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Prepared for

ANLECR&D

Brown Coal R&D

Scoping Study

by
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anlecr&d A report commissioned by Australian National Low Emission Coal R&D Program

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ANLECR&D:
BROWN COAL R&D SCOPING STUDY

REPORT SUMMARY

A review of the current situation regarding the utilisation of brown coal in low emissions power generation applications is presented. Discussions with stakeholders were held to collate key R&D activities required to support low emissions power generation utilising brown coal.

Research areas have been identified for utilisation of brown coal in power generation applications involving carbon capture.

To achieve substantial reductions in the CO_2 emissions from brown coal power generation will require a combination of energy efficient drying together with methods for the capture and sequestration of CO_2. Advances in these areas will also be applicable to the current brown coal fired power stations, many of which are expected to remain in operation for several decades.

The research on coal drying should focus on the use of steam fluidised bed drying technology but also considering other alternatives.

Since future brown coal utilisation options with combustion will almost certainly involve the use of dry coal firing with either super-critical combustion with carbon capture or oxy-fuel combustion and CO_2 removal, research on the coal behaviour under these combustion conditions is required. This research should address ash behaviour (slagging and fouling), corrosion, and materials issues that would occur under conditions of higher flame temperatures and higher steam pressures.

Gasification with pre-combustion capture also provides an option for low emissions power generation. Improved catalysts for water shift reactions without the need for separate removal of sulphurous species in the syn-gas prior to pre-combustion CO_2 combustion is desirable. Although fluidised-bed gasification is usually preferred for reactive coals (such as Victorian brown coals), entrained-flow gasification is currently widely practised. Activities to support the evaluation of brown coals under entrained-flow gasification including ash behaviour are also recommended

There are also opportunities to increase the process integration of carbon capture plant from brown coal combustion to utilise the latent heat present in wet flue gases.

Issues associated with oxy-fuel combustion of brown coal would be covered by the Oxy-Fuel ANLECR&D node; however, the option of oxy-fuel firing of a circulating fluidised-bed may offer specific advantages for brown coal. In particular the reduced peak temperatures may reduce the slagging, fouling and corrosion issues associated with pf combustion.

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ACRONYMS AND ABBREVIATIONS

Acronym	Definition
ACA	Australian Coal Association
ANLEC	Australian National Low Emissions Council
BCIA	Brown Coal Innovation Australia
CCS	Carbon Capture and Storage
CHTD	Continuous Hydrothermal De-watering
CO2CRC	Cooperative Research Centre for Greenhouse Gas Technologies
CPRS	Carbon Pollution Reduction Scheme
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTL	Coal-To-Liquids
DICE	direct injection coal engine
ECBM	enhanced coal bed methane
ECT	Environmental Clean Technologies Limited
ETIS	Energy Technology Innovation Strategy
GHG	Green House Gas
HRLT	HRL Technology Pty Ltd
HTW	High Temperature Winkler
IDGCC	Integrated Drying and Gasification Combined Cycle
IER	Ignite Energy Resources
IGCC	Integrated Gasification Combined Cycle
IPH	International Power Hazelwood
IPM	International Power Mitsui
LETDF	Low Emissions Technology Demonstration Fund
LVPCC	Latrobe Valley Post Combustion Capture Project
MOU	Memorandum of Understanding
MTE	Mechanical Thermal Expression
PCC	Post Combustion Capture
pf	Pulverised Fuel
R&D	Research and Development
RD&D	Research, Development and Demonstration
SCW	Super Critical Water
SECV	State Electricity Commission of Victoria
SFBD	Steam Fluidised Bed Drying
UBC	Upgraded Brown Coal

ANLECR&D:
BROWN COAL R&D SCOPING STUDY

REPORT

1 INTRODUCTION

ANLECR&D is developing an Australian national program for collaborative low emission coal R&D. The program will initially be funded by $75 million each from the Federal Government and the Australian Coal Association (ACA) over a seven year period. The R&D will be undertaken in ANLECR&D Research nodes that cover the following technical areas:

- Economic Studies
- Fundamentals
- Brown Coal
- Capture Technologies (Oxy-Firing, Post Combustion Capture, Gasification), and
- Carbon Storage.

The focus of the ANLECR&D program will be to facilitate early demonstration projects in the 2015 to 2020 timeframe.

HRL Technology (HRLT) has been commissioned to prepare a scoping study for ANLECR&D covering activities related to Brown Coal. The scoping study is to provide a review of the current situation regarding the utilisation of brown coal in power generation applications involving carbon capture. The review considers the current global state of the art, local issues, and gaps and opportunities.

The scope of the study specifically excludes other applications for brown coal including production of coal products or liquid fuels. Additionally, brown coal activities associated with oxy-fuel firing, post combustion capture and carbon capture, and geological storage will be undertaken as part of separate reviews and, therefore, are also outside the scope of this study. It is noted that the gasification node is largely focussed on entrained-flow gasification technologies whereas the reactive nature of brown coals favours fluidised-bed gasification. Consequently, brown coal gasification is addressed in this report. The other nodes are required to consider issues related to brown coal utilisation and in particular the Oxy-Firing and Capture nodes.

The budget for the ANLECR&D brown coal activities is about $1M per annum over seven years.

The scope of activities to be covered in developing the Brown Coal Scoping Study include:

- A review of the state of art:
- Update on operations of commercial and demonstration projects and significant pilot scale activities

- The potential technical, market, economic, public acceptability and legal barriers that need to be addressed
- Australian issues that need to be addressed for a successful demonstration program in the 2015 – 2020 timeframe
  - Unique or unusual aspects related to Australian deployment (fuel supply issues, environmental legislation, etc)
  - Unique or world class Australian skill sets
  - Interfaces or linkages with international programs

From the above activities, focus areas and priorities for ANLECR&D will be identified to develop work programs for utilisation of brown coal in power generation applications involving carbon capture.

2 BROWN COAL IN AUSTRALIA

Australia has about 24% of the world's economic resources of brown coal with substantial brown coal deposits occurring in Victoria, South Australia and Western Australia. There is over 100 billion tonnes of economically recoverable brown coal resources, all of which is in Victoria and over 90% in the Latrobe Valley, Gippsland [1].

Brown coal is currently only mined in Victoria, with 98% production (about 66 million tonnes per annum) from the Latrobe Valley mines. The brown coal is used mainly for the generation of electricity in adjacent mine mouth power stations with about 75% of Victoria's generation capacity of 9,000MW provided by brown coal fired plant. A small amount of dried brown coal briquettes are also produced for industrial and domestic use and for export. Some of the briquettes are also converted to a char product. Smaller Victorian brown coal deposits are exploited in Anglesea (power generation) and Bacchus Marsh (horticultural products).

At current utilisation rates, there is over 500 years of brown coal resources available within the Victorian Latrobe Valley.

There are also brown coal resources in the St Vincents and Murray Basins and around Pidinga in South Australia and a number of deposits in the south east of Western Australia (at Esperance, Scaddan, Salmon Gums and Balladonia). The South Australia and Western Australia resources are of poor quality (high moisture, high ash, and high salt) and are currently not commercially exploited although there are a number of proponents seeking to utilise these coals, typically for coal-to-liquids projects.

For the purposes of this study the South Australian Leigh Creek coals and the Western Australian Collie coals are considered as low-rank sub-bituminous coals rather than as brown coals.

[1] Geoscience Australia (2008). "Australia's Identified Mineral Resources".

3 BROWN COAL UTILISATION IN VICTORIA

Brown coal is an important economic resource for Victoria. Brown coal power generation represents about 6,500 MW (about 75%) of installed capacity in Victoria and directly employs around 1,300 people.

The location of the main coal areas in Victoria is presented in Figure 1.

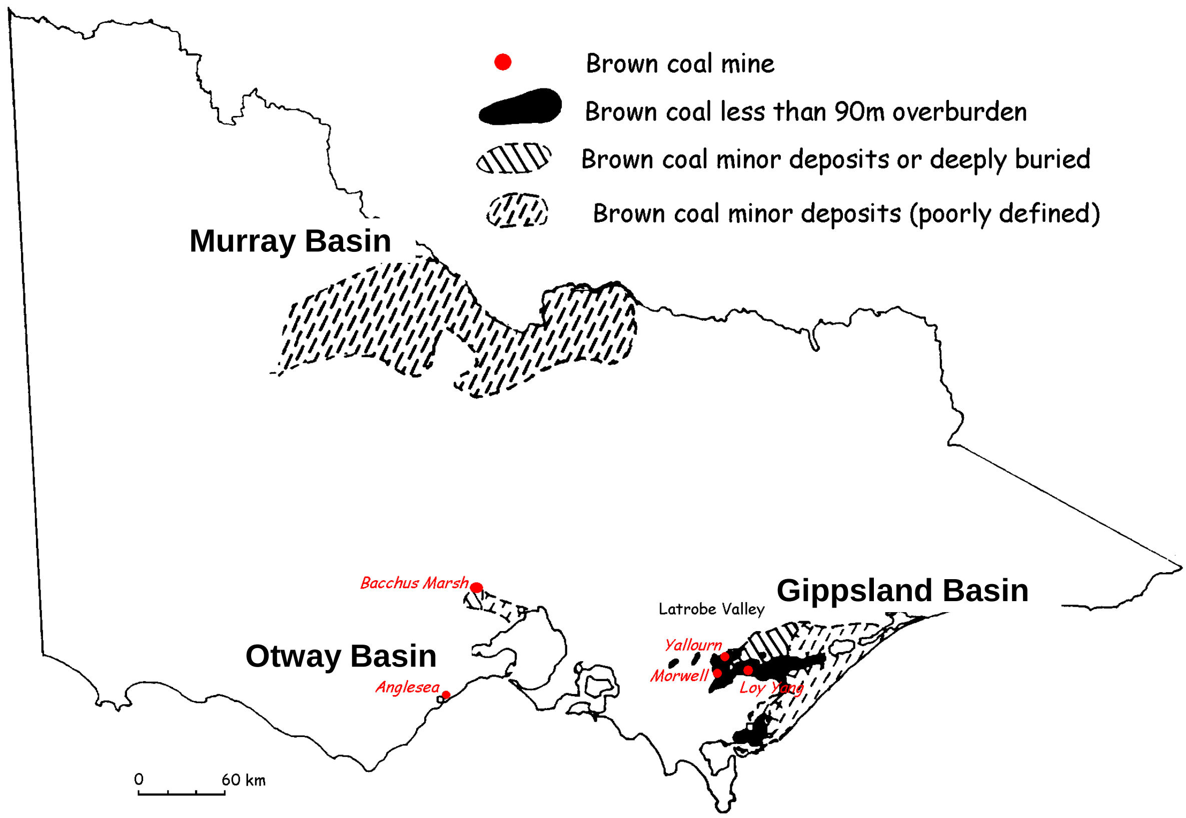

Figure 1: Location of Brown Coal Resources and operating mines in Victoria.

The brown coal deposits occur in three major basins. The largest deposits are in the Gippsland Basin, where the Latrobe Valley coalfield contains some of the thickest brown coal seams in the world. The deposit is up to 330 m thick and is made up of 4 main seams, separated by thin sand and clay beds. The Latrobe Valley is the centre of Victoria's electric power generation industry with mine mouth power stations located next to the Yallourn, Hazelwood and Loy Yang mines. Some brown coal is also dried and used for briquette production for local industrial and domestic use and for export.

Smaller brown coal deposits are also mined from the Otway Basin at Anglesea, supplying a small (150MW) adjacent power station. A small amount of Otway Basin coal is also mined at Bacchus Marsh, mainly for fuel and soil conditioning.

The coal seams in the Murray Basin are up to 40 m thick in some areas, but are buried beneath 100 m of overburden. The high ash content and deep burial makes this coal uneconomic under current conditions.

A summary of the Victorian coal reserves is presented in Table 1.

Victorian brown coal production (2002) is presented in Table 2. At current utilisation rates, there is over 500 years of brown coal resources available within the Victorian Latrobe Valley.

The average coal quality for the mined Victorian coal is presented in Table 3.

Table 1: Summary of Brown Coal Resources in Victoria

Basin and Area	**Quantity** [million tonnes]
Gippsland Basin	
Latrobe Valley Depression	158,026
Moe-Yarragon	773
Stradbroke	3,700
Won Wron Boodyarn	288
Alberton	4,887
Gelliondale	5,200
Murray Basin	
Kerang Deposits	19,599
Otway Basin	
Bacchus Marsh-Altona	15,110 (A)
Anglesea	390
Total All Basins	**207,973**

Source: Gloe and Holdgate (1991) [2]

(A): Except for a region near the western end of the deposit, most of this coal is covered by 100 m of basalt

Table 2: Production from Victorian Coal Mines (2002)

Basin and Mine	**Production (Million tonnes per annum)**
Gippsland Basin (Latrobe Valley)	
Loy Yang Open Cut	30.95
Yallourn Open Cut	15.65
Morwell Open Cut	18.98
Otway Basin	
Anglesea Open Cut	1.07
Bacchus Marsh	0.03 [a]

[a]: production for 1997/1998

[2] G.S. Gloe and G.R Holdgate (1991) "*Geology and Resources*" in "*The Science of Victorian Brown Coal*", Dr R.A. Durie, Editor, Butterworth-Heinemann

Table 3: Average Coal Quality Data for Victorian Coals

Property		Gippsland Basin (Latrobe Valley)			Otway Basin	
		Yallourn	Loy Yang	Morwell	Anglesea	Bacchus Marsh
Moisture	**(%ar)**	66.5	62.8	61.3	46.4	60.5
Ash	**(%db)**	1.7	1.3	3.0	3.8	7.4
Volatile Matter	**(%db)**	50.3	49.8	48.3	47.0	49.8
Fixed Carbon	**(%db)**	48.0	48.9	48.7	49.2	42.8
Carbon	**(%db)**	66.7	68.5	67.8	67.4	62.6
Hydrogen	**(%db)**	4.7	4.8	4.8	4.8	4.5
Nitrogen	**(%db)**	0.56	0.58	0.59	0.68	0.55
S total	**(%db)**	0.28	0.38	0.33	2.85	1.74
Calorific Value						
Net Wet	**MJ/kg**	6.9	7.9	8.4	12.1	8.3
Gross Dry	**MJ/kg**	26.1	26.2	26.4	27.4	25.6

Source: Gloe and Holdgate (1991) [2]

3.1 Major Users of Victorian Brown Coal

The current major users of Victorian Brown Coal are listed below:

- Loy Yang Power [3] operate the Loy Yang open-cut mine and Loy Yang A power station (4 units, total capacity of 2200 MWe). The station commenced operation during the 1980s. The Loy Yang coal is also supplied to the adjacent Loy Yang B power station [4] and for use for briquette production by Industrial Energy [5].

- International Power Mitsui (IPM) [4] operates the Loy Yang B power station. The station has two units that produce a total of 1,026 MWe of electricity using coal from the adjacent Loy Yang open cut mine. Unit 1 commenced operation in 1993 and Unit 2 commenced operation in 1996.

- TRUenergy [6] operate the Yallourn mine and Yallourn W Power Station (4, total capacity of 1,480 MWe). The Yallourn W Power Station was built in the 1970s.

- International Power-Hazelwood (IPH) [7] operate the Morwell mine and the adjacent Hazelwood Power Station. Eight units generate a total of 1,675 MWe, consuming about 18 million tonnes of brown coal annually. The first unit was commissioned in 1964 and the last units in 1971. The Morwell coal is also supplied to Energy Brix Australia for power generation and briquette production.

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[3] www.loyyangpower.com.au. Accessed 17 September 2009.

[4] ww.ipplc.com.au/Page.php?iPageID=141. Accessed 17 September 2009.

[5] www.hrl.com.au. Industrial Energy markets briquettes manufactured in a co-generation plant associated with the Energy Brix power station. Energy Brix Australia and Industrial Energy are subsidiaries of HRL Limited

[6] www.truenergy.com.au/Production/Yallourn/index.xhtml. Accessed 17 September 2009.

[7] www.ipplc.com.au/Page.php?iPageID=32. Accessed 17 September 2009.

- Energy Brix Australia[5] operates the Morwell Power station (170 MWe capacity). The associated co-generation plant is used for coal drying and briquette production. The brown coal briquettes are marketed by Industrial Energy[5] for local industrial and domestic use and for export. The briquettes are also supplied to Australian Char[8] for char manufacture.

- Alcoa of Australia Ltd operate a small brown coal open cut mine and 150 MWe power station located at Anglesea [9] which provides electricity for the company's aluminium smelter located at Point Henry, near Geelong. The station was commissioned in 1969.

- The Maddingley Brown Coal Company produces a very small amount of coal at Bacchus Marsh, mainly for fuel and soil conditioning. This coal is from the Otway Basin.

3.2 New Projects or Technologies Proposed for Victorian Brown Coal

A number of new projects utilising Victorian Brown Coal are at various stages of development or investigation:

- International Power-Hazelwood (IPH) is undertaking a mine extension into the Hazelwood West coalfield that holds 575 million tonnes of reserves, sufficient to supply the power station through to 2032. As part of the mine extension, IPH are also undertaking studies with the objective of reducing CO_2 emissions by 30-40% using a combination of coal drying, boiler and turbine upgrades and Post Combustion Capture (PCC) of CO_2 (see also Section 8.2).

- HRL Limited [10] has been granted an Exploration Licence over the Driffield coalfield in the Latrobe Valley. HRL Limited has also announced the "Dual Gas Demonstration project" for the Latrobe Valley. This project will generate 550MW of electricity using syngas from their IDGCC (Integrated Drying Gasification and Combined Cycle) technology with natural gas as a start up and supplementary fuel (see also Section 8.4).

- Monash Energy Ltd [11] has been granted an Exploration Licence over the Flynn brown coal resource (approximately 18,000M tonnes) in the Flynn/Gormandale region near the Latrobe Valley Loy Yang mine. Monash Energy proposes a Coal-To-Liquids (CTL) project with coal drying (steam fluidised-bed drying) and gasification (Shell Coal Gasification Process), power generation and CO_2 capture and sequestration.

- Latrobe Fertilisers Holdings Limited [12] are proposing a 1.2 million tpa urea fertiliser plant in the Latrobe Valley. The plant will use coal gasification to produce a syn-gas for ammonia production.

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[8] www.auschar.com.au

[9] www.alcoa.com/australia/en/info_page/anglesea_overview.asp. Accessed 17 September 2009

[10] www.hrl.com.au

[11] www.monashenergy.com.au. Accessed 17 September 2009

[12] www.latrobefertilisers.com.au. Accessed 17 September 2009

- Environmental Clean Technologies (ECT) Limited [13] are developing a brown coal dewatering process that results in the production of extruded brown coal pellets with low moisture.

- Exergen Pty Ltd [14] are developing their Continuous Hydrothermal De-watering (CHTD) process for the upgrading of brown coals through energy efficient water removal. A 200 – 350 tph demonstration dewatering plant is proposed for the Latrobe Valley.

- Ignite Energy Resources (IER) Pty. Ltd [15] are developing a Super Critical Water (SCW) reactor system to convert brown coal into high-valued oil and coal products. IER have entered into an MOU to develop a commercial test plant for its coal-to-oil technology at TRUenergy's Yallourn mine.

3.3 Use of Victorian Brown Coal in a Carbon Constrained World

Although the Latrobe Valley brown coal resource is a fuel source with low ash and low sulphur, the coal has high moisture which contributes to high CO_2 emissions relative to black coal and other fossil fuels.

Future utilisation of the brown coal resources for power generation and other applications will require the high CO_2 emissions to be addressed. This will require a combination of

- Increased efficiency of existing plant,

- The introduction of new low CO_2 emissions technology to supplement and replace existing generation, and

- Carbon capture and sequestration of CO_2.

The Latrobe Valley is in close proximity to carbon sequestration sites located in depleted oil and gas reservoirs in the Gippsland Basin (potential capacity of 2,000 million tonnes of CO_2) or in deep saline aquifers in the Gippsland Basin (potential capacity of 33,300 million tonnes of CO_2). For comparison, Victoria's annual CO_2 emissions are about 122 million tonnes.

To take advantage of the extent of the brown coal resources available within the Victorian Latrobe Valley (over 500 years of coal at current utilisation rates) and the availability of carbon sequestration sites, the Victorian Government is also promoting the use of Latrobe Valley coal as an export fuel though drying and upgrading of the coal or for use in the production of liquid fuels via gasification or direct liquefaction.

The Victorian Government has provided significant financial support for the introduction of low emissions and Carbon Capture and Storage technologies into Victoria. These include

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[13] www.ectltd.com.au. Accessed 17 September 2009

[14] www.exergen.com.au. Accessed 17 September 2009

[15] www.igniteer.com. Accessed 17 September 2009

- Energy Technology Innovation Strategy 1 (ETIS 1)

  $180 million was provided which leveraged a further $1.6 billion in private and public sector funding. The projects related to brown coal included

  - $50 million to HRL Limited for a $750 million 400 MW IDGCC plant. The federal government also contributed $100 million from the Low Emissions Technology Demonstration Fund (LETDF).

  - $30 million to International Power Hazelwood to develop a new large scale coal drying and combustion plant and a 25 tonne per day carbon capture demonstration plant. The project is valued at $370 million. The Federal Government has also contributed $50 million from the LETDF.

  - $12 million for Brown Coal Research and Development Grants including research in technologies for coal drying, carbon capture, oxy-fuel combustion and efficiency improvements.

  - $1.2 million for Brown Coal Research and Development Post Doctoral Fellowships.

  - $6 million for a Carbon Dioxide storage trial (geosequestration) in the Otway Basin.

- Energy Technology Innovation Strategy 2 (ETIS 2)

  Under the Carbon Capture and Storage fund, the Victorian Government has provided $110 million over six years in support of large-scale, pre-commercial carbon capture and storage demonstration projects. The projects should be capable of capturing at least 600,000tpa of CO_2. This funding is to support Victorian applications for flagship projects under the $2 billion CCS Flagships Program, administered by the Department of Resources, Energy and Tourism. Applications for the ETIS 2 projects closed in September 2009 and successful projects are to be announced in the first quarter, 2010.

The Victorian Government has also made application under the Commonwealth CCS Flagship Program for the development of the Victorian CarbonNet Project for Carbon Capture and Sequestration. The CarbonNet Project is a pipeline network to take CO_2 from point sources in the Latrobe Valley for sequestration using on-shore and off-shore sites located in the depleted oil and gas reservoirs in the Gippsland Basin. The Victorian CarbonNet Project is described in further detail in Section 8.1.

3.4 Brown Coal Innovation Australia (BCIA)

The Victorian Government has recently announced $16 million in funding for clean coal research related to brown coal utilisation to be delivered through a new organisation, Brown Coal Innovation Australia (BCIA) [16].

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[16] www.premier.vic.gov.au/minister-for-energy-resources/$16-million-for-new-clean-coal-research-announced.html. Accessed 25 Aug 2009

BCIA will be an independent company established to manage these new funds and will have a board appointed from industry and research organisations. A key role for the BCIA is to secure funding from ANLEC, other R&D grant programs and industry for Victorian brown coal research projects with a focus on low emissions brown coal technology.

The BCIA funding builds on a previous allocation of more than $9 million under the Victorian Government Energy Technology Innovation Strategy (ETIS) program that has supported brown coal research in Victoria over the last four years.

It is expected that the BCIA activities would be broader than ANLECR&D's scope and include upgrading of brown coal for export of dried coal and coal products, production of liquid fuels and fertilisers, in addition to low emissions power generation.

Coordination of the ANLECR&D program for Brown Coal with other funding sources, such as the Victorian Government BCIA, will be essential in order to maximise the benefit of the brown coal research programs.

4 BROWN COAL IN SOUTH AUSTRALIA AND WESTERN AUSTRALIA

There are currently no commercial operations utilising South Australian or Western Australian brown coals. Several projects are under various levels of investigation that involve the production of liquid fuels through either coal pyrolysis or gasification. None of these projects have power generation as the principal focus and, therefore, are outside the scope of the ANLECR&D program.

The typical analysis of South Australian low-rank coals is presented in Table 4.

Table 4: Typical analysis of South Australian low-rank brown coals

Coal Basin and Deposit Name	Moisture Content [%ar]	Ash Yield [%ar]	Volatile matter [%ar]	Fixed Carbon [%ar]	Calorific Value [MJ/kg]	Total Sulphur [%ar]	Chlorine [%ar]	Sodium in Ash [%wt]
Northern St Vincent Basin								
Bowmans	56	6	21	17	10.6	2.2	0.67	11
Clinton	53	9	18	20	9.4	1.9	na	16
Whitwarta	55	12	19	14	9.4	2.6	na	9
Lochiel	61	6	19	14	9.1	1.1	0.2	7
Murray Basin								
Anna	54	11	21	14	9.9	1.8	na	2
Sedan	58	9	19	14	9.4	2.3	0.08	3
Kingston	53	7	22	18	10.6	1.5	0.11	6
Moorlands	55	9	18	18	9.9	1.8	0.14	3

Source: *South Australian Department of Primary Industries and Resources* [17].

[17] "*Coal Resources in South Australia*" http://www.pir.sa.gov.au/pages/minerals/resources/commodity/images/coal_resources_sa.pdf

The South Australian low rank coals are generally high in moisture, sulphur, sodium and chlorine. Current activities involving these coals include:

- Syngas Ltd are proposing a Coal-to-Liquid (CTL) project utilising the South Australian Clinton lignite deposit and a Siemens gasifier.

- Hybrid Energy Australia (www.hybridenergyaustralia.com.au) are undertaking a technical evaluation of a Coal To Liquids project using gasification to exploit the lignite resource located in the Kingston area in south-east South Australia.

There are substantial deposits of poor quality lignite resources located in south-eastern Western Australia. These are generally characterised as high moisture, high sulphur, high ash and high salt. Current activities involving these coals include:

- Blackham Resources Ltd (www.blackhamresources.com) and Wesfarmers Premier Coal Ltd's 70/30 Scaddan Energy Joint Venture has completed a scoping study on the potential of producing Urea and Methanol at the Scaddan Energy Project near Esperance, in south-east WA.

- Spitfire Oil Ltd (www.spitfireoil.com) is developing a low temperature pyrolysis process with Curtin University to exploit the Salmon Gums lignite deposit in south-east WA.

- West Australian Metals Ltd (www.wametals.com.au) has an exploration tenement near Scaddan (south-east WA) and is considering a coal-to-liquids project.

5 STAKEHOLDERS

To deliver the objectives of the scoping study, HRL consulted with key stakeholders with interests in the utilisation brown coal. These included Victorian Government and other bodies, Victorian Power Generators, Academic researchers, applied research organisations.

These included

- Wyld group *(Bruce Godfrey)*
- Victorian Government (*Frank Larkins; Peter Redlich; Leigh Clemow; Alana Herz)*
- Monash University (*Sankar Bhattacharya; Alan Chafee; Tam Sridhar; Paul Webley; Andrew Hoadley; Rod Hill; Kerry Pratt, Vincent Verheyen*)
- CO2CRC / University of Melbourne (*Geoff Stevens; Sandra Kentish; Barry Hopper*)
- Yallourn (*Mark Pearson; Steve Pascoe; Geoff Gay*)
- LYA (*Richard Elkington; Roland Davies; Barry Dungey; Chris Badger*)
- IPRA (*Gary Smith*)
- CSIRO (*David Brockway; John Carras; Phil Schwartz*)
- HRL Developments (*Terry Johnson, Alf Ottrey*)

6 THE STATE OF ART FOR BROWN COAL UTILISATION

6.1 Introduction

Brown coal is typically utilised close to where it is mined due to the high moisture content, which makes it inefficient to transport. When dried, brown coal has a propensity for spontaneous combustion and risks of dust explosion need to be considered. Therefore, the utilisation of brown coals has been almost exclusively as a fuel for mine mouth power generation using pulverised fuel boiler technologies. In Australia, such technology has been used since the 1920s and is still in use today. Brown coal can also be successfully transported and stored in a dried lump briquetted form with reduced risks of dust explosions and self heating.

There have been significant improvements through increases in efficiency and implementation of new technologies to mitigate environmental impact. However, technologies for power generation from brown coal remain the least efficient with the highest greenhouse gas emissions. The low efficiency of brown coal relates to the high moisture content of the fuel.

The most efficient Latrobe Valley power station has an efficiency of about 29 percent (higher heating value basis) for a coal moisture content of 62 percent. The efficiency of the older brown coal generation units in Victoria is lower. The comparable efficiency for a power station utilising low moisture high-rank (black) coals is about 37 percent.

A major challenge for the brown coal industry will, therefore, be to remain competitive with other power generation technologies after implementation of a Carbon Pollution Reduction Scheme (CPRS).

To meet challenges facing the brown coal industry, there will be a need to develop new technologies for processing brown coals and to implement state of the art technologies.

The objective of this section is to present a review of the status of commercial brown coal technologies for power generation with particular focus on state of the art technologies. The review focuses on coal drying, pulverised fuel combustion technologies and gasification technologies. The status of major commercial and demonstration projects and significant pilot scale activities are also presented.

6.2 RWE BoA Technology with WTA Fluidised Bed Drying

The state of the art in both brown coal fired combustion and brown coal drying is RWE Power's brown coal-fired optimised plant technology (abbreviated in German as BoA) with WTA Fluidised Bed predrying.

6.2.1 RWE BoA Technology

Technology Status (for Brown Coal):

1000MW plant brown-coal fired supercritical plant commissioned in 2003 in Niederaussem, Germany.

Status in Australia (for Brown Coal):

No supercritical brown-coal fired plants are operating in Australia although there are super critical black coal stations. The Hazelwood 2030 project is evaluating new *technologies that could lead to the introduction of ultra-supercritical boilers utilising dried brown coal.*

A supercritical plant utilising the BoA technology (*without* brown coal predrying) was commissioned in Niederaussem, Germany in 2003. A schematic of the plant is presented in Figure 2. The efficiency of the 1000MW plant when utilising 52% moisture coal is around 38% HHV, which is considerably higher than a Loy Yang A Power station utilising the same (52% moisture) coal, for which the efficiency would be around 30% [18]. Contributing factors to the increased efficiency are listed below. The improvement in efficiency due to each factor is also included:

- Supercritical operation at higher temperature (580°C) and pressure (275 bar) to increase turbine efficiency and output (1.3% improvement)
- Improved heat recovery (0.9%) and process optimisation (1.1%)
- Improved turbine (1.7%) and cooling tower design (1.4%)
- Reduced auxiliary power requirements (1.3%)

The technology also provides improved environmental performance through:

- Reduced NOx formation through optimisation of burners
- Removal of over 99.9% of dust from the flue gas using high efficiency electrostatic precipitators
- Flue gas desulphurisation using lime

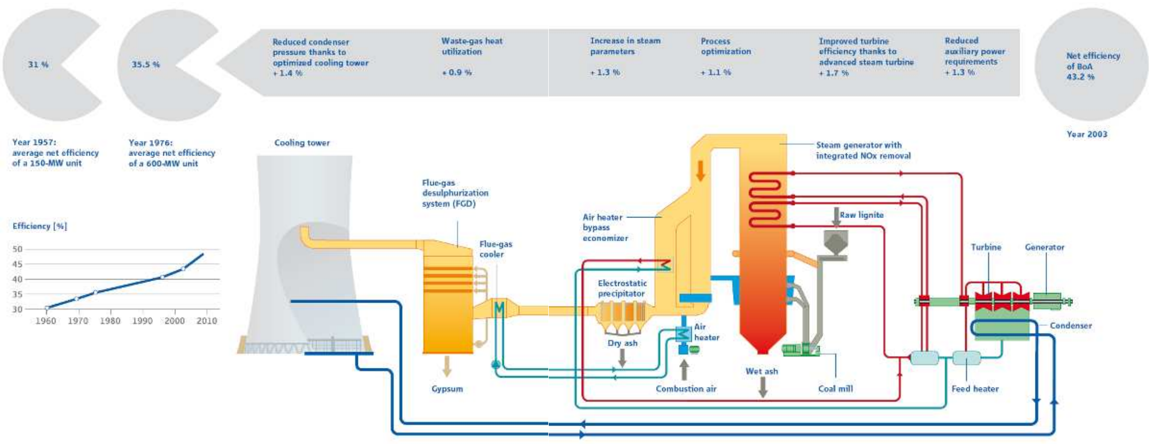

Figure 2. Schematic of RWE's BoA optimised plant technology brown coal fired technology (without brown coal predrying) [18]

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[18] RWE Power: Brochure – The Niederaussem Coal Innovation Centre, http://www.rwe.com/web/cms/en/235578/rwe-power-ag/media-center/lignite

The increased efficiency for the BoA Niederaussem plant relative to the technology used in the Latrobe Valley (Loy Yang A) is presented in Figure 3 [19]. For a feed coal of a given moisture content, the improvement in efficiency using RWE's BoA technology is around 7-8%.

Figure 3 also illustrates the influence of coal moisture content on power plant efficiency. For Loy Yang A, the plant efficiency for combustion of a 62% moisture coal is around 28% (HHV Basis). If the coal was dried to a moisture content in the range 10-20% then the plant efficiency would be improved to around 33%. This highlights the potential efficiency improvements that could be attained through pre-drying of the coal prior to combustion. Coal drying is discussed in more detail in the following sections.

Note: The efficiency improvement to the existing Loy Yang plant by utilising dry coal is theoretical. The current plant is not designed for utilising low moisture coals and generally a lower moisture limit of ~50% is suggested as a practical limit. Utilising of low moisture content coals would change the temperature distribution within the boiler and require changes to the burners, boiler design and heat exchangers. Higher gas temperatures would be expected to increase the extent of ash slagging and fouling within the boiler. Research and development work will be required to ensure successful utilisation of dried Victorian brown coal in specifically designed supercritical boilers.

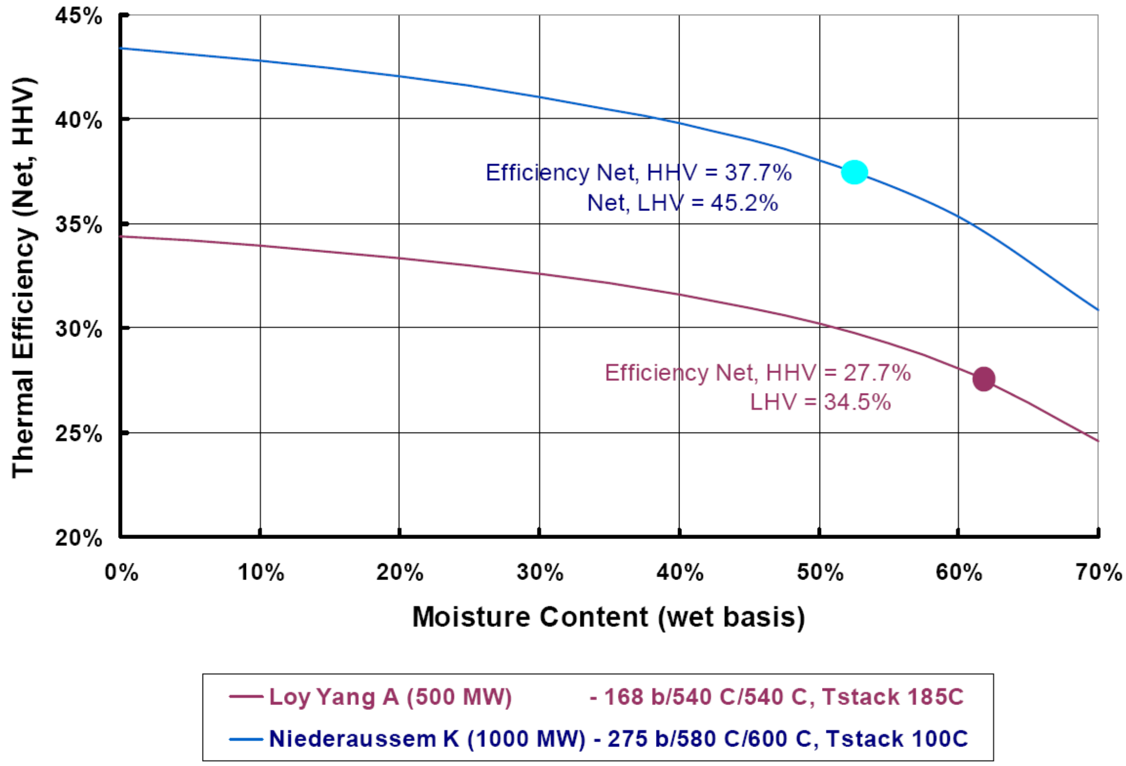

Figure 3. Influence of Coal Moisture Content on Power Plant Efficiency for the Niederaussem BoA plant (Germany) and Loy Yang A Power Station (Victoria) [19]

[19] From presentation by Richard Elkington, Loy Yang Power, Assessing Options to Develop a Lower Greenhouse Footprint

6.2.2 WTA Fluidised Bed Drying

Technology Status (for Brown Coal):

> *110 tonne per hour (dried coal) fine-grained demonstration fluidised bed drying plant incorporated in the 1000MW plant brown-coal fired supercritical plant in Niederaussem, Germany.*

Status in Australia (for Brown Coal):

> *70 tonne per hour fine-grained fluidised bed drying demonstration plant proposed by International Power Hazelwood (IPH) for incorporation into Hazelwood Power Station.*

Steam Fluidised Bed Drying (SFBD) was originally invented at Monash University (Victoria) by Professor Potter in the 1970's. The original SFBD concept consisted of cascading multistage dryers with heat recovery between each stage. Since the drying is performed in a steam atmosphere, it is inherently safe compared to using hot air as the drying medium, reducing the risks of fires and explosions.

SFBD was further developed by the East Germans using a single drying stage that led to the construction of several test and pilot plants including the 20 tonne/hour dry coal plant built in 1992 at Loy Yang A Power Station, Victoria by Rheinbraun and Lurgi. Although technically successful, the dried coal was expensive compared to available alternatives (ie dried brown coal briquettes, natural gas).

A variant of the SFBD drying technology is now in development that utilises -2 mm particles. This variant is called fine-grained fluidised bed drying and offers the advantages of higher heat transfer coefficients and shorter solids residence time in the dryer. It is claimed that the cost of the dryer plant and auxiliaries will be reduced to 40% of the original concept. The use of a vapour recompression cycle allows recovery of the latent heat of vaporisation and, therefore, high efficiency.

RWE now offer the WTA [20] SFBD drying technology in a number of variants - coarse grain or fine grain, with or without vapour recompression [21].

A demonstration of the WTA fine-grained fluidised bed drying technology is being implemented at the RWE BoA Niederaussem plant. The heat required for this process is extracted from the low-pressure steam from the BoA unit. The moisture content of the coal is reduced from over 50% to 12% wet basis. It is claimed that for brown coal fired plants using 100% WTA dried coal, the efficiency will increase by 5-6 percentage points. For the RWE BoA technology applied to German brown coals with 52% moisture this would equate to an efficiency of a dried coal fired plant of about 42% [18]. Victorian brown coals have a higher moisture content and the efficiency improvement will be lower since more energy would be required to dry the coal to the same moisture level.

The Niederaussem fine-grained fluidised bed drying demonstration plant processes about 20-30% of the feed brown coal to the station. The drying plant has a raw coal throughput of 210 t/h and an evaporation capacity of 100 t/h. Figure 4 presents a schematic of the

[20] WTA is a German abbreviation meaning fluidized-bed drying with internal waste heat utilization

[21] RWE Power Brochure. The WTA technology. An Advanced Method of Processing and Drying Lignite. www.rwe.com

implementation of the WTA drying in the BoA plant while Figure 5 presents a schematic of the WTA process as implemented at Niederaussem.

Significant advantages of the fine-grained fluidised bed drying technology are:

- High efficiency due to low operating temperatures and utilisation of the energy of the evaporated coal water
- Safe operation due to drying in an inert atmosphere.
- Compact design (reduced capital costs)

A fine-grained WTA plant without vapour utilisation has been proposed by International Power Hazelwood (IPH) for incorporation into Hazelwood Power Station as part of their program to extend the plant life beyond the year 2030. The demonstration unit to be installed on one of the Hazelwood boilers will process around 140tph of raw coal to produce around 70t/hr of dried coal.

Steam fluidised-bed drying is also an option being considered for coal drying for the Latrobe Valley projects proposed by Monash Energy [11] (Coal To Liquids) and Latrobe Fertilisers Holdings Limited [12] (urea production).

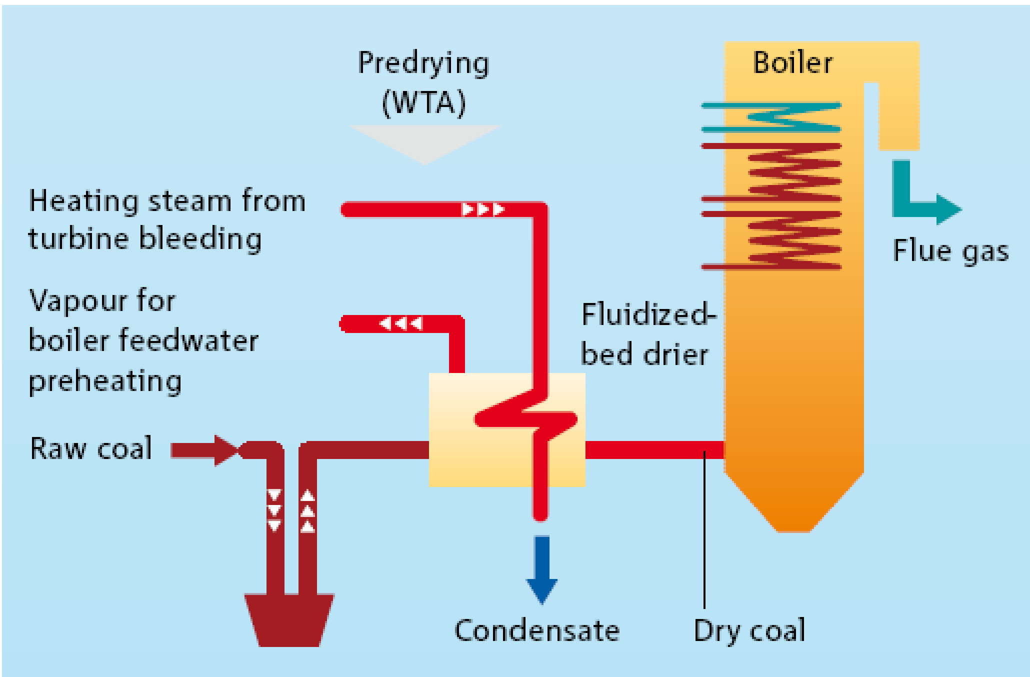

Figure 4. The BoA process with brown coal predrying. [18]

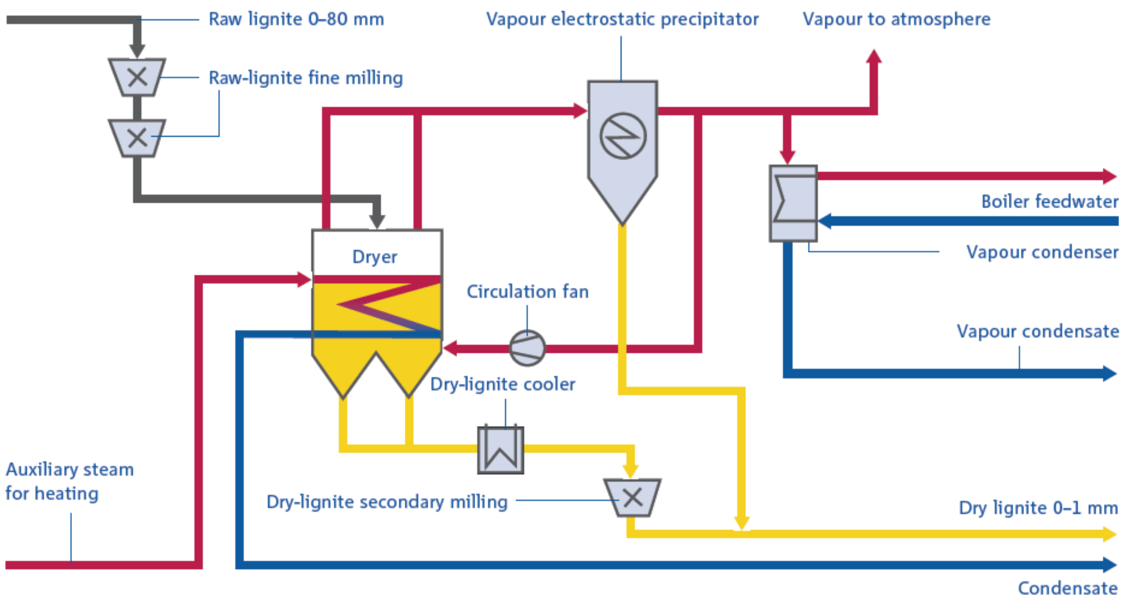

Figure 5. Schematic of the WTA fine-grained process as implemented at Niederaussem [22]

6.3 Other Coal Drying and Dewatering Technologies

The high moisture contents of brown coals significantly impact on the efficiency and thus environmental performance. A large amount of research and development has thus been directed at reducing the moisture content of brown coals. The moisture reduction technologies can be broadly classified into three main categories:

- Evaporative drying;
- Hydro-thermal (non-evaporative drying); and
- Other non-evaporative dewatering processes.

Comprehensive summaries of these drying and dewatering techniques are widely available (see, for example, Refs. [23] and [24]).

As described in the above section, WTA fine grained drying can be considered as state of the art in coal drying. Other technologies which are currently in use or under development at the demonstration scale are presented below.

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[22] RWE Power: Brochure – WTA Technology, http://www.rwe.com/web/cms/en/235578/rwe-power-ag/media-center/lignite

[23] Durie, R.A. 1991. The Science of Victorian Brown Coal: Structure, Properties and Consequences for Utilisation. ed. R.A. Durie. Oxford: Butterworth-Heinemann Ltd.

[24] Pikon, J., Drying of Coal, in Handbook of Industrial Drying, A.S. Mujumdar, Editor. 1995, Marcel Dekker: New York. 977-1006.

6.3.1 Integrated Flash Mill Hot Gas Drying

Technology Status (for Brown Coal):
Commercial

Status in Australia (for Brown Coal):
Practised in all Latrobe Valley power stations utilising brown coals.

In Victorian brown coal power stations, the coal is evaporatively dried by hot combustion gases in integrated mill/drying systems. In the process, coal is milled and dried simultaneously while entrained in a flow of hot recycled flue gas. The energy requirements are high, in the order of 3.2 - 4.5 MJ [25] per kg of removed water.

Flash mill drying was developed and commercialised in Germany in the 1930s and trialled in Victorian brown coal power stations in the late 1950s [26]. Although it is a well-established technology it still must be considered in a discussion on state of the art technologies as it widely used today and has been implemented in RWE's state of the art BoA process.

6.3.2 US DOE Lignite Fuel Enhancement Project

Technology Status (for Brown Coal):
75 tph Demonstration plant at Great River Energy's Coal Creek Station, North Dakota

Status in Australia (for Brown Coal):
Unknown. Expect concern regarding fire explosion hazards.

The Lignite Fuel Enhancement Project (LFES) is a part US DOE funded $US26M project being demonstrated at Great River Energy's 546 MW Coal Creek Station in North Dakota [27]. The process uses waste heat from the power station condenser to heat ambient air that is used for low temperature and partial drying of lignite coal in a fluidised-bed. The demonstration plant began operation in 2006, processing 75 tph of coal (14 percent of total fuel rate) reducing the coal moisture content from 40% to 30% moisture. This corresponds to a moisture removal of about 23kg/100kg dry coal. If this technology was applied to Latrobe Valley brown coals, the reduction would be comparable to reducing the coal moisture content from 60% to 56%, which would result in about 1% efficiency improvement. Higher levels of moisture could be achieved if some of the waste heat in boiler flue gas were recovered. For reactive brown coals, risks associated with dust explosibility and self heating when using air as the drying medium would need to be addressed.

6.3.3 Mechanical Thermal Expression (MTE)

Technology Status (for Brown Coal):
Demonstrated by RWE as 25 tph batch operation at Niederaussem power station, Germany. RWE decided to focus on steam drying and this work was discontinued.

Status in Australia (for Brown Coal):
Developed by CRC for Clean Power from Lignite leading to the construction and

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[25] Davy McKee (1984) Comparison of Technologies for Brown Coal Drying

[26] Allardice, D.J. (2000). The Utilisation of Low Rank Coals. The Australian Coal Review, (10), 40-46.

[27] Lignite Drying at Great River Energy's Coal Creek Station, http://mydocs.epri.com/docs/public/000000000001013060.pdf

operation of a 15 tpd demonstration plant at Loy Yang A Power Station, Victoria in 2008. No further development work planned.

MTE is a non-evaporative dewatering process which involves the application of mechanical pressure (1-10 MPa) at moderate temperature (150-200°C) to press the coal against a filter and 'squeeze' the water in liquid form from the coal. Moisture reductions of up to 70% are achievable. Relative to evaporative drying techniques, the energy requirements for MTE are low, around 500 kJ per kg of water removed. This equates to approximately 20% of the energy required in an evaporative process without heat recovery and therefore would be amongst the most energy efficient brown coal dewatering processes [28].

Investigation of the MTE process was initiated in the mid 1990's in Germany using a commercial flat-bed press commonly used in chipboard manufacture to dewater brown coal. The technology concept was proven and a 25 tonne/hour demonstration plant constructed and commissioned at the Niederaussem power station in Germany by RWE [28]. Although the technology has been proven successful, it has not been implemented at commercial scale and RWE has focussed development on the WTA drying technology (see Section 6.2.2).

The CRC for Clean Power from Lignite investigated MTE in parallel to the German program [28]. Whereas the German flat-bed press technology was a batch process with a 12 minute residence time, the CRC process was semi-continuous. Following laboratory and pilot-scale programs, a 15 tpd demonstration plant was constructed in Victoria at Loy Yang A Power Station in 2008 for the production of dried coal for use in power generation. Currently, no further development work on this technology is planned.

6.3.4 Upgraded Brown Coal (UBC)

Technology Status (for Brown Coal):

600 tph dry coal demonstration plant commissioned in South Kalimantan, Indonesia in December 2008. Project expected to run until March 2010.

Status in Australia (for Brown Coal):

6 tpd slurry dewatering process incorporated in the brown coal liquefaction (BCL) pilot plant, Victoria, 1987 to 1990.

The UBC process is a continuous solvent de-watering process, developed by Japan Coal Energy Center (J-Coal) and Kobe Steel, Ltd. The process is derived from the 6 tpd slurry dewatering process at the BCL (brown coal liquefaction) pilot plant in the Latrobe Valley, Victoria that operated during 1987 to 1990.

The UBC process is shown in Figure 6. The process incorporates vapour recompression of the evaporated water to improve the efficiency of the process (by recovering the water vapour's latent heat).

The coal is slurried with a solvent (light oil or kerosene), which is then sent to an evaporator where the water is evaporated. The evaporator operates at around 140°C and 350 kPa. Because of the low temperature and pressure during the drying stage no coal decomposition

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[28] McIntosh, M.J. and D.Q. Huynh 2005. Pre-drying of High Moisture Content Australian Brown Coal for Power Generation, 22nd Annual International Coal Preparation and Aggregate Processing Exhibition and Conference - Upgrading Low Rank Coals Symposium. May 2-5. Lexington, USA. 323-337.

reactions occur, reducing waste water treatment issues that exist with MTE and higher temperature coal upgrading processes. The slurry is centrifuged to recover the majority of the solvent and the centrifuge cake is then dried in a steam tube dryer to recover the remaining solvent. The dried coal is briquetted for shipment to reduce difficulties with dust and spontaneous combustion of the product. Asphalt is also added during the slurry making stage. The asphalt coats the pores in the dried coal, which is claimed to reduce the moisture re-absorption of the dried product and the spontaneous combustion propensity.

Kobe Steel began development of the UBC Process in 1993, applying the slurry dewatering technology from coal liquefaction. A 3-tpd plant operated in Java, Indonesia in 2004. A 600 tonne dried coal demonstration plant was subsequently built in South Kalimantan, Indonesia for a total investment of approximately AUD$100 million. The plant began operations in December 2008 and will continue until March 2010. The UBC demonstration project has the support of Japan's Ministry of Economy Trade and Industry through the Japan Coal Energy Centre (J-Coal), with Kobe Steel contributing its technological expertise.

Following completion of the demonstration program, capital and operating costs for the UBC process will become available and therefore the competitiveness of this drying technology for utilisation in Australia can be evaluated.

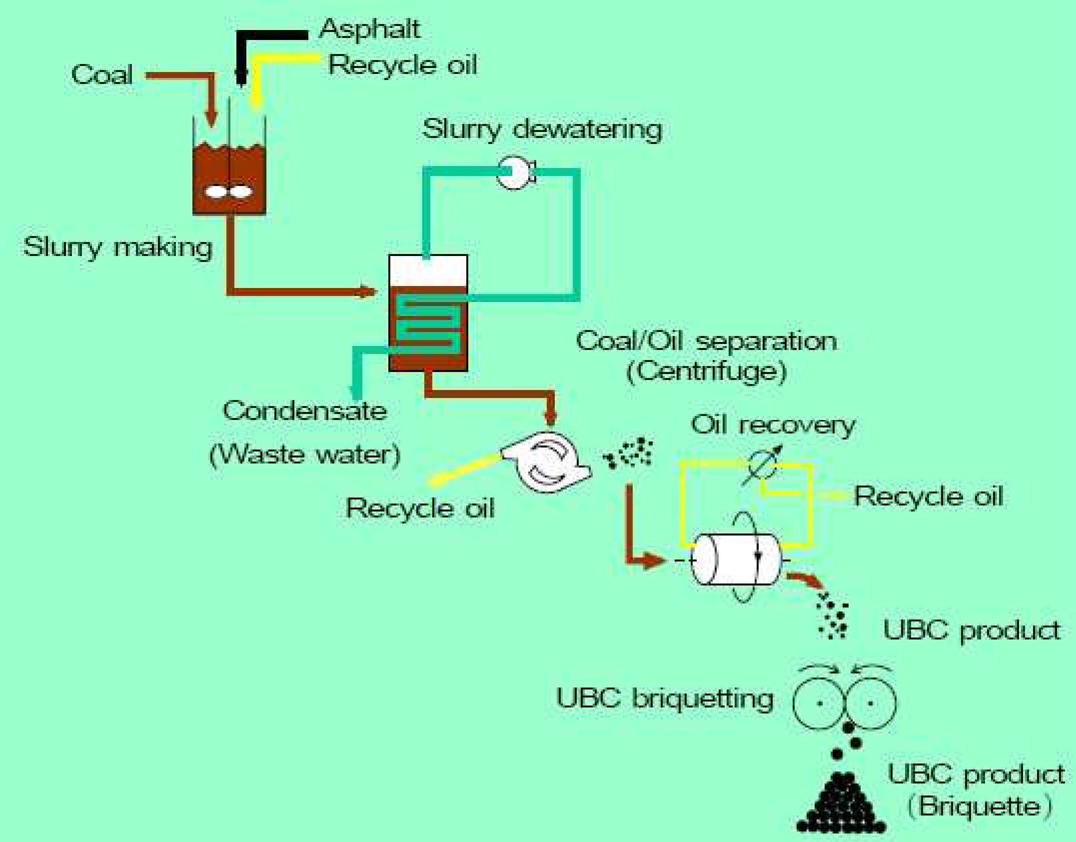

Figure 6: Processing scheme for the UBC Upgraded Brown Coal.

6.4 Brown Coal Gasification

Technology Status (for Brown Coal):

A number of technology vendors provide a range of gasification options although the use of gasification solely for power generation is limited. Utilisation of brown coal requires coal drying prior to gasification.

Status in Australia (for Brown Coal):

IDGCC is a low cost gasification option for power generation applications. Demonstrated at the 10MW scale.

Gasification is a proven technology, with over 30 commercial operations of at least 328MW_{th} equivalent output [29]. Table 5 lists the 30 largest commercial gasification projects around the world. The list highlights that there are few commercial gasification plants being used for power generation and even fewer operations using brown coal as the feed material. The majority of gasification operations use the syngas produced for chemical production. This is highlighted in Figure 7 which presents the distribution of uses for syngas produced from gasification process.

Table 5. Largest 30 commercial gasification projects [29].

Gasification Plant Owner	*Location*	*Gasification Technology*	*Output (MW_t equiv.)*	*Startup Year*	*Feed/Product*
Sasol-II	South Africa	Lurgi dry ash	4130	1977	Subbituminous coal/F-T liquids
Sasol-III	South Africa	Lurgi dry ash	4130	1982	Subbituminous coal/F-T liquids
Respol/Iberdrola	Spain	ChevronTexaco	1654	2004	Vacuum residue/electricity
Dakota Gasification Company	United States	Lurgi dry ash	1545	1984	Lignite and refinery residue/SNG
SARLUX srl	Italy	ChevronTexaco	1067	2000	Visbreaker residue/electricity and H_2
Shell MDA Sdn. Bhd.	Malaysia	Shell	1032	1993	Natural gas/mid-distillates
Linde AG	Germany	Shell	984	1997	Visbreaker residue/H_2 and methanol
ISAB Energy	Italy	ChevronTexaco	982	1999	ROSE asphalt/electricity and H_2
Sasol-I	South Africa	Lurgi dry ash	911	1955	Subbituminous coal/F-T liquids
Total France/EdF/ Texaco	France	ChevronTexaco	895	2003	Fuel oil/electricity and H_2
Unspecified owner	United States	ChevronTexaco	656	1979	Natural gas/methanol and CO
Shell Nederland Raffinaderij BV	The Netherlands	Shell	637	1997	Visbreaker residue/H_2 and electricity
SUV/EGT	Czech Republic	Lurgi dry ash	636	1996	Coal/electricity and steam
Chinese Petroleum Corporation	Taiwan	ChevronTexaco	621	1984	Bitumen/H_2 and CO
Hydro Agri Brunsbüttel	Germany	Shell	615	1978	Heavy vacuum residue/ammonia
Public Service of Indiana	United States	E-Gas (Destec)	591	1995	Bituminous coal/electricity
VEBA Chemie AG	Germany	Shell	588	1973	Vacuum residue/ammonia and methanol
Elcogas SA	Spain	Prenflow	588	1997	Coal and petcoke/electricity
Motiva Enterprises LLC	United States	ChevronTexaco	558	1999	Fluid petcoke/electricity and steam
API Raffineria di Anocona S.p.A.	Italy	ChevronTexaco	496	1999	Visbreaker residue/electricity
Chempoetrol a.s.	Czech Republic	Shell	492	1971	Vacuum residue/ammonia and methanol
Demkolec BV	Netherlands	Shell	466	1994	Bituminous coal/electricity
Tampa Electric Company	United States	ChevronTexaco	455	1996	Coal/electricity
Ultrafertil S.A.	Brazil	Shell	451	1979	Asphalt residue/ammonia
Shanghai Pacific Chemical Corp.	China	ChevronTexaco	439	1995	Anthracite/methanol and town gas
Exxon USA, Inc.	United States	ChevronTexaco	436	2000	Petcoke/electricity and syngas
Shanghai Pacific Chemical Corp.	China	IGT U-GAS	410	1994	Bituminous coal/fuel gas and town gas
Gujarat National Fertilizer Co.	India	ChevronTexaco	405	1982	Refinery residue/ammonia and methanol
Esso Singapore Pty. Ltd.	Singapore	ChevronTexaco	364	2000	Residual oil/electricity and H_2
Quimigal Adubos	Portugal	Shell	328	1984	Vacuum residue/ammonia

Note: F-T, Fischer–Tropsch synthesis; SNG, synthetic natural gas.

[29] Miller B.G. (2004), Coal Energy Systems, Academic Press

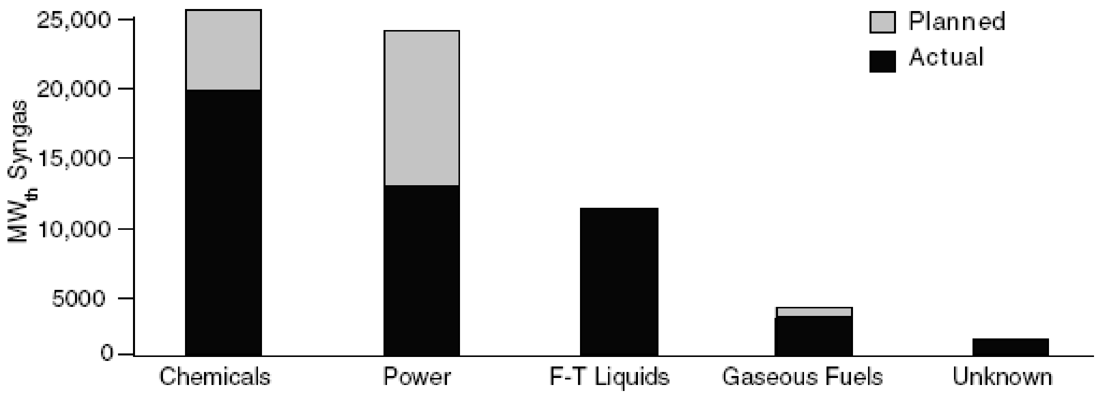

Figure 7. Distribution of gasification applications [29].

The Great Plains Synfuels Plant in Dakota, USA processes 18,000 tons of lignite per day for the production of synthetic natural gas [30]. A High Temperature Winkler (HTW) gasification brown coal gasification plant operated at Berrenrath from 1986 to 1997 for methanol synthesis gas production [31].

A major reason for the trend in the use of syngas for chemicals or liquid fuels production is that power is a low value product and therefore potential returns on investment will be low. Chemicals and liquid fuels represent higher value products and thus the potential return on investment is considerably greater compared to the use of syngas for power production.

Nearly all of the commercial gasification plants are based on oxygen-blown entrained-flow gasification. A notable exception for power production from lignite is Sokolovská uhelná (Vresová, Czech Republic). Dried brown coal is gasified in 26 Lurgi fixed bed gasifiers. Following syn-gas treatment, there is 400 MW of power generation using gas turbine/combined cycle. Options to replace the Lurgi gasifiers with fluidised-bed gasifiers was explored in the late 1990's/early 2000's as a means to reduce issues associated with tars generated from the Lurgi gasifiers [32]. More recently, the tar issue has been addressed by gasification using a 170MW_{th} Siemens entrained flow gasifier.

RWE have announced plans to build a 450MW integrated gasification combined cycle (IGCC) plant with CO2 capture, transportation and storage (CCS). The IGCC power plant will be constructed on the Goldenbergwerk site in Huerth, near Cologne and use local lignite

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[30] Dakota Gasification Company. www.dakotagas.com. Accessed August 2009.

[31] High Temperature Winkler (HTW) Coal Gasification. A Fully Developed Process for Methanol and Electricity Production. http://www.gasification.org/Docs/Conferences/1998/GTC9808P.pdf. Accessed August 2009.

[32] HTW Fluidized-Bed Gasification for 400MW IGCC Power Plant, Vresova – Czech Republic. http://www.gasification.org/Docs/Conferences/2000/Gtc00300.pdf Accessed August 2009.

resources [33]. The preferred gasification technology is entrained-flow gasification with HTW as a back-up.

RWE's HTW gasification technology is exclusively offered through Uhde. Uhde also offer the Prenflo entrained-flow gasification technology and licence the TEXACO coal/water slurry feed gasification system [34].

6.4.1 Integrated Drying and Gasification Combined Cycle (IDGCC)

Technology Status (for Brown Coal):

10MW-scale IDGCC Coal Gasification Development Facility (CGDF) operated 1996 to 1998 in Morwell, Victoria. Proposals for construction of a 400MW scale commercial demonstration well developed.

Status in Australia (for Brown Coal):

see above.

A gasification technology which does have potential for low cost power generation from low rank coals is Integrated Drying and Gasification Combined Cycle (IDGCC). IDGCC is a pressurised air blown fluidised bed technology which converts brown coal into a syngas. The integrated drying concept involves drying of the coal with hot fuel gas exiting from the gasifier. This approach also results in cooling of the fuel gas. Integration of the coal drying and gas cooling operations provides substantial cost savings whilst achieving high efficiencies through the combined cycle. A schematic of the IDGCC technology, which is being developed by HRL [10], is presented in Figure 8.

The IDGCC technology has been proven at the 10MW scale.

HRL Limited has also announced the "Dual Gas Demonstration project" for the Latrobe Valley. This project will generate 550MW of electricity using syngas from their IDGCC technology with natural gas as a start up and supplementary fuel. The project is approaching commercial closure and is planned to be operational by 2012-13 [35]. IDGCC is expected to deliver a 30 per cent reduction in carbon dioxide emissions and a 50 per cent reduction in water usage compared with the best brown coal-fired power generation plant in operation in the Latrobe Valley, Victoria.

IDGCC is also discussed in Section 8.4.

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[33] RWE Press Release: Site decision has been made: RWE plans to build a power plant in Huerth featuring coal gasification and CO2 capture
http://www.rwe.com/web/cms/mediablob/en/78734/data/0/7532/PM-RWE-AG-CCS-Entscheidung-EN.pdf
Accessed August 2009.

[34] Uhde brochure: Prenflo Gasification.
http://www.sheddenuhde.com/UploadFiles/4d/4d6e09bd-6a47-452d-b4e1-a65f4fe82fa5.pdf
Accessed August 2009.

[35] http://www.dpi.vic.gov.au/DPI/dpinenergy.nsf/LinkView/C89C9C21CF5F048DCA2574F2002581844CAC723B1D538D66CA25740C000D2004/$file/DPI_Coal.pdf
Accessed August 2009.

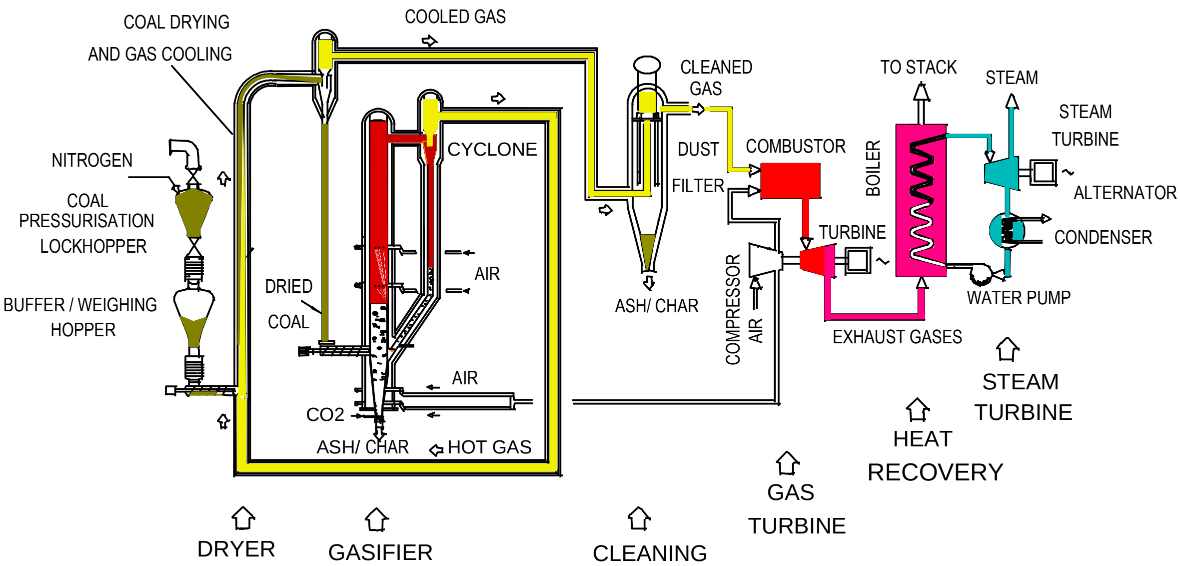

Figure 8: Schematic of HRL's IDGCC process [36]

6.5 Oxy-Fuel Combustion

Technology Status (for Brown Coal):
30 MW thermal Oxy-Fuel pilot plant in operation at Schwarze Pumpe, Germany using dried lignite.

Status in Australia (for Brown Coal):
Study on Oxy-Fuel retrofit to Latrobe Valley brown coal-fired boilers

Oxy-Fuel combustion, along with post-combustion capture, pre-combustion capture, is one of three carbon capture technologies under investigation by ANLECR&D. In Oxy-Fuel combustion, the coal is burnt in oxygen and recycled flue gas. Since the products of combustion are predominately H_2O and CO_2, after cooling of the flue gas and water removal, the flue gas is almost entirely CO_2. The CO_2 can be liquefied by compressing the remaining CO_2 rich flue gas without the need of a capture system.

There are currently no commercially operating Oxy-Fuel combustion plants although there are a number of operating pilot plants and small demonstrations. Vattenfall commissioned a 30MW Oxy-fuel pilot plant for use with brown coal at Schwarze Pumpe, Germany in September 2008 [37]. The initial test programme will run for three years. This project will also investigate possibilities of storing CO_2 in deep saline formations.

Unit 4 of CS Energy's Callide A Power Station in central Queensland [[38]] is being retrofitted to allow 30MW demonstration of Oxy-Fuel. This demonstration will use sub-bituminous coal.

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[36] Johnson, T.R. (2003) Future Options for Brown Coal based Electricity Generation – the Role of IDGCC, ANZSES Destination Renewables Conference, Melbourne

[37] http://www.vattenfall.com/www/co2_en/co2_en/879177tbd/879211pilot/index.jsp Accessed August 2009.

[38] http://www.callideoxyfuel.com/

In Victoria, there is a collaborative Oxy-Fuel research project funded under the Victorian Government ETIS program and involving the Latrobe Valley generators and researchers from Monash University and HRL Technology. The project is examining the option of retro-fitting of the Oxy-Fuel cycle to the existing Latrobe Valley coal-fired power stations. Both experimental studies of coal pyrolysis and combustion under Oxy-Fuel conditions and process modelling of the integration of the Oxy-Fuel cycle to existing Latrobe Valley coal-fired power stations are being performed. The evaluation of a purpose-designed Oxy-Fuel plant is currently not within the scope of the ETIS project.

It is not known if oxy-fuel combustion is more cost effective for CO_2 capture than post combustion CO_2 capture; however, a plant running oxy-fuel combustion is committed to full CO_2 capture. The option of partial CO_2 capturing and sequestration is possible with post combustion CO_2 capture.

7 COMMERCIAL SCALE COST DRIVERS.

There a number of factors that will influence the cost of implementation of low emissions power generation technologies. These include

- Project Capital and Financing costs
- Operating and Maintenance costs
- Emissions Trading (CPRS)
- Legislative requirements

There will also be costs involved to achieve the required specification of the CO2 quality for transport and storage and the commercial arrangements for CO_2 transport and storage.

Project costs will also be influenced by how the plant will operate within a contestable electricity market – for example if the plant is to operate as base-load, load following or two-shifting. Decisions would need to be made regarding of operation of energy intensive auxiliary plant associated with carbon capture. At times of high power demand and high power prices, commercial returns may take precedence over carbon capture and the decision may be to turn down or turn off the capture plant and accept the costs associated with emissions trading. The cyclic nature of operation would place additional requirements on the plant design and plant life which would need to be considered.

Quantifying the relative cost of these and how this may effect operation of commercial scale plant is difficult and beyond the scope of this study, however, these issues will be common to all coal-fired power generators.

The key cost driver which makes utilisation of brown coal different to black coals is the high inherent moisture content of the low rank coals. Once the brown coals are dried, the relative costs for power generation would be comparable to black coals although consideration of the different ash behaviour is required.

Therefore, the development of low cost and high efficiency coal drying technologies is essential for brown coal to be competitive against black coals.

8 STATUS OF MAJOR AUSTRALIAN BROWN COAL GENERATION PROJECTS WITH LOW EMISSION TECHNOLOGIES

8.1 Victorian CarbonNet Project for Carbon Capture and Sequestration [39]

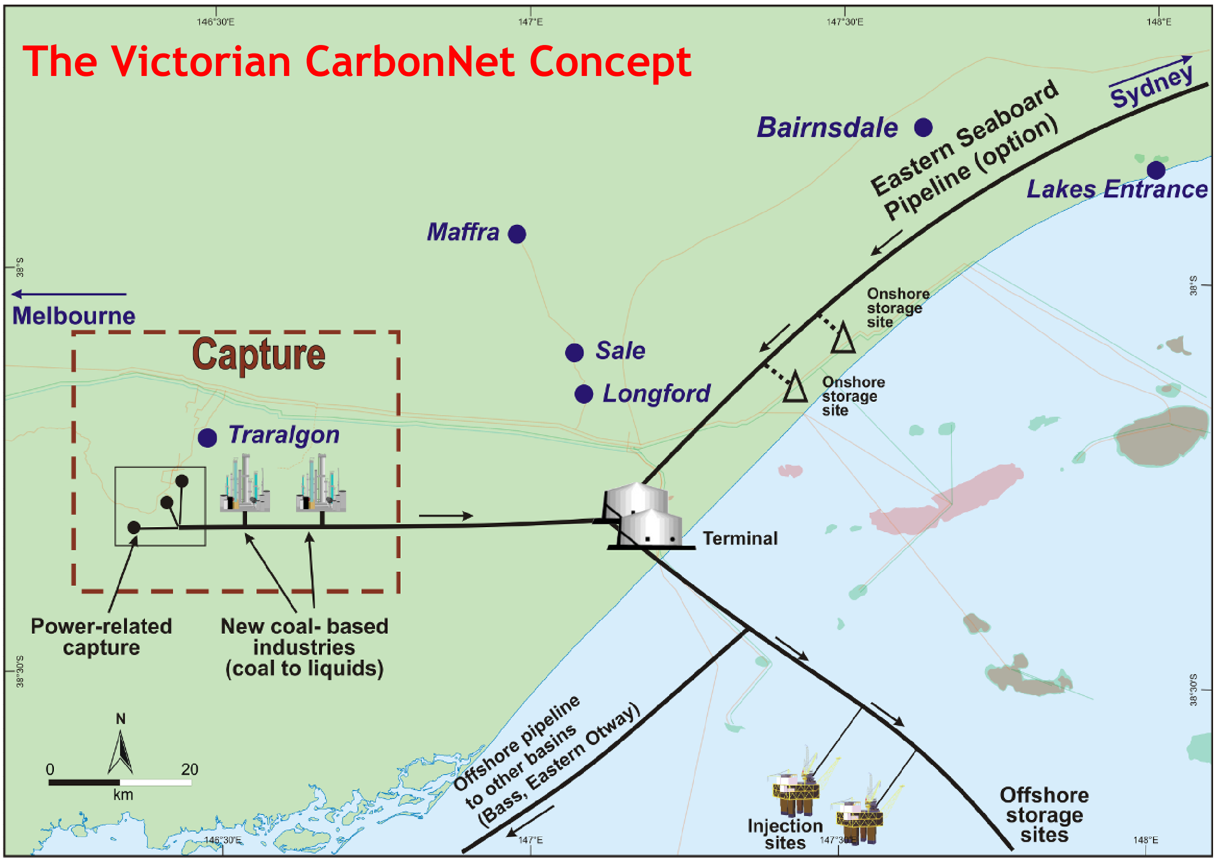
The Victorian Government is committed to the development of carbon capture and storage as part of the transition to a low emissions future. The Victorian Government's commitment has been demonstrated through the funding of low emissions demonstration projects under the Energy Technology Innovation Strategy (ETIS) 1 and more recently the ETIS 2 $110 million Carbon Capture and Storage (CCS) fund to support large-scale, pre-commercial carbon capture and storage demonstration projects.

The Victorian Government is encouraging the development of a multi-user CCS network to enable Victoria to maintain its generation of low-cost base load electricity and leverage the potential for other energy applications from brown coal (ie dried and upgraded coal products, liquid fuels and fertilisers). The CCS network will take advantage of the large potential for CO_2 sequestration sites in depleted oil and gas reservoirs and in saline aquifers located in the Gippsland Basin.

The Victorian Government's approach includes working collaboratively with the private sector to bring together clusters of CCS initiatives over time to form the foundation of the CCS Network. The Victorian CarbonNet concept for capture, transport and sequestration of CO_2 is presented in Figure 9. Features of the concept include

- Collection of CO_2 from carbon capture plants located at point emission sources in the Latrobe Valley, including power generation and new coal based industries
- Pipeline transport of CO_2 to onshore and offshore injection sites in the Gippsland basin.
- Potential for sequestration of CO_2 delivered from other states
- Potential for delivery of CO_2 to sequestration sites in other Basins.

[39] This section is based largely on material provided by Dr Peter Redlich, Director, Energy Technology Innovation, Department of Primary Industries, Victoria



Source: Peter Redlich, Victorian Department of Primary Industries.

Figure 9: The Victorian CarbonNet concept for capture, transport and sequestration of CO_2.

Development of the integrated CCS network over the next ten years (and beyond) will be based on the staged development of a commercial CCS network incorporating key foundation projects which will not only accelerate commercial CCS technology development but also drive network scale.

The network would be scaled up and expanded to incorporate large scale offshore carbon storage for Victoria's needs, and potentially to support the needs of other states as required.

It is envisaged that Victoria's CCS network will develop progressively over the next ten years and beyond, which would broadly incorporate:

- Finalisation of a clear and strong CCS enabling environment, including onshore injection and storage legislation and regulations in place and onshore acreage licences allocated.
- Early foundation elements defined and under development – capture, transportation and onshore storage including successful ETIS CCS projects, detailed onshore acreage exploration and development, trunk transportation infrastructure route defined and approvals secured, offshore assessments in progress.
- Early foundation elements operating and offshore storage under development, including definition and evaluation of sequestration sites,

- Expansion and scaling up (as required) of the network as additional CCS initiatives link in.

- Network expansion to incorporate other offshore storage basins and potentially to accommodate carbon transportation and storage from other states (if required).

Large scale CCS demonstration projects (integrated or separate capture or storage) will be key early stage network foundation projects.

The learnings generated from these projects will assist in building Victoria's technical and commercial knowledge and expertise in CCS, and support commercial deployment and expansion of the CCS network in Victoria.

8.2 Hazelwood 2030 Project

Hazelwood Power consists of nominally 8 x 200 MW capacity boilers commissioned between 1964 and 1971. The Hazelwood 2030 Project aims to extend the plant life to 2030 through retro-fit of low emission technology to take advantage of the available coal reserves.

The project is valued at $370 million and is supported by $50 million from the Federal Government's Low Emissions Technology Development Fund (LETDF) and $30 million from the Victorian Government's Energy Technology Innovation Strategy (ETIS) funding.

The two main components of the Hazelwood 2030 Project are:

(a) Coal Drying Component:

IPH plan to pre-dry coal using RWE's WTA fine grain fluidised-bed dryer (see Section 6.2.2). In the demonstration stage, the dryer will supply 50% of the fuel to Unit 1. The Unit 1 boiler will be modified to burn coal with 12-15% moisture instead of 62% moisture. This technology is currently being demonstrated in the most efficient new brown coal fired power plant in Germany, Niederaussem.

IPH is also proposing to add feedwater heaters to Hazelwood Units 1 and 2 to recover waste heat from the flue gas to improve plant efficiency; this energy would otherwise be lost to the atmosphere.

The Hazelwood Unit 1 turbines will also be replaced with upgraded turbines, including steam tapping points for the fluidised bed drier. At the same time, the Hazelwood Unit 2 turbines will be replaced for possible future WTA rollout.

These modifications will be expected to achieve a 20% CO_2 reduction.

(b) "Pilot" CO_2 Capture Component:

Capture of 25 tpd CO_2 (saleable to 50 tpd) using amine based technology from a slip stream of flue gas from Hazelwood Unit 8 (Unit 7 for 50 tpd) is being tested.

The CO_2 will be used in a refurbished carbonation plant to treat ash water and chemically sequestering CO_2 as an inert substance (namely calcium carbonate).

The overall objective of the Hazelwood 2030 Project is to obtain technical and financial confidence to support construction of an 800 MWe Ultra Supercritical boiler technology using dried brown coal firing with a 30% reduction in greenhouse gas emissions.

8.3 Latrobe Valley Post Combustion Capture Project (LVPCC), Victoria

The Latrobe Valley Post Combustion Capture Project (LVPCC) is developing technologies for post-combustion capture from the brown coal coal-fired power stations in the Latrobe Valley. The LVPCC involves International Power, Loy Yang Power, CO2CRC and CSIRO and is partly funded by the Victorian Government under the ETIS Brown Coal R&D fund. Pilot-scale activities are being performed at Hazelwood Power Station and at Loy Yang Power Station.

The post-combustion project at Hazelwood Power Station is being led by the CO2CRC. This project overlaps with the Capture Component of the Hazelwood 2030 Project. The CO2CRC is testing a range of solvents and different process configurations. In addition, post-combustion using adsorbent and membrane technologies are being developed using purpose-built rigs.

The post-combustion project at Loy Yang Power Station is being led by CSIRO. CSIRO have installed a mobile pilot post-combustion capture facility that is capturing around 1000 tpa of CO_2. A range of solvents for CO_2 capture are being examined.

Both projects do not involve plants that have flue gas desulphurisation or DENOx installed.

The pilot scale activities allow operational data and experience with brown coal flue gas to be obtained that has high moisture contents compared to black coal combustion. These activities are being supported by programs covering

- Laboratory research for new solvents,
- Laboratory and field research on gas separation and gas absorption technologies,
- Laboratory and field research on solid adsorbents and adsorption technologies,
- Testing of commercially available and new solvents in the Loy Yang Power and International Power-Hazelwood sites
- Assessment of PCC process and energy integration options, and
- Review of technical and economic viability of commercial use of PCC for existing and new Victorian brown coal power stations.

The Loy Yang Pilot Plant was commissioned in May 2008.

8.4 HRL Integrated Drying Gasification and Combined Cycle (IDGCC) project

See also Section 6.4.1.

HRL [10] proposes to develop a large commercial scale, brown coal power generation project in the Latrobe Valley, Victoria using their Integrated Drying Gasification and Combined Cycle (IDGCC) technology. This project will generate 550MW of electricity using syngas from their IDGCC technology with natural gas as a start up and supplementary fuel. The project is supported by $100 million from the Federal Government's Low Emissions Technology Development Fund (LETDF) and $50 million from the Victorian Government's Energy Technology Innovation Strategy (ETIS) funding.

The IDGCC technology has been designed for use with wet low rank brown coals. The technology uses the hot syngas from the gasification plant to dry brown coal which is then used as a feedstock for the gasifier. The drying of the coal cools the syngas, adds to the vapour content in the gas hence increasing the mass flow of gas through the combined cycle power plant. It is estimated that the technology will reduce emissions by about 30 per cent and require about 50 per cent less water than conventional power generation.

At this stage, it is not proposed that pre-combustion CO_2 capture will be implemented. HRL is working with the CO2CRC in the evaluation of CO_2 capture systems with support from the Victorian ETIS program.

9 STAKE HOLDERS SESSIONS: KEY ISSUES TO BE ADDRESSED

The objective of the ANLECR&D program for brown coal is to support flag-ship projects with low emissions power generation. Discussions with stake holders allowed issues of importance to be raised for consideration as part of this scoping document.

The issues raised with the stake holders have been collected and arranged into several broad themes as listed below.

It is recognised that existing brown coal-fired power stations have a high greenhouse gas (GHG) emission intensity relative to black coals or natural gas. During the transition to new technologies with lower greenhouse gas emission intensity, existing brown coal-fired power stations will continue to operate and therefore there is a need to develop and implement technologies to reduce emissions from this source

This can be achieved by either:

- Increasing the efficiency of existing plant through incremental improvements including the brown coal dewatering in an energy efficient manner; and,

- Use of carbon capture and sequestration of CO_2.

9.1 Brown Coal Drying

In all stake holders' sessions, coal drying was raised as the key challenge to improving the efficiency of utilisation of Victorian brown coal in existing and new plant. Issues related to coal drying raised during the stake holders sessions included:

Industry Expert on Coal Drying

Several groups raised the need for an industry expert to maintain a watch on current and developing coal drying technologies and trends. The expert would also act as the single contact for evaluation of new approaches or re-inventions regularly promoted by researchers and entrepreneurs.

Steam Fluidised-Bed Coal Drying (see also Section 6.2.2)

Steam Fluidised-Bed Drying (SFBD) is considered as a practical technology for coal drying at large scale. Steam fluidised-bed drying of brown coal was initially invented by Professor O E Potter at Monash University in the 1970's although further development and commercialisation occurred in Germany. International Power Hazelwood have proposed the use of RWE's 'fine grain fluidised-bed drier with integrated waste-heat recovery' as part of their program to extend the plant life to 2030. RWE's steam fluidised-bed drying technology has also been proposed for the Monash Energy coal-to-liquids project at Loy Yang and for CTL gasification projects proposed for lignite resources in both South Australia and Western Australia.

By using a vapour recompression cycle, there is also potential to recover the evaporated water from SFBD as a condensate that is suitable for industrial use.

There is a need to develop local expertise in steam fluidised-bed drying to support these projects.

The option of using alternative (renewable) heat sources for coal drying was also raised. For example, the use of solar energy or geothermal sources to provide the low grade steam for steam fluidised-bed drying rather than extraction of steam from coal-fired boilers.

The use of the hot-air Prototype Fluidised Bed Coal Dryer being demonstrated at the Great River Energy Coal Creek Station under the US DOE Clean Coal Power Initiative was not raised as an option for the Latrobe Valley brown coals. Compared to steam fluidised bed drying, the hot air dryer has increased risks of fires and dust explosions, particularly for the reactive Victorian brown coals.

Other Drying Technologies

- Kobe UBC "Upgraded Brown Coal" process (see also Section 6.3.4)

  UBC is a solvent dewatering process first demonstrated at the Brown Coal Liquefaction plant in Victorian (BCLV). An evaporative process, energy and water recovery is achieved using a vapour recompression cycle. A 600 tonnes per day drying and briquetting demonstration plant has been constructed in Kalimantan, Indonesia. Operations of the demonstration plant began in December 2008 and will continue until March 2010.

  The current focus of the UBC dewatering process is to upgrade low ash, high moisture content coals to a dry product with high calorific value for use as an alternative to thermal coals. For the UBC product to be accepted, the processing cost (cost of coal *plus* cost of drying *plus* cost of briquetting) must be less than the cost of a thermal coal.

  The results of the current demonstration program in Kalimantan, Indonesia will determine if the UBC solvent dewatering process with energy and water recovery will produce a product that is competitive against traded thermal coals.

  The UBC process may also have merit as an alternative coal drying technology for mine-mouth coal-fired power plants. In this case, the use of a briquetting plant would not be required as there would be minimal need for transport or briquetting of the dried coal.

Overall, it would be expected that the UBC process would have higher capital and operating cost compared to steam fluidised-bed drying, although UBC process would have an advantage of higher heat transfer coefficients and therefore reduced drying residence time and smaller reactor size.

Liaison with Kobe Steel on the status of the UBC should be maintained.

An independent evaluation of the technology for use with Victorian brown coals should be undertaken to provide a comparison against steam fluidised-bed drying.

- Entrained Flow Drying/Flash Drying

  The Victorian brown coal power stations, use hot combustion gases recycled from the furnace in an integrated mill/drying systems. In the process, coal is milled and dried simultaneously.

  The entrained flow drying technology developed by HRL as part of its IDGCC technology is a low capital cost option for drying wet fuels. By using the hot syn-gas as the drying medium, the fire and explosion risk associated with use of hot air are avoided.

  The main advantage of entrained-flow drying is its low capital cost although the technology is suitable only for milled particles (<10mm) and the short residence time (typically <1 second) may limit the extent of drying.

  Are there other situations that entrained-flow drying can be used for low cost coal drying? Entrained-flow drying could be used to partially dry brown coal to reduce the drying burden of more costly dryers. For example, the combination of entrained-flow pre-drying followed by steam fluidised-bed drying may offer reduced capital costs or higher throughputs.

- Mechanical-Thermal Expression (MTE) (see also Section 6.3.3)

  This non-evaporative dewatering technology was subjected to 14 years of investigation and development by the CRC for Low Rank Coals and the CRC for Clean Power from Lignite leading to the construction of a 15 tonnes per hour pilot plant at Loy Yang. Following completion of the pilot-scale program further development has been halted. German development of MTE has also ceased. Although energy efficient for water removal, there are a number of engineering and cost hurdles to be overcome before this technology can be realised.

  MTE was not considered worthy of further investigation in the medium term.

Coal Drying Fundamentals

The development of a 'break-through' drying technology may be achieved through an improved understanding of the relationships between the coal structure, surface properties and the water within the coal. Processes which result in the collapse of pores within the coal or elimination of oxygen functional groups can result in irreversible shrinkage and therefore loss of coal moisture. Research on the fundamental changes that occur to the coal during steam-fluidised-bed drying, MTE, pyrolysis and carbonisation, and hydrothermal dewatering have assisted in optimisation of these processes from a scientific basis. Further work on brown coal fundamentals is required.

Integration of Brown Coal Drying with CO_2 Capture.

There may be some unique opportunities for heat integration of CO_2 post combustion capture plants with coal drying plants. Although this activity overlaps with the ANLECR&D carbon capture node, brown coal combustion plant have very high levels of moisture in the flue gas which makes this different to black coal plant. The opportunity for optimisation of brown coal drying circuits with post combustion carbon capture plants was raised in several meetings.

Some issues raised by the CO2CRC/ Melbourne University include

- The high water content of brown coal requires careful consideration. An energy efficient capture design will only be possible if the water balance throughout the entire power station and capture plant is optimised. Specifically, how can best use be made of the latent heat of water as it passes through the capture plant? Is it best to remove all of the coal water through coal drying or are there benefits from retaining some water in the system? The CO2CRC / Melbourne University are addressing some of these issues as part of current research activities.

- The flue gas temperatures in brown coal capture are high relative to other fuel sources. How can these high temperatures best be integrated into a capture process to minimize total energy consumption? The CO2CRC / Melbourne University are addressing some of these issues as part of current research activities.

Any process which allows recovery of the latent heat of water in the flue gases from brown coal combustion will achieve significant efficiency improvements. The most beneficial way of recovery of the latent heat of water would likely be for coal drying. Therefore, innovation and optimisation of the overall coal drying-utilisation-capture cycle is required.

9.2 Brown Coal Upgrading and Beneficiation

There have been a number of processes that have been proposed for upgrading of brown coals. Typically the upgrading involves removal of moisture and collapse of the coal porosity to reduce moisture holding capacity of the coal. Some coal upgrading technologies also increase the coal rank through elimination of the oxygen contained within the coal structure.

Examples have included the Evans-Siemon hydrothermal dewatering process developed originally at Melbourne University and piloted at the 1 tonne per hour scale by SECV/HRL in the early 1990's. Exergen is currently developing a variant of this process called "Continuous Hydrothermal De-watering (CHTD)" in the Latrobe Valley [14].

Utilisation of a dewatered and upgraded brown coal provides the potential of increased efficiency and reduced CO_2 emissions. Modelling is required to determine the overall energy balances to ensure there is a net benefit in the utilisation of an upgraded brown coal.

Generally, it would be expected that production of an upgraded brown coal is suited for the export use rather then local use.

Upgrading of brown coal requires a fundamental understanding of the relationship between coal structure and surface properties.

Coal upgrading and beneficiation would also be required as part of the development of directly fired engines or carbon fuel cells (see Section 9.5.4).

9.3 Technology Exchange and Capacity Building

9.3.1 Commercialisation pathway for new projects

The most recent brown coal fired power plants in the Latrobe Valley (Loy Yang B) were commissioned in 1993 (Unit 1) and 1996 (Unit 2).

The former SECV R&D and Design departments provided the design basis for brown coal fired power plant based on a detailed understanding of the combustion behaviour of Victorian brown coal following extensive laboratory and pilot-scale trials. This level of Victorian engineering support for new power plant developments is no longer available. It is likely that future plants will use OEM technologies rather than specific technologies developed for/around Victorian Brown Coal. History has demonstrated that when overseas technologies are applied to Victorian brown coal, inevitably problems arise. This is because Victorian brown coal is unique and local expertise is required to adapt the technology and to solve the problems.

It was generally considered that there is a lack of suitable science and engineering expertise in brown coal to ensure that new technologies can be successfully introduced. There is a need to increase training in appropriate discipline areas.

9.3.2 Building Networks

The Victorian brown coal industry is small and therefore it is important that where possible, the industry leverages off other brown coal R&D activities being undertaken elsewhere, for example in the Germany, Japan, US, etc. Development of networks and relationships with active research groups and technology providers should be encouraged.

Encouraging exchange of technical personnel, conference attendance and preparation of annual ‘state-of-the-art’ reviews on various aspects of brown coal utilisation were all suggested.

9.3.3 Post-Graduate Training / Education

In several of the sessions, a concern was raised about the lack of suitably trained post-graduates with detailed knowledge of brown coal science and technologies, particularly as the industry is about to embrace a range of new technologies including fluidised-bed coal drying, supercritical combustion, gasification, coal upgrading/beneficiation, etc.

With the demise of the CRC for Low Rank Coals / CRC for Clean Power from Lignite, there has been little publicly funded RD&D specifically focussed on brown coal technology. Although the Victorian ETIS program is supporting some post-graduate and post-doctoral programs, these cover a broad range of areas with only a few projects covering fundamentals of brown coal technology. Overall, university research and training capacity has shrunk drastically owing to the lack of funding opportunities.

It was noted that universities are finding it difficult to attract postgraduate students into R&D projects involving brown coal due to competition from other research areas, for example biotechnology. Similarly, without a significant commitment to funding into brown-coal related R&D, it is difficult to attract suitable staff to lead projects.

Melbourne University noted that there were plans for a Masters course by course work in Energy Technology. This program could have a brown coal component.

It was also identified that there is a need to also improve the public perception of the risks associated with new coal technologies, particularly around CO_2 capture and storage. This could involve increasing the training and awareness of science and engineering professionals of the various issues related to new coal technologies and CCS to provide informed debate.

9.4 Costing Methodology

It was noted that cost studies are important in evaluating the competitive advantage of new technologies. It is difficult to compare the results of engineering costs studies performed by different groups within Australia or overseas since different costing methodologies and assumptions are applied. Having a standardised methodology would allow comparison of the technologies and a common basis. It is understood the CO2CRC has a developed a standardised methodology for their costing studies.

Costing is a focus of the NLEC Economic Studies node.

9.5 Advanced Power Generation Cycles

A number of advanced Power Generation cycles have been developed that offer the potential for increased efficiency for low rank coals. These include fluidised bed gasification (IGCC and IDGCC) or entrained flow gasification (IGCC) with pre-combustion capture; ultra-supercritical pf combustion with post combustion capture (PCC) and sequestration; and oxy-firing of ultra supercritical pf with sequestration. These technologies will need to be adapted to meet the unique requirements of Victorian brown coal, particularly with respect to coal dewatering and ash behaviour.

IDGCC (See Section 6.4.1) has been specifically developed for low rank coals and does not require a separate coal drying stage prior to utilisation. The other cycles require a dried coal feed to allow high efficiencies to be obtained and therefore coal dewatering options must be considered.

9.5.1 Gasification

Gasification is seen as a potential technology for the efficient utilisation of Victorian brown coals for power generation and the production of syn-gas for liquids and fertilisers production.

IDGCC, which integrates coal drying with syn-gas cooling, takes advantage of the high moisture content of brown coal to provide a cycle that promises relatively high efficiency at low capital cost compared to alternative options (see Section 8.4). Alternatively, the coal can be dried separately prior to gasification.

The following items were raised in conjunction with gasification:

- The Latrobe Valley brown coal resource could be mapped to determine the best prospective use for the resource. For example,
    - coals with high gasification reactivity may be more suitable for gasification applications
    - coals with lower moisture (ie deep coal seams) may be more suitable for power generation using combustion cycles.

- Although fluidised-bed gasification is expected to be a better option for reactive low rank coals, entrained flow gasifiers operating at higher temperatures (>1300°C) have been commercialised for utility applications. Monash Energy [11] and Latrobe Fertilisers Limited [12] are proposing the use of brown coal with steam fluidised-bed drying (RWE [21]) and entrained flow gasification for the production of liquid fuels or fertiliser. Steam fluidised-bed drying with fluid-bed gasification or entrained flow gasification could also be evaluated for power generation. There is limited available information on the gasification characteristics of Latrobe Valley brown coals in entrained flow gasification. Research into the ash behaviour under entrained flow conditions is required. CSIRO at Pinjarra Hills (QLD) operate a bench-scale pressurised high temperature entrained flow reactor for entrained flow gasification studies. This facility complement's HRL's pilot fluidised-bed coal gasification unit [10] located at Mulgrave (VIC).

- In the Latrobe Valley, the current power generation plants are mine-mouth operations with little ability to control the quality of the coal supplied to the station. Advanced power generation systems, such a gasification plants, are likely to be sensitive to fluctuations is coal quality (moisture content, ash yield, ash composition, slagging behaviour). The development of on-line coal quality analysers to monitor the coal quality and to take appropriate real-time action to minimise negative coal quality impacts is desirable. This could include rejection of the coal, blending with higher quality coal, changing gasifier operation etc. The use of on-line analysers is likely to be important for future management of coal quality. Developments in this area would also benefit existing and new generation mine-mouth power stations.

- Latrobe Valley coals have low sulphur content and therefore the use of a low-temperature Claus process for sulphur clean-up with gasification is not justified. The development of a warm gas sulphur removal technology is desirable, particularly if the syn-gas is to be shifted to maximise CO_2 removal for pre-combustion capture (shift catalysts are sulphur sensitive).

- There was discussion on the optimisation of syn-gas from brown coal gasification for the production of liquids fuels or fertilisers. This may involve the development of new catalysts or optimisation of the gasification conditions to achieve the appropriate syn-gas compositions. Such developments may also improve the removal of CO_2 in pre-combustion capture.

9.5.2 SuperCritical / Ultra-Supercritical Combustion

The 1,000 W Niederaussem supercritical plant in Bergheim near Cologne, Germany represents the current state of the art for brown coal power generation. In the future, steam-fluidised bed coal drying will be used to substantially increase efficiency. There are no supercritical and ultra supercritical plants operating with Latrobe valley brown coal. Evaluation of supercritical and ultra supercritical plants for use with Victorian brown coal is required, particularly with dry coal firing. Issues that need to be addressed include

- Firing with dried brown coal can yield higher flame temperatures and increased potential for corrosion from alkali-rich ash.
    - Do new materials/alloys need to be developed?
    - Can flue gas recirculation be used to control peak flame temperatures?
- Evaluation of the combustion characteristics, fouling, deposition propensity, and deposit/slag-attack on advanced boiler materials and gaseous emissions of brown coals in the ultra super critical boiler technologies.
- Economic evaluations to evaluate the benefit of dry-coal supercritical combustion

9.5.3 Oxy-Fuel Combustion

Some work examining the option of the retrofit of oxy-fuel firing to the existing Latrobe Valley boilers is being performed as part of a collaborative research project funded under the Victorian Government ETIS program and involving the Latrobe Valley generators and researchers from Monash University and HRL Technology.

These studies should be extended to include the feasibility of a purpose designed oxy-fuel ultra super-critical boiler operating on dry coal to allow comparison with a pf ultra super-critical boiler (or fluidised-bed combustor) with PCC operating on dry coal.

The option of Oxy-CFB (oxygen firing of circulating fluid-beds) should also be examined. The lower peak temperature compared to pf combustion would overcome the problems associated with high alkali ash. This activity would build on the fundamental and pilot scale CFB experience gained by the CRC for Clean Power for Lignite. Fluid-bed combustion also provides the option of co-firing with other fuels and in particular biomass and wastes as a means of reducing the greenhouse intensity of power generation from brown coal.

9.5.4 Alternative Technologies

Two technologies identified by CSIRO for further investigation were

- The direct injection coal engine (DICE) which consists of highly efficient large diesel engines modified to use coal water fuels and utilising PCC for carbon capture and with subsequent storage. It is claimed that DICE using a brown coal water slurry would be cost competitive to a new supercritical plant with drying and give a 40-45% reduction in CO_2 over the best existing plants, and 25% over the new technologies being developed with various forms of integrated drying.

- The Direct Carbon Fuel Cell promises efficiencies of up to 80%. In these devices, power is generated by elemental carbon particles (immersed in molten electrolyte) and atmospheric oxygen. The coal is thermally decomposing at low temperatures yielding very reactive carbon and off-gas rich in hydrogen and simple hydrocarbons. The flue gas from the fuel cell is near pure CO_2, thus obviating the need for capture prior to compression and storage.

Coal beneficiation is a key to the implementation of high efficiency coal technologies. It is important to clean or upgrade the coal only to the extent necessary to achieve the coal quality required for these technologies.

9.6 Optimisation of Usage of Brown Coal Resources.

Optimisation of the utilisation of the Latrobe Valley coal resource was raised by several groups.

Currently decisions on coal utilisation are based largely on the ease of mining and the fouling potential of the coal for use in pf combustion plants. A more selective utilisation of the resource may be more efficient. The Latrobe Valley brown coal resource could be mapped to determine optimum resource utilisation. For example, deep seam coals have a lower moisture content and therefore provide the option of more efficient power generation (although may still requiring a dewatering step?). Some coals may have high reactivity and therefore more result in more efficient gasification. Other coals may be more suitable for use in direct liquefaction, production of specialist carbon products or manufacture of dried-coal briquettes for export, or preparation of carbons.

Much of the coal quality information required for such mapping is currently available in coal bore records.

9.7 Carbon Capture

Some of the issues raised related carbon capture included:

- Is it possible to divert some of the CO_2 into other products to reduce the amount of CO_2 for sequestration - for example, capture of CO_2 with ash to form building products? Any option that reduces the amount of CO_2 generated (for example coal drying) or diverts some CO_2 into other product streams, reduces the total amount of CO_2 to be captured and sequestered.

- Combustion of brown coal results in a flue gas with high moisture content compared to black coals. An energy efficient CO_2 capture design will require the water balance throughout the entire power station and capture plant to be optimised. Specifically, how can best use be made of the latent heat of water as it passes through the capture plant? Is it best to remove all of the coal moisture through coal drying before utilisation or are there benefits from retaining some water in the system?

- The flue gas temperatures in brown coal capture are high relative to other fuel sources. How can these high temperatures best be integrated into a capture process to minimize total energy consumption?

- Desulphurisation is not practiced in Australia. How will flue gases containing (generally) low levels of NOx and SOx species be handled in carbon capture plant. Is a mild form of deNOx/deSOx prior to capture required?

- Latrobe Valley generators use ESPs for particulate removal. This may mean that the flue gas to the CO_2 capture plant may have higher particulate loads than a bag house. What is the impact of particulates on CO_2 capture sorbents or solvents (particularly since the fly ash may contain high levels of alkali species)?

- Specification for pipeline quality CO_2 for transport and storage required (Capture/sequestration node issue)?

- Sequestration into off-shore depleted oil fields is currently the best understood of the sequestration options, but other options such as sequestration into aquifers and deep coal seams hold promise.

    - Mapping suitable deep brown coal sequestration sites and determination of their potential as sequestration targets.

    - Create techno-economic models of the viability of sequestration options in brown coal rich areas.

- Deep coal seams may also provide a storage option for CO_2 as an alternative to depleted oil or gas reservoirs or to saline aquifers. If methane is present then enhanced coal bed methane (ECBM) may also be an option as a low emissions technology for electricity production, as the coal seams that provide the source of the methane also act as the sink for CO_2 storage.

9.8 Water Usage / Recovery

- Steam fluidised-bed drying provides the option of recovery of evaporated water as a condensate suitable for industrial use. Investigation into suitable uses for the water stream is required.

- Can water be collected / separated from CO_2 capture plant for industrial use?

- University of Melbourne have suggested as a possible research stream through ANLECC is to recover water directly from the flue gas prior to carbon capture using membrane technology. Recent trials conducted in Europe suggest that it is possible to suspend membranes directly into the flue stack to recover high purity water directly into the vacuum condenser. This technology could be researched for use with wet flue gases.

9.9 Chemical Looping

Monash University proposed investigations of chemical looping as a means of simplifying CO_2 capture. Chemical Looping supplies oxygen to the combustion or gasification process by reduction in situ of a recirculating metal oxide oxygen carrier (most commonly Fe, e.g. haematite, or Ca, e.g. limestone) which is then re-oxidised by air in a separate reactor. Thus, nitrogen is excluded from the flue gases, making CO_2 capture simpler, but without the need for an oxygen separation plant. The process, including carbon capture, is projected to have similar efficiency and cost of power generated as a conventional pulverised fuel boiler. Although this technology is under development overseas, Monash University proposes a program in the context of a low temperature gasifier/combustor applied to Victorian brown coal and lignites in general. Issues requiring attention include the high moisture content, ash composition, low sulphur content, gas composition and fouling.

10 SUGGESTED RESEARCH AREAS FOR ANLECR&D BROWN COAL

The focus of the ANLECR&D program will be to facilitate coal R&D projects in support of early demonstration of power generation technologies involving carbon capture in the 2015 to 2020 timeframe. R&D will be undertaken in a number of technical areas including Economic Studies, Fundamentals, Brown Coal, Capture Technologies (Oxy-Firing, Post Combustion Capture, Gasification) and Carbon Storage. Brown coal utilisation has a number of unique attributes, principally associated with the high inherent moisture content, to justify separate attention within ANLEC.

Brown coal is generally a very clean fuel for power generation but has high CO_2 emissions, resulting from its high moisture content, low calorific value and low thermal conversion efficiency. The CO_2 emissions intensity of the most efficient brown coal fired power stations currently in operation in Victoria (pf-fired subcritical steam cycle) is around 1160 kg/MWh. This can be compared to pf-fired supercritical steam cycle using black coal which has CO_2 emissions of the order of 810 kg/MWh.

To achieve substantial reductions in the CO_2 emissions from brown coal power generation will require a combination of energy efficient drying together with methods for the capture and sequestration of CO_2. Advances in these areas will also be applicable to the current brown coal fired power stations, many of which are expected to remain in operation for several decades.

The focus on brown coal R&D programs for power generation, therefore, should include the following activities. These activities will also assist in the training and development of the scientific and engineering expertise required to support the implementation of new and advanced brown coal power generation technologies. The need to rebuild these skills in the context of new utilisation technologies was a common theme in the stake holder discussions.

In all these areas, economic evaluations are required to allow the relative costs of different options to be evaluated.

- **Coal Drying and Beneficiation**

  The Coal Drying and Beneficiation activities should generally be in support of the implementation of steam-fluidised bed drying which represents the state of the art in brown coal drying. A demonstration of fine-grained SFBD is to be implemented by IPH on Units 1 and 2 as part of the Hazelwood 2030 project. SFBD has also been proposed by several groups in Victoria, South Australia and Western Australia as means of drying brown coals prior to gasification and liquid fuels production. The Coal Drying and Beneficiation activities relevant to SFBD include

  - Improving the understanding of the relationship between the coal physical structure and drying behaviour.

- Understanding the fundamentals of SFBD including fluidisation behaviour, drying kinetics, equilibrium moisture content, heat transfer, etc.

- Process integration and optimisation:

  - Integration with the coal drying power plant steam cycles,

  - Use of coal pre-drying (entrained-flow drying?) to reduce the fluid-bed footprint/cost or increase throughput,

  - Use of other waste heat or low grade heat sources for coal drying including geothermal or solar energy.

  - Integration of coal drying plant with carbon capture plant.

- Storage and handling of the dried coal including self-heating and dust explosibility

- Utilisation of water condensate recovered from coal drying

The Kobe UBC coal drying and beneficiation process should also be briefly evaluated as an alternative to SFBD. This technology is currently being developed for production of dried brown coal for export; however, there may be opportunities to optimise the process to produce dried coal for mine-mouth power generation. The activities that are indicated for SFBD R&D are also relevant to UBC. Of particular importance is the relative cost of UBC compared to SFBD.

Other coal drying and beneficiation technologies such has hydrothermal dewatering do not fit into the current scope of the ANLECR&D but should be supported under other programs such as the Victorian BCIA fund for brown coal research.

- **SuperCritical and Ultra SuperCritical Combustion**

The state of the art for power generation with combustion involves the use of SuperCritical and Ultra SuperCritical plants. Although there are supercritical plants using black coal operating in Australia, there are no supercritical plants using brown coal. The 1,000 MW Niederaussem plant in Germany is a supercritical plant operating on brown coal plant. The Niederaussem plant does not use dried coal firing although SFBD is to be demonstrated with 25% of the fuel flow to be dried.

Any new pf fired combustion plant utilising Victorian brown coal would almost certainly involve the use of coal drying with a supercritical steam cycle with either oxy-fuel firing or PCC. Victorian brown coal has unique ash properties and therefore specific R&D activities are required to establish the potential behaviour of the coal in supercritical combustion environments. Firing with dried brown coal can yield higher flame temperatures and increased potential for corrosion from alkali-rich ash. These activities fall within the scope of the ANLECR&D including support for the current activities proposed by IPH under the Hazelwood 2030 project. Supporting R&D activities could include

- Investigation into the material requirements for operation at the higher steam and the higher flame temperatures that would be obtained with dry coal firing under supercritical conditions, particularly given the higher alkali concentrations found with brown coal. Do new materials need to be developed?

- o Evaluation of the slagging and fouling characteristics, deposition propensity and deposit/slag-attack.
- o Can flue gas recirculation be used to control peak flame temperatures and modify ash behaviour?
- o Economic evaluations to evaluate the benefit of dried brown coal supercritical combustion with PCC or dried brown coal supercritical oxy-fuel combustion

Following the decommissioning and demolition of the SECV/HRL 1000 hr combustion furnace, there is no longer a pilot combustion test facility within Australia to examine the long term behaviour of brown coals under realistic combustion conditions. Although outside the budget available under ANLECR&D, consideration to supporting the development of a suitable long term test facility should be given. The facility should support investigations under supercritical and oxy-fuel firing conditions and combustion of dry coal and biomass co-firing and be able to examine long term materials corrosion, ash deposition and emissions from brown coal utilisation. The ability to link to small carbon capture rigs would be desirable.

- **On-Line Coal Quality Monitoring**

Since brown coal power stations are mine-mouth operations there is limited ability to control the quality of the coal supplied from the mine. On-line systems to monitor the coal quality being supplied the station would allow real-time optimisation of plant operation in response to changes in coal quality. The corrective actions that may be taken based on coal quality may include

- o Adjustment of flux or additive addition to control ash properties (particularly with slagging gasifiers)
- o Adjustment of plant operation in response to changes in coal moisture content, ash yield or calorific value
- o Rejection of out-of-spec coal

In some cases, coals with specific properties, for example very low ash, may be targeted for high value applications such as manufacture of carbons for metallurgical reductants.

Developments in this area would also benefit existing and new generation mine-mouth power stations.

- **Gasification**

Victorian brown coals have high gasification reactivity which makes them suitable for use in fluidised-bed gasification. Although fluidised-bed gasification has lower carbon conversion than entrained flow gasification, lower temperature operation provides a process and cost advantage. There are currently few examples of coal gasification plants operating for power generation only with coal gasification plants generally used for chemicals or liquids fuels production. These gasifiers are usually based on entrained flow gasification with oxygen and stream as the gasification agents.

HRL's IDGCC technology is a potential option for low cost power generation from wet brown coals. The low cost is achieved through high efficiency (combined cycle) and low capital cost (air gasification and elimination of the need for a separate coal dryer). Other groups proposing gasification using low rank coals in Australia are considering the use of a SFBD with oxygen-blown entrained flow gasification with the aim of producing a syn-gas for the production of liquid fuels or chemicals. RWE have announced plans to build a 450MW integrated gasification combined cycle (IGCC) plant with CO2 capture, transportation and storage (CCS) near Cologne, Germany [33] using local lignite resources. The preferred gasification technology is entrained-flow gasification with HTW fluidised-bed gasification as a back-up.

There are a number of activities related to brown coal gasification that fall within the scope of the ANLECR&D. Some of the activities listed below may be more appropriate under the gasification node. Optimisation of brown coal gasification processes for the production of liquid fuels or chemicals is outside the scope of ANLECR&D although this represents a high value application of gasification. Such activities should be supported under other funding schemes, for example BCIA.

Brown coal gasification activities relevant to ANLECR&D include

- Mapping of the Latrobe Valley coal resource to determine best coals for gasification applications in terms of reactivity and ash behaviour. This activity should also evaluate the suitability of the coal resource for other applications.

- Evaluation of SFBD/entrained flow gasification (including air gasification) as an alternative option for power generation from brown coal. These activities should include a cost study for comparison against fluidised-bed gasification and investigations into brown coal ash behaviour under high-temperature entrained flow gasification conditions.

- Development of methods for evaluation of brown coal ash behaviour and material impacts (ie alkali corrosion) under gasification conditions – both entrained flow and fluidised-bed.

- Warm gas clean-up as a means of removal of sulphurous species to avoid the loss in efficiency from low temperature processes for sulphur removal (ie Claus process).

- Development of sulphur resistant water shift catalysts to shift CO/H_2O to CO_2/H_2 as part of the pre-combustion carbon capture.

- Development of on-line coal quality analysis systems to allow real-time control of gasifier operation in response to changes in coal quality. For example, controlling additive levels to control ash behaviour

- **Carbon Capture**

Most of the activities related to carbon capture from brown coal power generation would be expected to be covered within the ANLECR&D Capture Node; however, the high level of moisture present within brown coals provides some additional issues that are brown coal specific.

- Carbon capture from high moisture content flue gases that also contain NOx and SOx species, including consideration of materials performance.
- Process integration of flue gas cooling/carbon capture plant with coal drying plant to increase overall efficiency. Utilisation of the latent heat that is present in the water vapour in the flue gas.
- Re-use of water condensed from flue gases from brown coal utilisation.

- **Oxy-Fuel Combustion**

  Activities related to the Oxy-Fuel Combustion are generally expected to be covered within the ANLECR&D Oxy-Firing Node.

  Oxy-fuel combustion of raw brown coal introduces specific issues associated with high moisture content fuel gases, however, any new brown coal plant utilising an oxy-fuel combustion cycle will include coal drying to increase efficiency. As with PCC, there may be opportunities to integrate flue gas cooling with coal drying. The issues listed above under supercritical and ultra supercritical combustion are also relevant for oxy-fuel firing.

  Oxy-CFB (oxygen firing of circulating fluid-beds) may be an option more suitable for dried brown coal since the lower peak temperatures compared to pf combustion will reduce the problems associated with high alkali ash. This activity would build on the fundamental and pilot scale CFB experience gained by the CRC for Clean Power for Lignite. This activity would be brown coal specific.

  Oxy-CFB also provides the option of utilisation of alternative fuels including biomass.

  There are similarities between oxy-fuel firing and chemical looping, however, chemical looping is still at the fundamental R&D stage and not considered a priority research area.

- **Power Plant Operation with a contestable electricity markets**

  There are a number of issues associated with power plant operation with a contestable electricity markets that require investigation.

  A technical economic assessment on the operational strategies to align operation of energy intensive plant associated with carbon capture with the demands to ensure a commercial return on electricity generation would be desirable. Under conditions of high power prices, there would be pressure to turn-down or switch off auxiliary power consumption. Actions could include turning down or off plant associated with coal drying and carbon capture. Dry coal can be stockpiled to allow for intermittent operation of coal drying. Additional carbon credits can be purchased to offset emissions if the carbon plant is turned-off. There will be implications of plant life and reliability with cycling of plant operation and this should be investigated.

- **Other Activities**

  A number of other activities related to brown coal utilisation were raised during discussions with stakeholders. Although, these activities are considered as outside the scope of ANLECR&D for power generation, these have been collated and will be presented to the BCIA as a separate report. These items include

  - Fuel switching including biomass co-firing
  - Development of export industries based on dried Victorian brown coal in either a powdered or lump coal
  - Production of a chars and activated carbons and other upgraded brown coal products
  - Use of syngas from gasification for the production of liquid fuels or chemicals
  - Two shift operation of power plants
  - Underground coal gasification as a means of exploiting deep unmineable brown coal resources
  - Recovery of water from brown coal processing
  - Use of brown coal water slurries for direct injection coal engine

11 CONCLUSIONS

The objective of this scoping study is to provide a review of the current situation regarding the utilisation of brown coal in power generation applications involving carbon capture and to identify research areas to support flagship low emissions power generation technologies.

Discussions with stakeholders were held to collate key R&D activities required to support low emissions power generation utilising brown coal.

Research areas have been identified for utilisation of brown coal in power generation applications involving carbon capture. These research areas, briefly summarised below, support the activities of flagship projects for low emissions power generation.

To achieve substantial reductions in the CO_2 emissions from brown coal power generation will require a combination of energy efficient drying together with methods for the capture and sequestration of CO_2. Advances in these areas will also be applicable to the current brown coal fired power stations, many of which are expected to remain in operation for several decades.

Research on coal drying should include improving the understanding of the relationship between moisture and coal structure and focus on the use of steam fluidised bed drying technology whilst also considering other alternatives.

Since future brown coal utilisation options with combustion will almost certainly involve the use of dry coal firing with either super-critical combustion with carbon capture or oxy-fuel combustion and CO_2 removal, research on the coal behaviour under these combustion conditions is required. This research should address ash behaviour (slagging and fouling), corrosion, and materials issues that would occur under conditions of higher flame temperatures and higher steam pressures.

Gasification with pre-combustion capture also provides an option for low emissions power generation. Improved catalysts for water shift reactions without the need for separate removal of sulphurous species in the syn-gas prior to pre-combustion CO_2 combustion is desirable. Although fluidised-bed gasification is usually preferred for reactive coals (such as Victorian brown coals), entrained-flow gasification is currently widely practised. Activities to support the evaluation of brown coals under entrained-flow gasification including ash behaviour have been recommended to provide an alternative option.

There are also opportunities to increase the process integration of carbon capture plant from brown coal combustion to utilise the latent heat present in wet flue gases.

Issues associated with oxy-fuel combustion would be covered by the Oxy-Fuel ANLECR&D node, however, the option of oxy-fuel firing of a circulating fluidised-bed may offer specific advantages for brown coal and fall within the Brown Coal node.

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