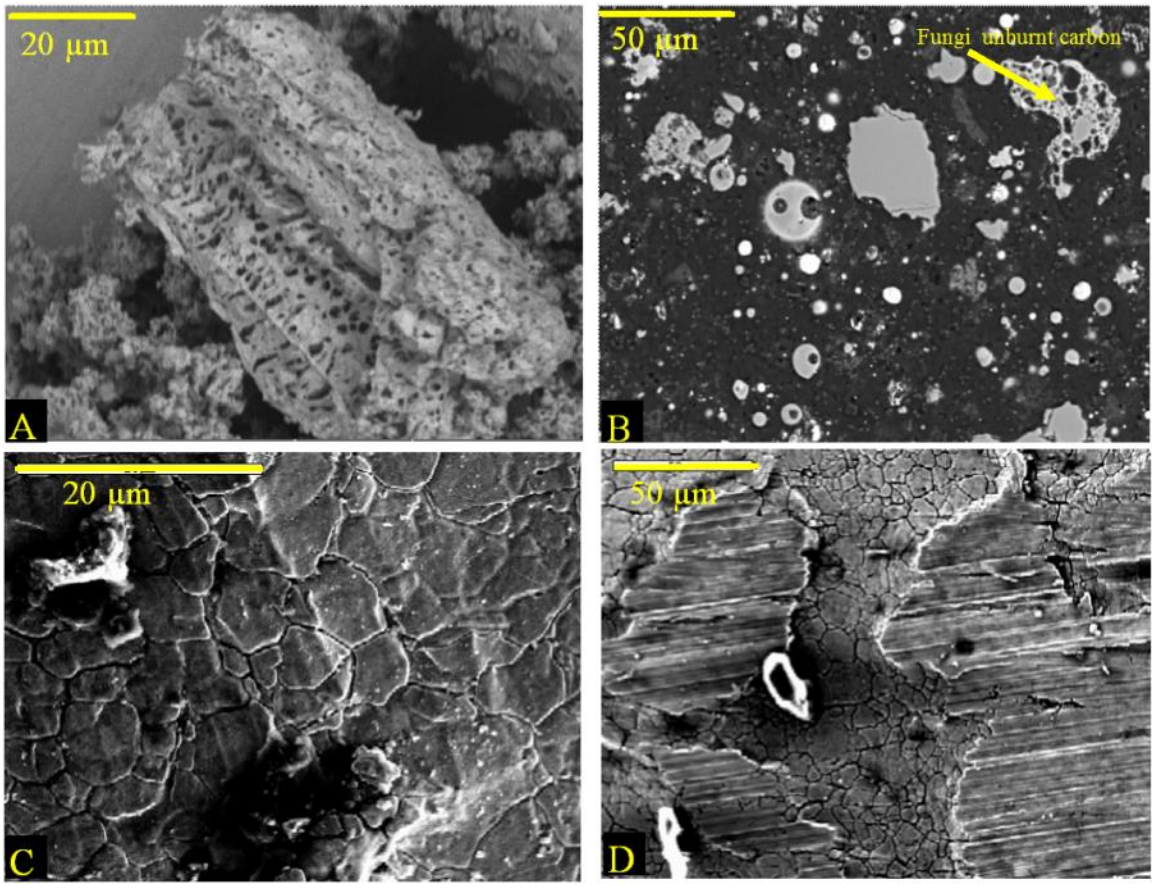

Figure 1: *SEM micrographs top row: Char identified in flyash sampled downstream of PCC plant flue gas inlet - A Woody structure - B Funginite structure*
Bottom row: *Surface of aged metal packing from a PCC absorber column -C Particle accumulation and grain boundary corrosion -D Depletion of metals from the surface of packing materials and grain boundary corrosion*

SPOTLIGHT ON BCIA

Latrobe Valley Community Forum

Positioning brown coal for a brighter future

An update on Brown Coal Innovation Australia's research and skills programs for environmentally responsible brown coal utilisation

Emerging technologies offer Victoria the potential to transform Latrobe Valley brown coal into a wide range of environmentally responsible applications and products – including low- and zero-emissions power, hydrogen for export, carbon fibres and polymers, fertiliser and soil improvers, and upgraded coal for iron and steel manufacture.

Looking to the future, the Latrobe Valley could be host to a range of high-technology industries manufacturing value-added products from our valuable coal feedstock.

Brown Coal Innovation Australia Ltd (BCIA) is supporting this change.

BCIA is an independent, not-for-profit company, established with government funding to co-invest in the development of technologies and people.

Over the past six years BCIA has supported investment in research and skills for environmentally responsible uses of coal, and has secured support and further investment from governments and nearly 50 local and international companies and research institutes.

Come and hear how BCIA is funding research to drive the future of brown coal, and the possibilities for environmentally responsible coal use beyond the lifespan of the current power stations.

DATE/TIME:
Tuesday 14 February 2017, 5.15pm – 6.30pm (entry from 4.45pm)

VENUE:
Grande Promenade Room, Century Inn, 5 Airfield Rd, Traralgon (next to LRH)

RSVP by email kirstyn.krausz@bcinnovation.com.au
or phone (03) 9653 9601.

Light refreshments will be available following the forum.

Entry is free, but RSVP is required

MEMBERSHIP

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 MEMBER
Positioning brown coal for a low-emissions future

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.

BCIA is delighted to announce that Coal Energy Australia has joined as a full member, extending BCIA's partner network.

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 program including development and demonstration projects.
- **Access to a Wide-ranging Expertise** 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 organisations through the BCIA newsletter *Perspectives* and website.

Brown Coal Innovation Australia Current 2016 Members

CALENDAR OF EVENTS

14 February 2017
Latrobe Valley Community Forum
Location: Traralgon, Australia
Emerging technologies offer Victoria the potential to transform Latrobe Valley brown coal into a wide range of environmentally responsible applications. Come and hear how BCIA is funding research to drive the future of brown coal, and the possibilities for environmentally responsible coal use beyond the lifespan of the current power stations.
For further details visit: http://www.bcinnovation.com.au/NewsEvents

28 February – 3 March 2017
12th IEA CCC workshop on Mercury Emissions from Coal (MEC)
Location: Mpumalanga, South Africa
The event will combine a one-day workshop on Energy Efficiency and Emission Challenges for South African and neighbouring African regions (co-hosted by the US State Department) with the three-day 12th annual Mercury Emissions from Coal workshop, co-hosted by UNEP, DEAT and Eskom, which encompasses a more multi-pollutant ethos. Both meetings will consider emissions of all micro-pollutants to air, not just mercury.
For further details visit: http://mec12.coalconferences.org/ibis/MEC12/home

7 – 9 March 2017
Spring Coal Forum 2017
Location: Clearwater Beach, USA
The Spring Coal Forum has been one of the highlights of the coal industry calendar and will attract senior industry executives from companies that produce, supply, transport, ship, trade and consume coal. The program features presentations from coal suppliers, utilities, railroads and energy traders, along with industry-wide perspectives from leading consultants and government representatives.
For further details visit: http://www.infomine.com/events/Spring.Coal.Forum.2017--IM41941.aspx

28 – 30 March 2017
World CTX 2017 Conference
Location: Beijing, China
This event is run over three days. Day 1 focusses on Coal To X Technology updates including IGCC; day 2 will look at Operations, Projects and Economics, Environment; and day 3 includes Operations, Roundtable and 2017 World CTX Award Presentation Ceremony.
For further details visit: http://worldctx.com/

8 – 12 May 2017
The 8th International Conference on Clean Coal Technologies
Location: Carbonia, Sardinia, Italy
The IEA Clean Coal Centre's 8th international conference on clean coal technologies (CCT2017) will once again be co-hosted by the Sotacarbo Research Centre. With strong international participation from both the coal power industry and research institutes, the CCT conference series remains the foremost platform for networking within the global coal research community. Three days of technical sessions and keynotes from leading figures in the industry will cover all aspects of clean coal technologies and highlight the most cutting edge research.
For further details visit: http://www.cct2017.org/

5 – 8 September 2017

The 34th Annual Pittsburgh Coal Conference

Location: Pittsburgh, PA, USA

By providing an open forum for discussion, The International Pittsburgh Coal Conference wishes to promote research activities that advance the economic benefits of coal technologies while greatly reducing their environmental impact. Sessions for this conference include Gasification Technologies, Clean Coal Demonstration and Commercial Projects, Combustion Technologies, Clean Coal and Gas to Fuels, Sustainability and Environment, Carbon Management, Coal Science, Coal Mining, Coal Bed and Shale Gas.
For further details visit: http://www.engineering.pitt.edu/Sub-Sites/Conferences/PCC/_Content/2016-Conference/

12 – 14 September 2017

2017 Mid-Atlantic Biomass Energy Conference and Expo

Location: Pennsylvania, USA

For further details visit: http://www.energy.psu.edu/civicrm/event/info?reset=1&id=134

11 – 12 October 2017

All-Energy Australia Exhibition & Conference 2017

Location: Melbourne Convention & Exhibition Centre

All-Energy Australia is Australia's biggest and highest quality clean and renewable energy conference. Free to attend, the conference features over 200 industry speakers across 7 session streams over two days.
For further details visit: http://www.all-energy.com.au/conference/