Perspectives
ON BROWN COAL

MARCH 2016 – ISSUE 16

OFFICAL NEWSLETTER OF BROWN COAL INNOVATION AUSTRALIA

IN THIS ISSUE

CEO'S UPDATE

Dr Phil Gurney
BCIA CEO and Director

There is a lot going on for brown coal at the moment

In December 2015, Australia signed the Paris Agreement, a global accord that seeks to limit dangerous climate change by reducing emissions of CO_2 into the atmosphere. To meet this commitment, we must change the way we use coal. Those looking to the future of Australia's brown coal resources have taken this challenge to heart.

As you will see in this issue of *Perspectives*, many of the new coal developments are moving away from traditional power generation towards value-added products from coal. They are also seeking to balance environmental concerns with securing continued economic benefit from this premium resource.

The 18th March 2016, will be a milestone day for the Latrobe Valley, with the launch of a new carbon capture pilot plant. The Post-Combustion Capture plant is a major Australian-Japanese collaboration bringing together industry and researchers to support long-duration testing of CO_2 absorbents on real flue gas. Successful completion of such research will provide vital data necessary for the scale up of this technology in Australia (page 12).

The Latrobe City Council see new uses of coal and new investments in coal developments as one of the key platforms to the future economic development of the region (page 9). They are seeking input into the development of their regional economic development strategy. The focus on coal as a driver of economic development is supported by the results of BCIA's recent Coal to Chemicals member report (page 5), which shows that new Coal to Products (CTX) industries can be viable in Australia.

And new coal developments, leading to value-added products, are now proceeding towards commercial deployment. To emphasise this point, we feature an article by Ignite ALDP on their commercial-scale demonstrator plant. This project has secured funding, and has undertaken community consultation and environmental impact studies (page 10).

BCIA's recent seminar (page 16) showed that there is significant continued interest in agricultural uses of coal – for example how coal-derived products can improve soil organic carbon levels, which have been depleted by modern farming methods. As an action from this, BCIA has developed a new report on 'Applications for Brown Coal in Australian Agriculture', which is now available to BCIA members. This report shows that soil productivity can be improved using coal-derived products. This is a very prospective area and a summary of this report is provided on page 7.

Late last year, the Australian motoring press reported the story that Toyota and Kawasaki Heavy Industries were seeking to power a new fleet of cars with hydrogen sourced from gasification of Victorian brown coal. A challenge for many uses of hydrogen is how to effectively store it. BCIA funded student Amandeep Oberoi has been looking into the use of activated carbons from brown coal for this. He updates us on his research on page 14.

Key to supporting any new, environmentally responsible uses of coal will be to ensure that the technology risks associated with building these projects are minimised. This requires a strong local R&D workforce that has a thorough knowledge of Australian coal chemistry and how projects can develop in Australia. The article by Vince Verheyen (page 2) shows how Federation University is helping to maintain this research base, supporting both carbon capture research and coal industry developments.

These developments show that those who believe "coal is dead" are missing the mark. However, with so much going on, it is easy to forget that continued investment is required to ensure the impetus towards new, environmentally and economically responsible developments of brown coal continues.

It is innovation that will underpin the economic value of brown coal in an emissions constrained future – and it is the research community, working together with industry, who will deliver this. BCIA is continuing to advocate with the owners of Australian brown coal resources for continued support to ensure that funding is available for our ongoing program of activities. We will keep you updated on our progress.

TECHNOLOGY

What's happening in brown coal research within Gippsland?

By Dr Vincent Verheyen, Leader Carbon Technology Research Centre, Federation University

> Vincent has a PhD on the structure of brown coal and has extensive industry, research and development experience in the Coal to Products (CTX) area having worked for the VBCC (Victorian Brown Coal Council), CCV (Clean Coal Victoria), HRL, Monash and now Federation University.

CCS Research Laboratory, Gippsland Campus, Federation University

Political and social pressure is pushing Victoria to move away from producing electricity from brown coal to a new generation of cleaner technologies. The legacy baseload power stations will gradually need replacing with a new efficient means of energy generation. However, there is an exciting opportunity for new manufacturing industries producing value added products particularly gases and liquids based on this bountiful and clean carbon resource.

Federation University, Gippsland campus is located on the edge of the Latrobe Valley's brown coal deposits and overlooks Victoria's coal fired power stations. Coal research is the focus of the new Carbon Technology Research Centre (CTRC) which currently has a revitalised analytical facility. The CTRC has benefited greatly from a A$2.3 million grant from the Federal Government through the Education Investment Fund (EIF) program. The refurbished laboratories and new equipment were established to support the CarbonNet Project in Gippsland Victoria (CCS Flagship Project). The funding and the CCS Flagship project have enabled Federation University to develop a comprehensive integrated analysis facility. The formation of a Latrobe Valley based, analytical and education facility focussing on energy training and research towards environmentally benign and economically viable PCC (Post Combustion Capture) operation has been and continues to be a key goal for Federation University.

In addition to supporting CSIRO CCS projects, the CTRC laboratory and research team will address broader national CCS R&D strategies by extending support to other CO_2 CRC members where needs and capabilities align. As always, the CTRC team remain keen to work with companies involved in demonstrating value added product technologies from brown coal. The CTRC has enjoyed stroptimization ong support from the local electricity generators, BCIA, Latrobe City, CSIRO and primary industry agriproducts suppliers amongst others.

Through post-graduate research and the provision of analytical services, the CTRC continues to contribute to the understanding and identification of value added product technologies from brown coal.

Current research and planned projects in this theme

- Exploring industrial ecology to manage waste stream associated with commercial capture.
- Minimising degradation of capture systems (Opex reduction).
- Co-capture of other gases besides CO_2, i.e. SO_2 (Capex reduction).

The CTRC's approach here is to exploit the special properties of our brown coals and not to attempt conversions best suited to higher rank coals. The very high moisture, state of organic matter preservation and atypical ash chemistry all require targeted research towards high value add technologies which take natural advantage of these properties.

Current research and planned projects in this theme

- Optimisation of water based fuel properties for Direct Injection Carbon Engines (heavy fuel oil replacer based on brown coal).
- Improving products and production processes for upgrading humic compounds from brown coal for agricultural use.
- Developing special sorbents and ion exchange materials exploiting the natural properties of brown coal.
- Using the future abundant supply of CO_2 from Carbon Capture as a chemical pre-treatment for brown coal. Supercritical CO_2 has potential as an effective and clean solvent for the extraction of valuable chemicals prior to further utilisation as a fuel. This CO_2 product could also be used to ion exchange cations and modify the permeability / reactivity of brown coal feedstocks for use in DICE fuels.
- Investigating the volatile organic compounds (VOCs) released during drying and torrefaction of brown coal, and the physical changes in the gel structure of brown coal during drying. The recent mine fire has heightened awareness of the potential harm associated with uncontrolled atmospheric release of coal derived compounds. Our team is initiating a new research program into identifying and quantifying these compounds.
- Biological treatment / remediation of brown coal process waste streams. Thermal treatment of brown coals generates process waters of variable quality. Research into the properties of these waters would assist in optimising their treatment for reuse or recycling. By-products from other coal uses including chars, ashes and inferior coals could form part of the tailored water treatment package. Mine rehabilitation research is a potential new subset in this theme.

The special properties of our brown coals should not be seen as a barrier to commercialisation – rather an advantage in preparing a niche range of products. The scale of the resource and its ready access will drive companies with both foresight and research support, towards a new manufacturing future.

Should you have a project you would like the CTRC team to work on, or for further information, please contact Vincent Verheyen using this website link federation.edu.au/CCTC.

Figure 1: Variation in ash appearance from sized brown coal fractions.

Figure 2: Refurbished analytical laboratory revealing some of the trolley enabled instruments which enable hybrid separation / detection techniques such as IC/ICPMS, LC/ICPMS, GC/QTOFMS.

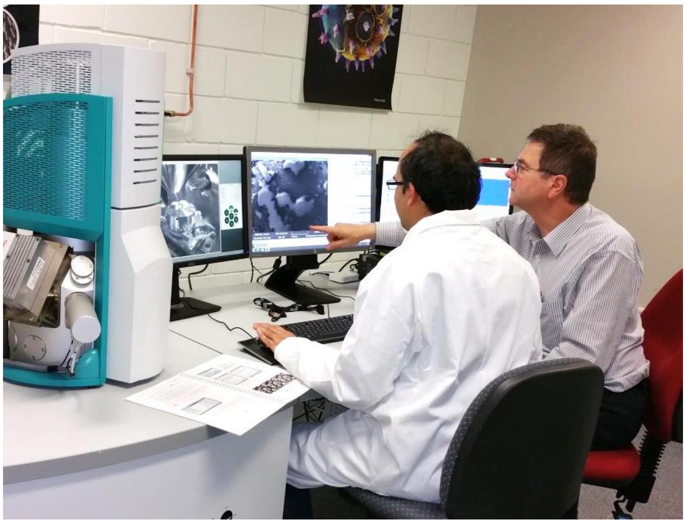

Figure 3: New scanning electron microscope with variable pressure SE detector and also fitted with an EDS package enabling elemental analysis.

BROWN COAL INNOVATION AUSTRALIA

RESEARCH

New BCIA funded studies on Coal to Chemicals, Coal to Hydrogen

By Dr Phil Gurney, CEO and Director, BCIA

BCIA undertakes a variety of studies looking to understand what is required to deliver the optimum environmental and economic benefits from continued use of Victorian brown coals. In recent years, BCIA has participated in or commissioned studies in areas as diverse as solar gasification of coal, novel carbon dioxide storage options, and how to reduce the commercialisation risks of developing coal-water fuels for use in stationary diesel engines.

With a continuing local and international focus on novel uses of coal, BCIA has recently commissioned a report on the opportunities and prospects for Coal to Products (CTX) projects in Victoria. This report, which has been delivered by Strategic Energy Consulting and Gamma Energy Technologies, provides a "techno-economic" analysis of various Coal to Chemicals options, focussing on a route to products through gasification. It shows that both hydrogen and urea production could be economic at today's prices.

The report provides an overview of the global trends for CTX, and a high-level analysis of selected CTX options that may be applicable to Victoria. The economic study, with construction cost data derived from the 2015 "Australian Power Generation Technology Report", enabled the estimation of the range of production costs for the various product options, and high-level estimates of the regional economic benefits of CTX projects.

Together with a breakdown of the capital and operating cost, this data was used to estimate which CTX options could be viable at today's commodity prices. The report also analysed what else would need to happen to make projects feasible, and provided a review of how effective government support could be in securing the regional benefits, and supporting the long-term sustainability of such projects. Given that new projects would likely have limits set on CO_2 emissions, the authors also considered how the cost of capture and storage of CO_2 would affect project economics.

In undertaking the report, the authors considered only Coal to Chemicals options based on mature technologies. However, it was noted that there were technology risks associated with building these projects as "First-of-a-Kind" in Australia. The report therefore relied on the assumption that a local R&D workforce was available to support adaption of technologies to local conditions. This local R&D workforce would have a thorough knowledge of Australian coal chemistry, the physical properties of coal, Australia's environmental requirements, what has been done here in the past, what works, and what is known not to work.

The study analysed a "generic" technology solution, and further work would be needed to adapt the results to any particular project. Using this generic approach the authors have been able to show the following.

1. The local and regional benefits of a large coal to chemicals facility would be substantial during both the construction and operation stages. Peak construction labour would be approximately 6,000 jobs – with long-term operational roles approximately 400–500.

2. The economic feasibility of a coal \ within the upper bound of current market prices, however the price is sensitive to carbon dioxide price.

- The cost of hydrogen production is within the upper bound of current market prices, however the price is sensitive to carbon dioxide price.

- As production costs are dominated by operating costs, capital subsidies are not likely to be a useful incentive for hydrogen production.
- Urea may also be feasible, however the mid-point price for the cost of urea is above current market prices.
  - Capital subsidies or other financial instruments (e.g. loan guarantees) would both lower the cost of product – reducing the project risk – and make the process more economic.
  - Urea production is relatively insensitive to the price of carbon dioxide.
- Synthetic petroleum products (from a Fischer–Tropsch facility) are not likely to be feasible unless the crude oil price is over A$130 billion for the life of the facility.
- Both methanol and ammonia would require significant subsidies or assistance to become competitive with current market prices for those products.

Noting that the cost of hydrogen production from Victorian brown coal is dominated by operating costs, BCIA also recently participated in a study undertaken by the Energy and Environmental Research Center in North Dakota. This study tested at pilot scale the use of a novel membrane technology aimed at reducing the cost of hydrogen separation in gasification reactions.

The final report of this activity is titled "Demonstration of pilot-scale hydrogen and CO_2 separation membrane technology on North Dakota coal-derived syngas". The report provides data from the pilot on testing with North American coals, as well as a desktop modelling study using data from previous gasification studies on Victorian coals undertaken in 2003. The study showed that the use of membranes in this way could make a significant improvement in process efficiency, with the implication that this could translate into reduced operating costs, and increased project viability, for a hydrogen production facility.

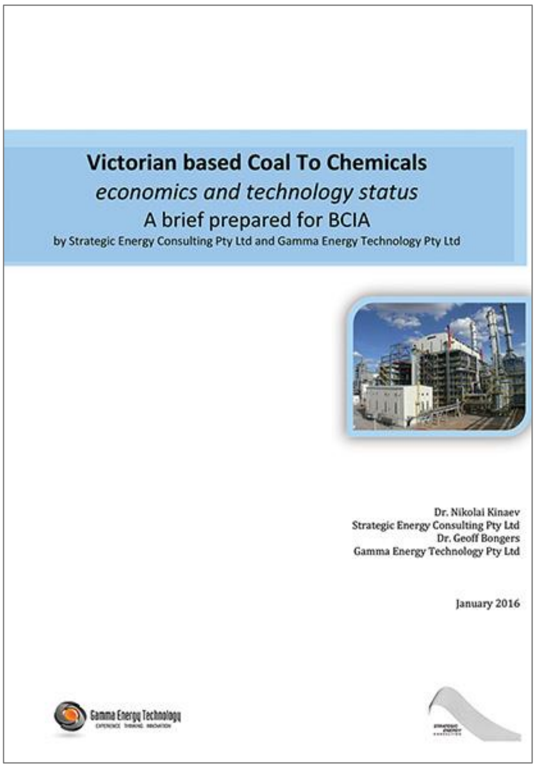

Figure 1: Front cover of 'Victorian based Coal to Chemicals economics and technology status' report by Strategic Energy Consulting and Gamma Energy Technology, January 2016.

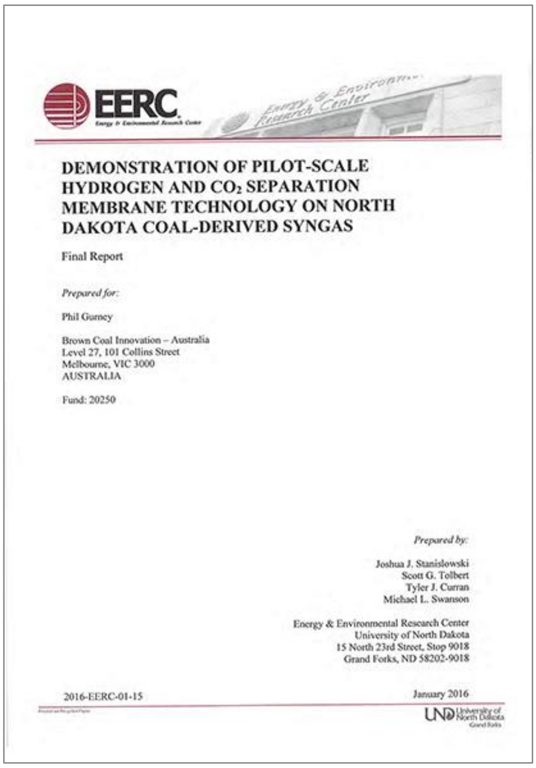

Figure 2: Front cover of 'Demonstration of pilot-scale hydrogen and CO_2 separation membrane technology on North Dakota coal-derived syngas' report by Energy & Environmental Research Center, University of North Dakota, January 2016.

Applications for brown coal in Australian agriculture

By Dr David McManus, Research Investment Manager, BCIA

The BCIA workshop ‘Agricultural applications for brown coal’, held in December 2015 (see page 16), identified a range of prospective new opportunities for Victorian brown coal. Detailed discussion of these options was hampered however, by a lack of information on the work that was done in the past.

To fill this information gap, BCIA has prepared a report for BCIA members, titled ‘Applications for Brown Coal in Australian Agriculture’. The report summarises the publicly available literature and illustrates the broad range of potential agricultural products that can be derived from brown coal.

One surprising result of the analysis undertaken in the report is the quantity of off-farm carbon inputs required to improve the carbon content of Australia’s agricultural soils. If this demand were met solely by products derived from Victorian brown coal, it would require 170 million tonnes per annum of run-of-mine coal – far in excess of current Victorian production rates!

As recommended by workshop delegates, a central theme of the report is the potential of brown coal products to increase the concentration of organic carbon in Australian soils. Since European settlement, the concentration of soil organic carbon (SOC) in Australia has fallen, by as much as 60% in some areas, adversely affecting plant productivity and soil health. Similar declines in SOC stocks have occurred worldwide and it is vital that this trend be reversed.

In recognition of this problem, Australia was the first of 25 nations to endorse the “4/1000 Initiative: Soils for Food Security and Climate” during COP21 in Paris in December 2015. The ‘4/1000 Initiative’ represents a shared commitment to increasing the global SOC reserve by 0.4% annually. It aims to improve agricultural productivity and help feed a growing world population, and to assist in slowing the rate of global warming by ‘locking up’ carbon from atmospheric CO_2 in the soil.

While Australian soils are generally poor in organic carbon, Victoria is blessed with abundant deposits of ancient decomposed plant matter, in the form of its massive brown coal reserve. In principle, Victorian brown coal is ideal for boosting the carbon content of soils.

When used as a soil amendment, brown coal can help to build soil carbon, improve productivity and increase profitability. As was discussed in the workshop, industry-led research will be needed to transform raw brown coal into commercial products that can cost-effectively be transported and utilised on farming land across Australia.

One of the main challenges identified in the report is that there is currently no well-defined way to quantify the financial benefits of increased SOC in agricultural soils. This makes it difficult to define the value proposition for products intended to boost SOC levels. Large-scale field trials are needed to properly quantify the costs and benefits of using brown coal to build soil carbon levels, and to understand the longevity of coal-derived organic carbon in the soil.

At the present time, humic substances represent the main agricultural market for coal-derived products, both in Australia and elsewhere. Humic substances represent the ‘active ingredient’ in brown coal and, in dry form, are much cheaper to transport but more expensive to produce. The report suggests that humic substances will continue to be regarded as premium, high-performance ingredients in specific applications, e.g. foliar sprays and fertigation.

Humic substances appear to have potential for use in animal feed supplements, where they are reported to improve stock health, growth rates and feed conversion efficiency. This is a premium application with great potential significance for Australian agriculture.

The report identified organo-mineral fertiliser products as another attractive market opportunity. Organo-mineral fertilisers are based on blends of brown coal and/or humic substances with proven fertiliser ingredients (either chemical or biological). There is good scientific support for the use of such products to increase the efficiency of N and P fertilisers, which makes for a simple value proposition. The report suggests that there is potential for a number of new manufacturing businesses in this area.

Surface application of brown coal is an inexpensive way to reduce ammonia emissions from intensive animal rearing operations, such as beef cattle feedlots. Most Australian beef cattle feedlots are in NSW and Queensland, so transportation cost is an issue to be addressed. The report recommended that opportunities be investigated in similar intensive industries (e.g. poultry, pork) in Victoria.

The report also considers potential agricultural uses for Latrobe Valley fly ash, a by-product of electricity production from brown coal. Applications for the fly ash are generally limited because of its strong alkalinity and high concentration of boron. The report suggested that there may be potential agricultural applications in areas of high rainfall and/or acidic soils, where boron deficiency is a problem. In these areas, the high boron content of fly ash would be an advantage.

Production of agricultural inputs from brown coal is an attractive way to create a new manufacturing industry in Victoria. The capital and processing costs are relatively low, and there is a large potential market. There is definitely a role for the use of brown coal in boosting the organic carbon content (hence productivity and profitability) of Australian agricultural soils. Innovative, cost-effective new products are needed to achieve this, along with performance data that establishes a clear value proposition for the farmer. Industry needs to take the lead in developing these opportunities, supported by the academic expertise that is already in place.

BCIA intends to facilitate further industry-academic collaboration in this area, to support the creation of new industries and employment in Victoria.

(Copyright © 2016 Latrobe City Council)

Economic Development Strategy out for public consultation

Latrobe City Council has released its draft Economic Development Strategy for public consultation. The strategy aims to position Latrobe City as the engineering capital of Australia.

Council are recognising the region's history of innovation and engineering expertise which will open doors for future growth.

The draft strategy points to our industrial past as the way forward. We already have the skillset, the work ethic, the big power industry players. The strategy is designed to not only take advantage of the resources we have located here but to look at ways of moving away from mainstream engineering to more niche or advanced manufacturing. The strategy has been divided into the following two areas.

1. The engineering capital of Australia.
2. The 'nuts and bolts'.

LatrobeCity
a new energy

You can have a say until close of business on 6 April 2016.

Submit your feedback by emailing Donna.Taylor@latrobe.vic.gov.au or uploading a form at latrobe.vic.gov.au/Get_Involved/Have_Your_Say/Have_your_say_on_the_Economic_Development_Strategy

Ignite ALDP (IALDP)
Adding value to Victoria's vast lignite resources

What is the Advanced Lignite Demonstration Program (ALDP)?
The ALDP is an initiative being jointly funded by the Australian and Victorian Governments to accelerate the development and deployment of emerging lignite upgrading technologies in the Latrobe Valley. This program plans to reduce the greenhouse gas emissions from lignite, improve the economically recoverable return from lignite and provide employment opportunities in the Latrobe Valley and broader region.

About Ignite ALDP

Ignite ALDP (IALDP), a subsidiary of Ignite Energy Resources (IER), was selected as one of only three successful companies globally to win the highly competitive ALDP in Victoria. IALDP will receive A$20 million funding via the ALDP grant program, and a A$30 million investment from key strategic partner PT. Bukit Energy Investama. The A$84 million project will see IALDP engineer, construct, commission and operate a 142,000 tonne p.a Commercial Demonstration Module (CDM) in the Latrobe Valley. This plant is a scale up of the third generation large pilot plant currently operating at IER's Somersby, NSW facility.

Based on a successful ALDP project, IALDP aim to roll out commercial scale plants in the Latrobe Valley and globally.

Cat-HTR Technology

The Ignite CDM is a commercial scale module of the patented Catalytic-Hydrothermal Reactor (Cat-HTR) and can do the following.

- Rapidly and economically upgrade lignite into:
  - Synthetic crude oil (Syncrude) – that can be further refined to petrol, diesel and chemicals.
  - Micronised refined carbon (MRC) – that can be used for advanced power generation, with lower carbon emissions than the current lignite generated electricity and can also be used for blast furnace feed in steel production.
- Is a net producer of water when in operation.
- Can co-process lignite with waste biomass (e.g. wood waste and agricultural waste), further reducing the emissions footprint of the resultant products.

The products from the Cat-HTR process therefore have broad application outside the typical power generation use of lignite, opening up new markets and adding value to Victoria's vast lignite reserves.

IALDP believe that their Cat-HTR technology supports Victoria's vision of maximising the value of lignite while minimising its environmental impact, building a sustainable energy future, and supporting local job creation.

IALDP Plant Location

The Ignite CDM will be constructed on EnergyAustralia's site south of the Yallourn open cut mine and the Princes Highway, off Marretts Road in Yallourn, Victoria.

Committed to Community Consultation

IALDP is committed to ongoing consultation with the community through the life of the Ignite CDM project.

- On 22nd October 2015, the IALDP website went live – ignitealdp.com.au
- IALDP conducted two public community drop-in centre events on the 10th and 14th November 2015 at Morwell Bowling Club, with some 25 people in total attending.
- An 1800 project phone number has been set up, as a further touch-point with the community.

Figure 1: One of the IALDP community events held in November.

Figure 2: IER pilot plant in Somersby, NSW.

Environmental Protection

Environmental impact is a key consideration for the construction and operation of the IALDP project. Each project stage will have a comprehensive environmental management and protection component. All site works will adhere to strict legislative controls and be undertaken in accordance with industry best practice.

Supporting Jobs and Economic Development in the Latrobe Valley

The ALDP project aims to foster economic development in the Latrobe Valley with employment opportunities both in the construction and operational phases.

More information on employment opportunities, once they become available, will be provided on the IALDP website.

Ignite ALDP Project Update

IALDP are pleased to advise of key recent achievements regarding the Commercial Demonstration Plant project.

- On the 23rd December 2015, IALDP received notice that the Financing and Security Conditions Precedent under the Victorian and Commonwealth Government's A$20 million ALDP grant had been met, enabling the commencement of the ALDP project in the Latrobe Valley.
- On the same day, IALDP also received the planning permit approval from the Latrobe Council for the ALDP.
- The next key milestone IALDP are working toward is the submission of the Environmental Protection Agency (EPA) of Victoria's permit.

Where can I find out more?

- For more information on Ignite ALDP, including a list of community FAQs, please visit ignitealdp.com.au.
- 'Subscribe for Updates', to receive latest news and project update emails ignitealdp.com.au/subscribe-for-updates.

- Or call the free information line on 1800 320 469.

Ignite ALDP is a subsidiary of Ignite Energy Resources – igniteer.com.

Figure 1: Unloading modules with crane (Copyright 2016, AGL).

PICA Post-Combustion Capture Project

By Aaron Cottrell, CSIRO Senior Engineer / Project Leader – PICA Project

CCS (carbon capture and storage) is a key technology. It has a major role to play in minimising the costs of meeting global emissions reductions targets, and can also help create opportunities for "negative emissions" which are likely to be necessary if we are to limit global temperature rises to 1.5°C. The technology can be applied both to power generation, for example electricity production from brown coal, and to industrial processes such as fertiliser manufacture that also generate significant volumes of CO_2.

PCC (post-combustion carbon dioxide capture) technology utilising amine based liquid absorbents is expected to be one of the most promising CCS technologies to be applied to large scale coal-fired power plants. However, conventional PCC technologies have a high energy consumption from the power station's steam cycle, and face major capital and operational costs. Research is required to reduce these costs, and drive greater uptake of CCS.

The PICA project is a major research collaboration between CSIRO, IHI Corporation (Japanese technology provider), and AGL, supported by BCIA. The name PICA is an acronym formed from PCC and the project partners IHI, CSIRO and AGL.

The PICA project will fill knowledge gaps on how PCC systems can be most effectively operated on real flue gases from actual coal-fired power plants, especially during long-term operation. Its objective is to both improve emissions reduction efficiency and demonstrate pathways to reduce the capital and operational costs for CO_2 capture.

The project uses a pilot plant that was manufactured by IHI in Japan. This plant has been designed to be easily transportable, with the potential to re-use it for other testing campaigns after the PICA project completes.

The PICA pilot plant was first tested and evaluated in Japan in 2015. Then the plant was disassembled and transported to Australia, and was connected to the AGL Loy Yang power plant in late 2015. Commissioning and testing then followed, and the site will be officially opened on Friday 18th March 2016.

CSIRO will conduct a two-year evaluation of two advanced liquid absorbents, two advanced process designs and an advanced gas / liquid contactor. The combination of these three aspects represents a significant step forward in PCC technology application for brown coal-fired power stations.

The duration experiments differentiate this project from known PCC pilot plant test results and will make a significant contribution to the global body of research into amine based reactive gas / liquid absorption for CO_2 capture.

Successful completion of the project would enable scale-up of the next technology phase and potential for a larger-scale demonstration project.

In addition to research outcomes, better knowledge of the CCS process will support skills-development for the brown coal industry through the expansion of training opportunities.

Figure 2: Completed PICA Plant on site at AGL Loy Yang.

For more information please visit csiro.au/en/Research/EF/Areas/Coal-mining/Carbon-capture-and-storage

BCIA MEMBER

SKILLS

Electrochemical storage of hydrogen in activated carbon made from brown coal

By Amandeep S. Oberoi, PhD student, School of Engineering (Aerospace, Mechanical and Manufacturing Engineering), RMIT University, Melbourne

Continuous power production and energy supply has been a major challenge in the field of renewable energy generation for a long time. One solution to the problem is that hydrogen obtained from renewables can be utilised in a solar electricity supply system as a long-term energy store to enable the system to supply energy continuously on a year round basis. Yet a challenge remains in finding a safe, economical, lightweight and compact form of hydrogen storage.

Conventional hydrogen storage systems include storage of hydrogen as a gas at high pressure in a pressure vessel, as a cryogenic liquid at very low temperatures, and in solid-state form in metal and chemical hydrides. Current hydrogen storage systems have various restrictions in terms of volumetric and gravimetric energy densities, net-energy losses, and cost-effectiveness. Electrochemical storage of hydrogen in solid media, in particular carbon-based materials, is a promising alternative storage method, and has been actively researched over the past decade.

Recent research at RMIT University has led to the novel concept of a 'proton flow battery'. In the proton flow battery, a solid hydrogen storage electrode is integrated into a single Proton Exchange Membrane (PEM) cell that can operate reversibly as an electrolyser to split water or as a fuel cell to generate electricity. In electrolyser mode, hydrogen ions, that is, protons, emerging from the membrane enter the solid storage directly, and then react with electrons and the atoms of the storage material to form a hydride without producing hydrogen gas. Hence in principle, a proton flow battery would be an ideal device to store surplus electrical energy from a solar energy system for resupply at times of low or zero solar input.

Electrochemical storage of hydrogen in activated carbon (aC) electrodes as part of a reversible fuel cell in a proton flow battery, offers a potentially attractive option for storing surplus electrical energy from inherently variable solar and wind energy resources. Running in charge mode, intermittent electricity is fed to a Proton Exchange Membrane (PEM) electrolyser that splits water into hydrogen and oxygen. Running in supply mode, stored hydrogen is fed to a PEM fuel cell, along with oxygen from the air, and electricity is generated once again. This system promises to have a roundtrip energy efficiency comparable to lithium ion batteries, while having higher gravimetric and volumetric energy densities.

Figure 1: Proton flow battery.

Previous work on the proton flow battery at RMIT has investigated the performance of two novel electrode materials. The first was a novel composite metal hydride-nafion polymer material, which established the feasibility of the proton flow battery concept. However, the use of metal hydride had certain limitations, namely the high cost and mass of the metal alloy powder.

The second electrode was a composite of nafion and activated carbon. Activated carbons have attracted considerable research interest as a solid-state hydrogen storage medium because of their high internal surface area, high pore volume, and light weight. However, the initial electrode design was limited by poor hydrogen transport into the ultramicropores of the activated carbon particles.

My PhD research has been conducted under the supervision of Professor John Andrews, with funding support from BCIA. My research involved an investigation of the use of porous activated carbon electrodes and sulphuric acid as a liquid proton conductor.

Activated carbon (aC) powders made from Victorian brown coal were supplied by Monash University, Melbourne, Australia (Professor Alan Chaffee's group), and those from phenolic resin were obtained from CIC Energigune, Spain. These powders were activated after potassium hydroxide (KOH) addition and the percentage of KOH was varied to obtain different samples with a range of micropore volumes and surface areas (activation done by Lachlan Ciddor, PhD student of Prof. Alan Chaffee, Monash University, and Dr M. Karthik, research associate, CIC Energigune, Spain).

Their proton conductivity was measured by electrochemical impedance spectroscopy, double layer capacitance with cyclic voltammetry using a split flat coin cell (shown in Figure 2), and hydrogen storage capacity by galvanostatic charging and discharging in a three-electrode electrolytic cell (shown in Figure 3) with 1 M sulphuric acid as electrolyte.

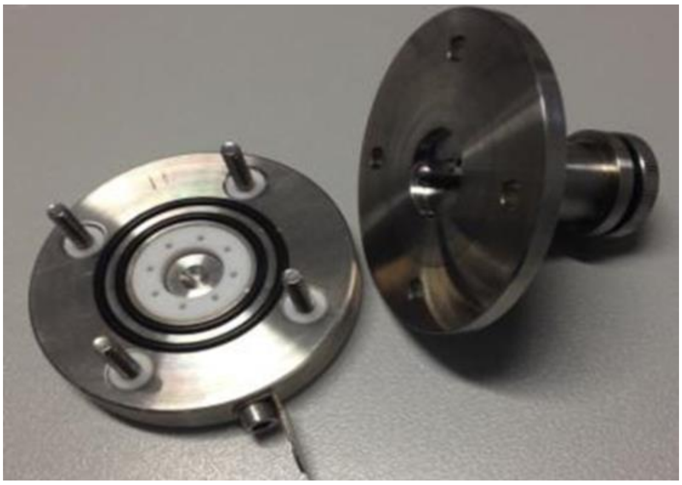

Figure 2: Split flat coin cell used to measure double layer capacitance [Oberoi A. 2015].

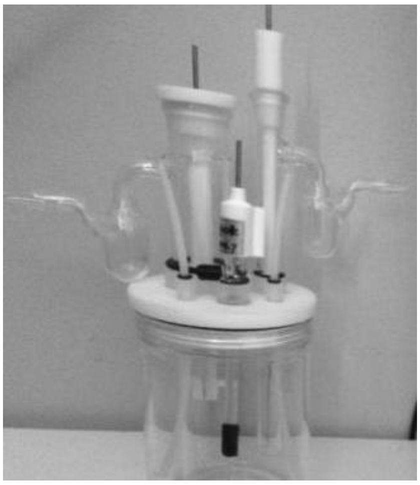

Figure 3: Three-electrode electrolytic cell used to measure hydrogen storage capacity.

Importantly, all the sample aC electrodes have shown promising results in terms of mass% of hydrogen electrochemically and electro-statically stored within them. Specifically, hydrogen storage capacity of aC samples made from Victorian brown coal was found to be in the range of 0.58%–1.36% mass, which is comparable with the capacity of commercial metal hydride-based hydrogen storage cylinders.

My PhD research has contributed experimental data on reversible electrochemical storage of hydrogen in solid carbon-based material in acid electrolytes, including activated carbons made from brown coal. It has also enhanced scientific understanding of the factors, especially pore volume and surface area, influencing hydrogen storage inactivated carbons. Further work is still needed however, to prove the technical feasibility of a proton flow battery incorporating a carbon-based electrode.

Amandeep Oberoi was successful in obtaining a scholarship from BCIA in 2014 to support his research. Amandeep has submitted his PhD thesis, which is currently being examined. BCIA congratulates Amandeep on this accomplishment, and wishes him every success in his professional career.

EVENTS

BCIA Agricultural Applications Seminar

BCIA's 'Agricultural Products from Brown Coal' workshop was held in Melbourne at the Monash University Conference Centre on 17th December 2015, and forms part of the BCIA workshop series 'Building the R&D plan to support a new brown coal industry'.

Products derived from Victorian brown coal are already being used in Australian agriculture, but there is potential to expand the range of products using new manufacturing technologies. This workshop was intended to bring together industry, academic and regulatory experts who had expressed an interest in this area, and to facilitate collaboration that could eventually lead to new manufacturing industries in Victoria.

Angeline Bartholomeusz, Business Development Manager at Monash University, provided an informative presentation on potential funding opportunities, which is always a topic of great interest. The round-table discussion that followed, led by BCIA's Dr David McManus, provided an opportunity for participants to get to know each other and highlighted both opportunities and challenges.

Participants expressed frustration that agricultural products derived from lignite are widely used overseas but have been ignored by Australian fertiliser companies. There are good opportunities for Australian products in the international market, but they need to be cost-effective and marketed properly.

Figure 1: Angeline Bartholomeusz, Monash University, presenting to workshop participants.

Local product trials have demonstrated that soils can be progressively improved with lignite-based products, with higher plant growth and improved stock health. These results need to be validated with large-scale independent field trials but funding opportunities are limited.

It was apparent that there is no lack of product opportunities or technical expertise. The main barriers seem to be a lack of understanding in the Australian market, and the lack of a mechanism and funding to build the necessary working partnerships.

BCIA's Dr Phil Gurney concluded the workshop by highlighting three potential actions that were identified during the day.

1. Reduce risks by developing a local carbon fertiliser product based on a proven product as sold overseas.
2. Partner with Australian farmer cooperatives to trial products, with the support of university research and regulators.
3. Engage State government for funding to support pilot-scale product manufacture, field trial evaluations and market engagement.

This workshop started the process of developing a roadmap for new manufacturing industries based on Victorian brown coal.

Another workshop is planned in this series to help set the research agenda to support growth of this industry sector. In support of this, BCIA has developed a new report on 'Agricultural Products from Brown Coal' (see page 6). If you are interested in attending the planned event or have an interest in developing new agricultural products from coal, please email BCIA at info@bcinnovation.com.au.

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.

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** in including access to our MEMBERS only web portal.
- **Participation in BCIA's Skills Development activities**, international linkages and networks and community forums.

- **Recognition of each member** organisation's commitment to a low-emissions future for brown coal with opportunity to promote member organisation through the BCIA newsletter *Perspectives* and website.

Brown Coal Innovation Australia Current 2016 Members