Cooperative Research Centre for
Coal in Sustainable Development

Research Snapshots

2005-2006

CRC AUSTRALIA

Established and supported under the Australian Government's Cooperative Research Centre's Program

Our Vision

To optimise the contribution of COAL to a sustainable future.

Our Mission

Provide solutions and pathways for coal in sustainable development through:

- collaborative and responsive research focusing on utilisation and by-products;

together with

- related synergistic research opportunities in other coal chain areas.

Our Values

- Sustainable Development
- Scientific Integrity and Excellence
- Solutions Orientation
- Collaboration
- Innovation

Definition of Values

Sustainable Development	*"development that meets the needs of the present without compromising the needs of future generations . . . a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made consistent with the future as well as present needs."* (1987 "Our Common Future" World Commission on the Environment – Brundtland Report).
Scientific Integrity and Excellence	internationally recognised research that is relevant to industry needs and provides solutions and pathways for coal within a sustainable development framework.
Solutions Focus	research and other activities are driven by the need to address real world, industry issues.
Collaboration	skilled science teams founded on strong collaborative relationships between research and industry participants.
Innovation	the development and commercialisation of new and improved processes, products and services through research and technology transfer.

Quality and Focus of the Research Program

Relevance	research is founded on participant needs and aligned to the CCSD Vision and Mission.
Industry Engagement	industry actively participates in the research process to drive its usefulness and application to current and /or emerging industry problems.
Research Management	research projects are managed efficiently and effectively to ensure internationally recognised outputs.

Contents

CONTENTS

CCSD RESEARCH SNAPSHOTS

CCSD

Further information can be obtained on the CCSD website at

www.ccsd.biz

or by contacting CCSD by email on

administration@ccsd.biz

or phoning

+61 7 3871 4400

Sustainable development requires making informed technical and policy choices.

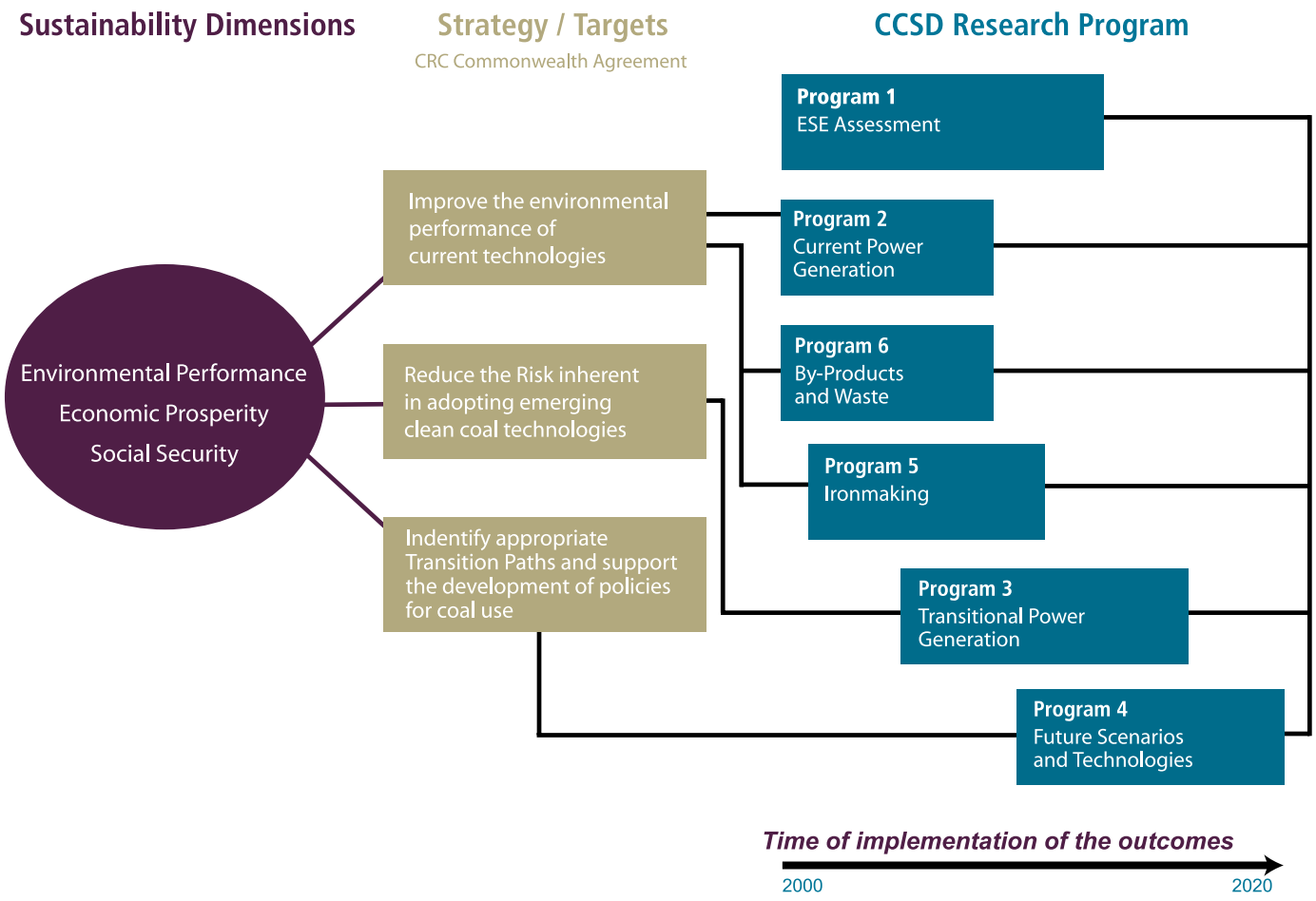
The three dimensions of sustainability – **Environmental, Social and Economic** – form the basis of the CCSD research program.

The CCSD research program is designed to improve the understanding of the environmental, economic and social impacts of coal utilisation. With this improved understanding informed technical and policy decisions in relation to more sustainable options can be made.

The structure of the research program has been designed to ensure:

- that the areas of research have measurable impact in at least one of the sustainability dimensions; and
- that mechanisms are in place for wide-ranging debate about the issues and outcomes identified as being significant.

Research Strategies – Relevance



The CCSD research effort can be grouped under three themes:

- **Informing Strategic Decisions**
- **Understanding Coal Performance**
- **Improved Environmental Performance**

Informing Strategic Decisions

Australian coal as a globally traded commodity is by far the nation's richest export earner and there is a need to support its markets and responsibly secure its future, mindful that the stage is set in an international theatre. By contrast, coal fired electricity generation while played out in a much more domestic locale, is no less important in its economic, environmental and social impact on Australian society.

In this context, CCSD undertakes research that informs the strategic decisions required of the coal and electricity generation businesses in Australia whose investment decisions are driven by separate and different commercial dynamics.

Understanding Coal Performance

Understanding the intrinsic nature and characteristics of coal fuel and how they relate to performance in a suite of present and emerging technologies is the basis from which CCSD has grown its research reputation and credibility. Built over twelve years of research into coal matter, mineral matter and environmental issues, the Centre's capability is supported by a foundation in coal and combustion science. The Centre's current research program focuses on coal performance in IGCC, Oxy-fuel and Ironmaking technologies.

Improved Environmental Performance

In measuring, monitoring and predicting emissions from coal utilisation, CCSD research has the skills, capabilities and research portfolio to serve both emissions reduction strategies and proactively inform policy decisions for the longer term regulation of the coal supply and utilisation industries.

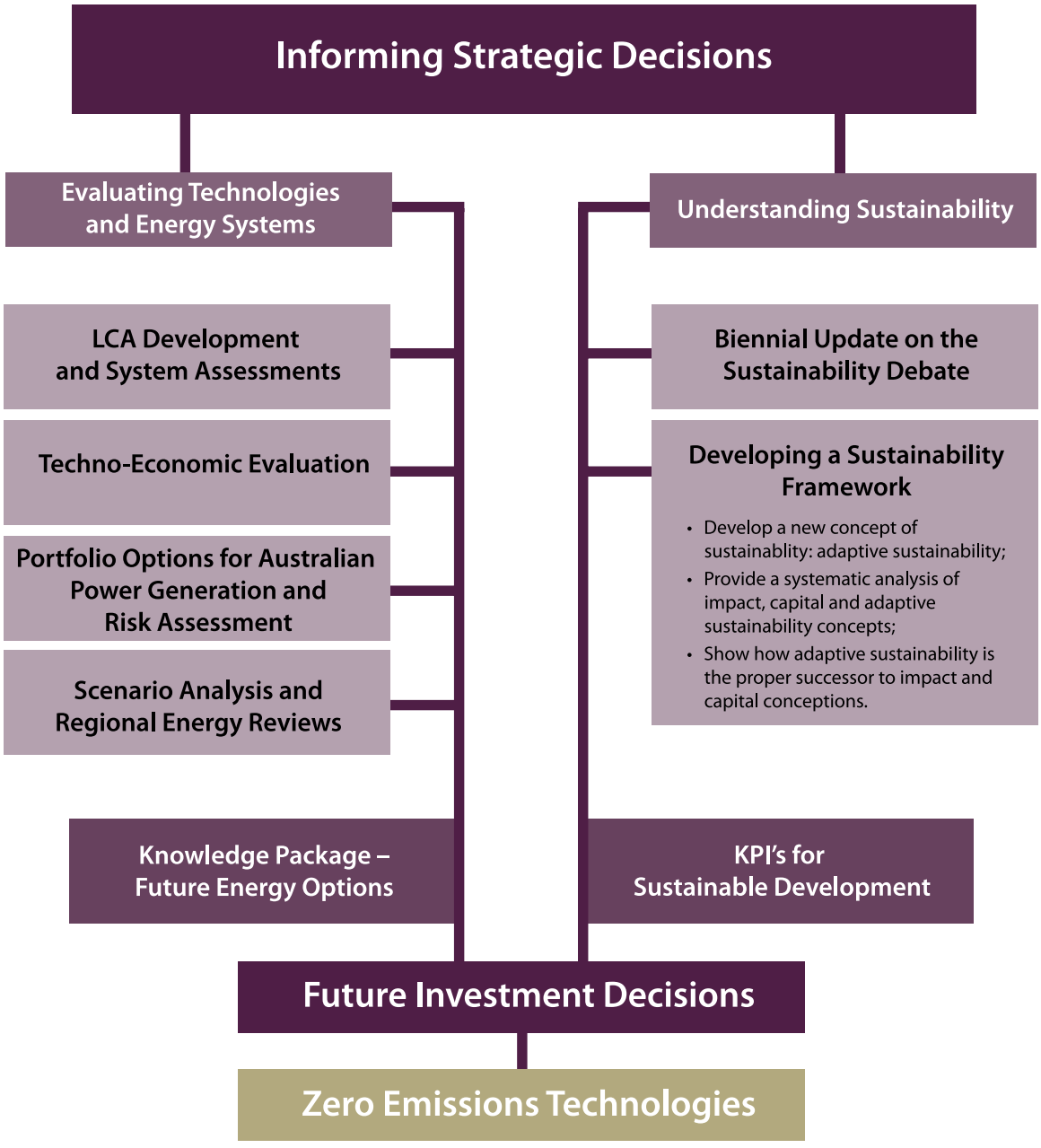
The relationship between the Centre's research themes, programs and projects is contained in the table below:

INFORMING STRATEGIC DECISIONS	UNDERSTANDING COAL PERFORMANCE	IMPROVED ENVIRONMENTAL PERFORMANCE
Project 1.1 Coal in a Sustainable Society	***Project 2.2 – concluded*** Coal Quality Assessment	***Project 2.1*** Emissions from Current Power Generation
Project 1.2 Sustainability Dimensions and Impacts	***Project 2.3*** Improvements in PF Operations	***Project 6.1*** Waste Management
Project 1.3 Long-Term Sustainability of Coal	***Project 2.4 – concluded*** Development of PF Operations	***Project 6.2*** Utilisation of Solid Waste and By-Products
Project 1.4 – concluded Social Frameworks, Broader Sustainability Review	***Project 2.5 – concluded*** Advanced Process Modelling Tools for Coal Power Generation Applications	***Project 6.3*** Environmental Assessment of Fly-ash Use in Mine Backfill Applications
Project 1.5 – concluded Cleaner Production Principles and Tools	***Project 2.6*** QEMSCAN for Characterisation of Coal and Utilisation By-Products	
Project 3.3 Power System Evaluation	***Project 3.1*** Entrained-Flow Gasification	
Project 3.5 – concluded Oxy-fuel Feasibility Study	***Project 3.2 – concluded*** Fluidised Bed Combustion	
Project 4.1 Portfolio Options and Risk Assessment	***Project 3.4*** Oxy-Fuel Science and Technology	
Project 4.2 – concluded Greenhouse Gas Reduction and Options	***Project 4.4*** Membrane Reactors for Water Gas Shift Reactions	
Project 4.3 – concluded Barriers to Coal Utilisation Technology Change	***Project 5.1*** Coal Use in Blast Furnaces	

Informing Strategic Decisions

The Informing Strategic Decisions theme includes all Centre activity that provides information and tools that support decision making and cultural change related to sustainable development and technology investment. It includes Life Cycle Assessment (LCA), future scenarios, portfolio selection, cleaner production principles, the sustainability debate, greenhouse and power systems evaluation.

Anticipated Outcomes: Provide targeted knowledge and tools to inform decision-makers.



PROJECT 1.1
COAL IN A SUSTAINABLE SOCIETY

Introduction

Awareness is growing about the impact of coal-derived emissions on our environment. Coal however, plays a major role in energy supply and metallurgical processes. More information is therefore needed to identify, understand and quantify how coal impacts our environment. Further to this, information collected gives insight on how can coal be utilized in a more sustainable way.

The project uses life cycle assessment (LCA) to address this issue. LCA assists in following coal emissions from cradle to grave, or from raw material acquisition through production, use and disposal.

Achievements for the Year

To assist in bench marking carbon emissions performance, the Centre provides life cycle analyses for the state electricity grids. Having reported on the 2001 emissions data, two grid updates were completed for the 2003 reporting period in New South Wales and Victorian. The report for Queensland is also nearly complete. During this year, the Centre also updated its techno-economic assessment of power generation options for Australia. This report summarises technology assessments of low emission electricity generation technologies in an Australian context, with a time horizon of 2015.

Future Work

Forth coming reports in the following years will include a life cycle assessment of the Australian electricity grid for YEJ 2003, a life cycle assessment of natural gas production in Australia and the greenhouse gas effects of spinning reserve for high penetration renewables. The latter study will assess the issue of providing additional backup for intermittent renewable power at a high level of penetration.

Products for 2005/2006

TA 58 – LCA of the NSW Electricity Grid for Year Ending June 2003

Phil Brown, Aaron Cottrell, Matthew Searles, Louis Wibberley, Peter Scaife

This report gives the results of a life cycle analysis (LCA) for the New South Wales grid for the year 2003. It includes emissions from the supply of other materials and services for mining, transportation, generation and distribution. The table below shows the average inputs and outputs related to 1MWh of power generation, on both a transmission and distribution grid basis.

Key findings are:

- Overall system efficiency has improved since 2001, though marginally.
- In New South Wales the assessment shows water consumption has increased substantially over the past three years on a MWh basis.
- There was very little change in the greenhouse gas intensity of the grid from 2001 to 2003.
- There has been a decrease in NO_X emissions per MWh of output.
- Electricity generation made a smaller contribution to the state total for SO_X emissions as a percentage in 2003 than it did in 2001.
- Particulate emissions for the NSW grid are evenly spread between coal mines and power stations, with 52.2% coming from power stations and 47.7% from coal mines. Power stations hold the dominant share due to the use of electrostatic precipitators at some power stations. Overall, the emission per MWh of generation has decreased, as well as the grid's share of the state total.

	2001		CY2003		
Parameter	Transmission grid	Distribution grid	Transmission grid	Distribu-tion grid	Difference[a] (%)
INPUTS					
Resource energy (GJ)	10.75	11.38	10.67	11.30	- 0.7%
Fresh water (m^3)	1.11	1.17	1.51	1.59	+ 36.0%
OUTPUTS					
GGE (kg CO_2-e)	974	1031	967	1025	- 0.6%
NO_X (kg)	2.92	3.09	2.40	2.55	- 17.8%
SO_X (kg)	4.14	4.38	4.33	4.59	+ 4.6%
Particulates (kg)	0.19	0.20	0.15	0.16	-21.1 %
Solid waste (kg)	111	117	104	111	- 6.3%

[a] Based on transmission grid

TA 57 – LCA of the Victoria Electricity Grid for YEJ 2003

Phil Brown, Aaron Cottrell, Louis Wibberley, Peter Scaife

In a similar study to the NSW report highlighted earlier, LCA results for the Victorian electricity grid were also reported.

The table below shows the average inputs and outputs related to 1MWh of power generation, on both a transmission and distribution grid basis.

In comparison to other state grids completed in this series to date (Queensland and NSW), Victorian electricity has:

- higher greenhouse gas emissions and resource energy consumption;
- lowest NO_X and SO_X emissions;
- the increase in fresh water consumption is significant;
- particulate emissions from power stations only are similar to those for Queensland and four times higher than NSW.

	2001		2003		
Parameter	Transmission grid	Distribution grid	Transmission grid	Distribu-tion grid	Difference[a] (%)
INPUTS					
Resource energy (GJ)	14.61	15.66	14.33	15.24	-1.9%
Fresh water (m^3)	1.40	1.50	2.70	2.87	+92.9%
OUTPUTS					
GGE (kg CO_2-e)	1402	1503	1437	1529	+2.5%
NO_X (kg)	2.03	2.18	2.18	2.32	+7.4%
SO_X (kg)	2.84	3.04	3.02	3.22	+6.3%
Particulates (kg)	0.61	0.65	0.36	0.38	-41.0%
Solid waste (kg)	14.4	15.4	15.1	16.1	+4.9%

[a] Note that the differential is based on the per MWh electricity from transmission grid (not including SMHEA)

TA 52 – Techno-Economic Assessment of Power Generation Options for Australia

Louis Wibberley, Aaron Cottrell, Doug Palfreyman, Peter Scaife, Phil Brown

The study summarises technology assessments of low emission electricity generation technologies in an Australian context, with a time horizon of 2015. The study recommends that Australia's options for power generation out to 2015 should take into account the following conclusions:

- New pulverized fuel (pf) plant should be the highest efficiency possible with provisions for future retrofit for near-zero emissions.
- The options provided by Integrated gasification combined cycle (IGCC) are likely to be the biggest driver for the increased adoption of the technology.
- For new build plants, both oxy-pf and post combustion capture should have similar costs.
- For Victoria, efficient production of power from lignites is highly dependent on integrated drying and use of advanced supercritical plant, or integrated drying gasification combined cycle (IDGCC) technology under development by HRL.
- Gas reserves as coal seam methane are very large, but require an integrated approach to obtain the most advantage from the resource.
- Solar thermal appears to be the most promising technology for large scale, baseload electricity generation from renewable energy. Australia has one of the most promising solar resources in the world for this technology.
- Australia is in a unique position with regards to nuclear power – the largest, low cost uranium resources, largest thorium resources, world's best immobilisation technology, stable geological environments, and is a large exporter of uranium. New generation nuclear technology combines step change improvements in burnout rate, inherent safety, and capital costs, and scale for economic operation.

Despite extensive analysis over the last few years, no clear technology winner has emerged for all situations. Also one should not discount the ultra high efficiency options that continue to emerge in a carbon constrained environment.

PROJECT 1.2
SUSTAINABILITY DIMENSIONS AND IMPACTS

Introduction

The project aims to deliver the conceptual assessment and planning frameworks for determining the contribution of coal chain industries to a sustainable Australia.
The major issues investigated in 2005-2006 include:

- Development of analysis of Australian integrated sustainability assessment best practice for coal chain;
- Analysis of industrial network capacities relevant to their sustainability assessment, especially their adaptability; and
- Construction of a framework for KPI (Key Performance Indicator) analysis and development – especially for adaptability KPIs.

Achievements for the Year

Two industry discussion papers have been published and publicly available at www.ccsd.biz. This CCSD project is well on the way towards developing a distinctive, forward-looking, strategic approach to sustainable development that is both sound in itself and able to offer coal chain industries a superior framework and principles within which to prepare and evaluate their own responses to the increasing need for sustainable development. During the year the project published a general methodology for "integrated sustainability assessment", showing how it has been applied within Australia to several large-scale regional resource management issues, and indicating how it might be applicable to the energy sector.

Future Work

Future work includes developing the discussion of industrial networks as a tool for sustainable planning and the sustainability performance assessment. The project also has plans to investigate adaptive energy scenarios (scenario + pathway spaces) with Australian constraints and priorities.

Products for 2005/2006

RR 53 – Sustainabilities: A Systematic Framework and Comparative Analysis (July 2005)

Thomas Brinsmead, Cliff Hooker

This report develops such a unified "systems perspective" from which to understand and comparatively evaluate three alternative conceptions of sustainability namely – impact, natural capital and adaptiveness – on the basis that the concept of sustainability is a tool that is used to assist human decision making.

This approach shows that despite the diversity of scope and conceptual formulation of sustainability policy, there is a systematic structure to the field worth understanding in its own right. There are three broad conceptions of sustainability namely (1) the reduction of environmental impact, (2) the preservation or enhancement of natural capital and (3) the preservation or enhancement of adaptive capacity, that is, of resilience.

As a policy tool, each succeeding conception of sustainability provides a more sophisticated perspective than the previous. In particular, the conception of adaptive sustainability, currently emerging, is the most general, though less developed methodologically, containing the ethics of the earlier conceptions as cruder, partial versions and additionally containing their causal models as degenerate special cases. Moreover, adaptive sustainability deserves our commitment in its own right and has important practical lessons for structuring sustainability strategies and policies by industries and governments, as illustrated here through examples. Discussion 4: Three Concepts of Sustainability Systematically Framed (July 2005) is a useful summary of the aforementioned ideas.

Discussion 5: Integration in Sustainability Assessment (April 2006)

Cliff Hooker, Thomas Brinsmead

This paper describes a general methodology for "integrated sustainability assessment", showing how it has been applied within Australia to several large-scale regional resource management issues, and indicates how it might be applicable to the energy sector. However the methodology can be applied at all scales down to individual energy company and the primary aim of this paper is to make it generally available to decision makers rather than to develop a specific proposal.

The paper summarises methods used in other Australian integrated sustainability assessments, extracted from a detailed comparative review (Brinsmead T 2005, Integrated Sustainability Assessment: Identifying Methodological Options, Report to the National Academies Forum, see http://www.naf-forum.org.au/papers.asp). In particular, three assessments stand out for their integration in some specific respect and case studies of these are introduced as examples. They are: the North-West shelf marine regions study, the South-East Queensland Healthy Waterways study, and the NSW Comprehensive Regional Assessment forestry study. None of these lies in the energy sector, making application of integrated assessment there the more urgent.

PROJECT 1.3
LONG TERM SUSTAINABILITY OF COAL

Introduction

The substantial component of this project is monitoring, digesting and over viewing global climate change and energy response studies. In addition, energy scenarios for targeted countries (eg Japan, Korea) and specific industry sectors (eg aluminium) are critically assessed and used to develop alternative scenarios for long term energy use ("future worlds").

The main tool/method used is Systems Assessments (based increasing around process modelling with an LCAs theme), and includes technology modelling, techno-economics, externalities, and predictions based on experience curves normalised for Australia situations. The work program has steadily changed to increased process and technical modelling to support the earlier broader LCA-type assessments with more information and a greater level understanding. The work therefore includes both energy systems and technology options.

Achievements for the Year

Four Technical Assessment Reports were published during the year.

TA 45 – Energy Scenarios – Europe by Andre Urfer

TA 50 – An LCA of WA's South West Interconnected Electricity Grid Year Ending 2002 by Aaron Cottrell, Jason Nunn and Louis Wibberley

TA 51 – Western Australia (WA) Energy System by Peter Scaife, Andre Urfer, Phil Brown, Aaron Cottrell, Jason Nunn, Louis Wibberley

TA 53 – Energy Scenarios – India by Peter Scaife, Phil Brown, Aaron Cottrell, Louis Wibberley

The major achievement reported in TA 50 – "An LCA of WA's South West Interconnected Electricity Grid Year Ending 2002" provide a more detailed study than in previous reports, which tend to focus only on greenhouse gas emissions, and includes several other key performance indicators - resource energy and fresh water consumption, greenhouse gas emissions (GGEs), NO_X, SO_X, particulates and solid waste emissions. More specifically, it was reported that the South West Interconnected System (SWIS) accounts for 20% of the State's total energy consumption, GGE and SO_X emissions, the biggest contributor being Muja power station. Ash from Muja and Collie power stations support the cement industry giving a GGE credit of 0.5% with potential to increase to 2.5%.

The final report TA 53 – "Energy Scenarios – India" found that India is projected to account for 20% of the increase in primary energy consumption in Asia out to 2020. The same increase is expected for the increase in coal consumption, being mostly related to power generation. Also, if India increases its consumption of its own coal, the environmental implications include large generation of fly-ash, poor blast furnace efficiencies and entrained flow gasification problems. India is competing with China for energy resources and is driven to improve the availability of electricity as shortages are impeding economic growth. Australia is in a strong position to supply its cleaner coal to support India's growth, but a clean coal technology roadmap is lacking but there exists opportunities for collaboration in this area.

Future Work

Another technical report, "Synergies with Renewables: Concentrating Solar Thermal" will be made available (now completed). Three more major tasks are to be completed in the future. First is the regional energy review for South Korea (due December 2006), the second is a preliminary techno-economic assessment of retrofit options for reducing CO_2 emissions from existing pf using novel capture technologies (due April 2007) and finally a systems assessment of infrastructure for near zero emissions power generation (due December 2007).

Products for 2005/2006

TA 45 – Energy Scenarios – Europe (January 2006)

Andre Urfer

With about four gigatonnes of carbon dioxide emissions, Europe contributes 16% to total global CO_2 emissions. Carbon intensity on a GDP basis has decreased by 38% since 1980, standing at 0.27kg per AUD2000 in 2003. In contrast, per capita carbon emissions have remained fairly steady, being 8.9 tonnes per person in 2003. Europe is committed to the targets agreed upon in the Kyoto protocol, which aims to lower overall emissions from the six greenhouse gases carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons and perfluorocarbons. The emissions trading scheme which commenced in 2005 is one instrument implemented to control emissions. The trading unit is called allowance, i.e. the right to emit one tonne of CO_2-e, and its price has markedly risen from about AUD 12 at the beginning of the year to AUD 35-40 since August.

Almost two thirds of all coal-fired plants, accounting for 60% of total coal-fired capacity, are more than 25 years old. A substantial part of the aging plant infrastructure will therefore need to be replaced in the medium term. Coal will only be considered as a viable replacement option for old capacity, if cleaner coal technologies are technically and commercially proven when decisions need to be made.

TA 51 – Western Australia Energy System (March 2006)

Peter Scaife, Andre Urfer, Phil Brow, Aaron Cottrell, Jason Nunn, Louis Wibberley

The study assessed present and future energy supply in Western Australia. The state has a relatively small installed capacity of approximately 6GW (13% of Australian capacity) with non-grid generators supplying a substantial 28%. Coal currently accounts for only 40% of total fuel used for power generation.

- WA is a large exporter of NG as LNG, but coal is not exported.
- Approximately 50% of primary energy is consumed in mining, minerals processing and manufacturing.
- Energy consumption by industry is: electricity generation (36%), manufacturing (24%), transport (22%) and mining (12%).

Supply industry predicts that electricity demand on the South West Interconnected System (SWIS) grid will continue to grow by 3-4% annually (equivalent to a growth of 80-120MW/year), which will result in an additional 1,200MW of generating capacity being required by 2010.

Since commencing this report, potential CO_2 sequestration sites have been identified approximately 40km off the coast near Perth. Suitability of these sites for CO_2 storage is likely to have a marked influence on future technology-fuel mix used for power generation.

TA 50 – An LCA of WA's South West Interconnected Electricity Grid Year Ending 2002 (March 2006)

Aaron Cottrell, Jason Nunn, Louis Wibberley

The LCA has been carried out to provide a baseline assessment of the environmental impacts of power generation, transmission and distribution in Western Australia. The LCA results include emissions associated with externalities, eg coal mining, chemicals and gas supply. The results also compare the SWIS with the overall energy consumption and emissions for the State. The latter includes all major combustion, agricultural, waste and fugitive emissions.

Parameter	SWIS (per MWh)	SWIS total for 2001-02 (per annum)	State total 2001-02 (per annum)	SWIS % of State total
Resource energy	13.05 GJ	138.0 PJ	712 PJ	19
Fresh water	1.45m^3	16.5 GL	545 GL	3
GGE	1,018 kg CO_2-e	10.8 Mt	59.9 Mt	18
NO_x	3.29 kg	37.5 kt	420 kt	9
SO_x	4.85 kg	55.2 kt	320 kt	17
Particulates	1.78 kg	20.3 kt	750 kt	2.7

- The SWIS accounts for approximately 20% of the States total resource energy consumption, GGE and SO_x, but has only a minor contribution to water consumption, NO_x and particulates.
- The main contributor of GGE and SO_x and particulate emissions from the SWIS is Muja power station. This is a combination of its high output (49% of the SWIS) and higher emission intensity.
- Approximately 90% of SO_x emissions are from coal combustion.
- The high particulates emissions from Muja are due to lack of particulate controls on the older A and B units. These units contribute 97% of the emissions from Muja, or 84% of the particulate emissions from the SWIS. Most of the other emissions are from open cut coal mines.
- Both Muja and Collie power stations supply around 15% of the fly-ash to the concrete industry – a rate of 40,000tpa, or 3.5kg of product ash/MWh from SWIS.
- Current utilisation of fly-ash gives a GGE credit of 0.5%. There is potential to increase this credit to 2.5% by full utilisation of ash for cement.

TA 53 – Energy Scenarios – India (April 2006)

Peter Scaife, Phil Brown, Aaron Cottrell, Louis Wibberley

India is at an earlier stage of economic development than China, but has a similar rate of growth in percentage terms. India is the world's sixth largest energy consumer, and the world's third-largest producer of coal. It is predicted that India will be responsible for about 20% of the increase in primary energy consumption in Asia out to 2020, with about 90% of the increase in coal use being related to electricity generation.

Electricity generation will remain coal based, at least up to 2020, supplemented by increasing generation from gas, increasingly imported, nuclear which will change over time to Fast Breeder Reactor technology, and hydro and renewables.

A clean coal technology roadmap for India, that outlines research, development, demonstration and deployment efforts in different advanced coal technologies, is required to prioritise the country's needs in moving towards a sustainable energy future based on coal. There will also be opportunities for collaboration in clean coal technologies, including the development of coal seam methane (for which Australia has growing expertise).

After coal, the next largest source of energy is biomass. Biomass is estimated to be around 30% of India's total primary energy, but, since this is almost entirely non-commercial, it is normally not included in official energy statistics.

PROJECT 1.4
SOCIAL FRAMEWORKS, BROADER SUSTAINABILITY REVIEW

Introduction

This project provides the coal mining and electricity generation industries with current thinking on the role of coal in the transition to a sustainable energy future for Australia. This information is seen as valuable input into their strategic planning process.

The coal and power generation industries recognise it is essential to keep abreast of leading edge thinking on sustainable development and the role of coal. In 2005-2006 this project has continued to provide industry participants with recent thinking on sustainability issues related to the coal industry, particularly in relation to the social change required to move to a more sustainable energy future and how that might be achieved.

Achievements for the Year

Following a series of small discussion forums (Explorums) conducted with a range of stakeholders during 2005-06, a Sustainability Seminar was held on 26 July 06 in Sydney as a collaborative activity with CSIRO and cLET.

Discussion groups including industry and community organisations identified three main barriers to the societal change needed to bring in 'clean' technologies:

- lack of public knowledge and poor communication about climate change and range of technology options;
- people's beliefs, values and consumer habits; and
- lack of political and commercial leadership.

Leading UK researcher, Professor Steve Rayner of Oxford University, said there was a trend towards increasing public participation in major technology decisions. He added that there were three major factors – trust, liability and consent – which were critical in shaping society's views of new technologies. However he cautioned that citizen participation was not a panacea when it came to introducing new technology, and revitalised representative structures were also needed to manage innovation.

Future Work

This project is scheduled to conclude with final reporting in the 06-07 year.

PROJECT 3.5
OXY-FUEL FEASIBILITY STUDY

Introduction

A detailed engineering feasibility study, with costs and technical findings, is needed for converting an existing pf boiler at Callide A power station near Biloela, Queensland to oxy-firing.

The oxy-fuel working group was established under the Australian Coal Association COAL21 program and included the following organisations: CS Energy, Stanwell Corporation, Tarong Energy, Ishikawajima-Harima Heavy Industries (IHI), IHI Engineering Australia, Cooperative Research Centre for Coal in Sustainable Development (CCSD), Centre for Coal Utilisation, Japan (CCUJ), Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), Xstrata Coal, Australian Coal Association Research Program (ACARP), and The University of Newcastle.

The primary objective of the project is to deliver a reference design with comprehensive technical and cost details for an oxy-fired retrofit of an existing Australian pf boiler, as the basis for a first of-a-kind demonstration plant, including CO_2 capture, transport and geological storage. The specific goals of the project are to:

- Examine, assess and document the detailed engineering requirements for a Callide A boiler retrofit;
- Compare the engineering and costs of an oxy-fuel retrofit with a post-combustion capture technology retrofit;
- Provide a preliminary assessment of the engineering requirements and plant costs for a large-scale commercial oxy-fuel plant; and
- Provide an assessment of the retrofit potential for existing PF plants in Japan, SE Asia and Australia.

Achievements for the Year

During the year the feasibility study was finalised and focussed on the following tasks:

- Understanding coal reactivity and heat transfer behaviour under oxy-fuel combustion conditions (i.e. O_2/CO_2) compared to air combustion conditions (i.e., O_2/N_2), and determining various physical parameters for input to a boiler model to predict the performance of the test unit and to determine optimum firing conditions;
- Development of an initial design for the modification of the test unit;
- Initial assessment of the technical and economic impact of O_2 purity at the front-end of the process on the design of the CO_2 compression train at the back-end of the process; and
- Preliminary assessment of the Denison Trough geological formation west of Callide for its potential for CO_2 geological storage.

Future Work

The project is in the final reporting stage. An Australia-Japan Partnership was formed under an MOU in March 2006 to develop a demonstration project for this technology.

PROJECT 4.1
PORTFOLIO OPTIONS AND RISK ASSESSMENT

Introduction

Several dimensions of the Centre's research on sustainable development suggest that in an uncertain business environment, preserving future options retains real and significant value. It favours investment opportunities which offer flexibilities that preserve an oragnisations capacity to adapt. Project 4.1 introduced the concept of real options to the CCSD as a methodology for evaluating flexible technological options. A set of electricity generation portfolio options were developed using an economic model of the electricity market. The goal is to develop a prototype model which can assess the optimal technology option(s) under the most important uncertainties by applying an adaptation of the real options approach. The project uses methods that have recently been developed to provide a wide ranging analysis of the options for investment in electricity generation in the context of the key risks such as carbon constraints faced by investors.

Achievements for the Year

The project progressed research that modifies the real options approach to examine investment under carbon price uncertainty.

Future Work

Technical Assessment 59 – *"Impact of Carbon Price Uncertainty of Investment in Selected Electricity Generation Options"* is due for completion in December 2006. This work will be followed by scenario analyses that assess likely impact and optimised pathways for the Australian asset portfolio.

Understanding Coal Performance

Current Technologies

Co-firing Coal/Biomass

- Major Project 2.4:
  - Handling
  - Milling
  - Combustion
- Trace Elements in Biomass (Scoping Study) *Completed*
- Protocol for TE Sampling (Scoping Study)
- Coal/Biomass Characterisation (Scoping Study) *Completed*

PF Efficiency Improvements

Coal Characterisation Tools

Advanced Technologies

Gasification
Coal Selection and Use
- Coal Conversion
- Heterogeneous Reactions
- Ash/Slag

Oxyfuel
Fundamental Studies
- Heat Transfer
- Combustion
- Gas Quality

Oxyfuel
Demonstration
- Feasibility Study

Pressurised Fluidised Bed Combustion (PFBC)

Ironmaking
Low-Temperature Blast Furnace (BF)

Membrane Gas Separation Technologies (Minor Study)

Coal Performance Knowledge and Tools

- CCSD Toolbox (Characterisation Tools)
- Handooks (Coal/Biomass, Coal Blending, Gasification)
- Services – modelling and testing

Performance Improvement and Low to Zero Emissions from Coal-fired Plants

PROJECT 2.2
COAL QUALITY ASSESSMENT

Introduction

CCSD has continued its development of analytical and modelling tools for characterising coal and ash. CCSD and Intellection Scientists have continued to develop QEMScan – a scanning electron microscopy based technique – to measure the minerals in pulverised coal as well as the ash and slag products of combustion. Major achievements include substantial improvement in the capability of QEMScan following improvements to the sample preparation and data processing protocols. The project is scheduled for completion in June 2006 with final reporting expected shortly thereafter.

Achievements for the Year

CCSD sponsored research with Intellection has delivered major improvement in QEMScan's coal characterisation capability. This year, the research established and improved the SIPS for QEMScan analysis of minerals in coal. Data processing improvements significantly reduced analysis time to a fraction of prior requirements. This gives the technique both improved accuracy and productivity as technique for coal characterisation.

Future Work

This project is concluded.

Products for 2005/2006

QEMScan Analysis of Coals and SIP Sensitivity

Alan Butcher, Al Cropp, Paul Gottlieb

The results of QEMSCAN analysis of the 14 coals reflect those generally produced by alternative industry standard methods (e.g. XRD), although it is recognised that some minor refinements are still required. The foundations have been laid for further development work, primarily on the SIP, to allow QEMSCAN to also measure chars, cokes and brown coals.

With the new iExplorer software, analyses are now able for the first time to make use of any attribute of a coal or mineral particle to produce a 'fingerprint'. These fingerprints can be tailored to cater for a particular end-use (e.g. combustion characteristics, boiler erosion, ore characterisation or environmental emissions), and may allow coals to be grouped by various 'types'.

Subsequently several developments have been implemented with regards the processing of SIP data, allowing much greater discrimination of phases and elements, improvements in the sample preparation techniques used, and developments in advanced modes of measurement to improve speed.

A Comparison of QEMScan and CCSEM Analyses of Pulverised Coal

Yinghui Liu, Raj Gupta, Terry Wall

Results from this study shows that both CCSEM and QEMSCAN can:

- positively identify the major minerals occurring in coals including quartz, kaolinite, siderite, calcite, pyrite, dolomite, ankerite, apatite, illite and chamosite;
- quantify the major minerals occurring in the coals, generally following the order: Clay minerals > Quartz > Siderite > Calcite in the samples studied;
- identify the relative abundance of the elements Si, Al, Fe, Ca and Ti in the order of Si>Al>Fe>Ca>Ti in samples studied. And both techniques give information on the distribution of major elements into different mineral phases;
- accuracy of results can be improved if all the bias in sample preparation, measurement process and offline data processing can be minimised; and
- can be used as quantitative tools for mineralogy analysis, combined use of other analytical techniques to predict coal ash performance.

The particle size distribution reported by QEMSCAN is in a good agreement with CCSEM data, showing that size of minerals decreases as size of coal particles decrease and size of included minerals is finer than the size of excluded minerals.

CCSEM was found to be better for estimating the coal-mineral associations.

PROJECT 2.3
IMPROVEMENTS IN PF OPERATIONS

Introduction

Performance of PF power stations is often situation-specific and relates to characteristics of coal or coal blends fired and plant design. Generic issues are commonly related to incomplete coal combustion, ash slagging, fouling and deposition, erosion in mills and burners, and constraints resulting from coal blending. All these affect power station availability and efficiency.

This Project aims to systematically study fundamental pyrolysis behaviour of selected Australian lower-rank coals – WA Coals – under a wide range of well-controlled conditions, with focus on large coal particle pyrolysis.

Achievements for the Year

Two theses were submitted for examination during the year.

The study of the interrelationship between char reactivity concluded work to understand its effects on unburnt carbon in fly-ash. The results show that the unburnt carbon has a bi-modal distribution where the majority of the unburnt carbon is present in the forms of either large unburnt char particles or small carbonaceous materials associated with fly-ash particles. The two forms of unburnt carbon are very different in terms of their morphology and combustion reactivity.

A second study characterising ash deposits concluded work to understand the formation and mitigation of fouling and slagging in utility boilers. The study showed that there was no evidence of substantive equilibration during deposit growth.

The project continues to accumulate experimental data on:

- the effect of pyrolysis conditions especially the effect of particle temperature-time history on the product distributions and product characteristics of Collie coal briquette pyrolysis;
- the effect of inorganic species in the pyrolysis of Collie coal;
- the influence of catalytic species in pyrolysis;
- effect of inherent moisture in the pyrolysis of Collie coal; and
- effect of pyrolysis reactions coupled with transport phenomena in large particles.

During the year, the work presented potential strategies for using the briquette chars in metallurgical applications and its feasibility for producing char for metallurgical applications.

Future Work

The first is a report detailing the pyrolysis behaviour of large coal particles together with the effect of particle size, on the characteristics and properties of pyrolysis products. The project will also develop strategies of practical applications of the coals, including thermal upgrading of WA coals and their performance in the production of metallurgical reductants, conventional pf combustion, oxy-fuel combustion, gasification and poly-generation. A doctoral thesis is also due for completion at the end of 2008.

Products for 2005/2006

Characterisation of Ash Deposits for the Development of a Predictive Model on Boiler Performance (Progress Report)

Hui Ling Wee, Hong Wei Wu, Dong-ke Zhang

In the literature, quantitative characterisation of deposit microstructures were carried out mainly on ash deposits formed in laboratory- or pilot-scale combustors, which may not adequately represent the characteristics of ash deposits formed in full-scale boilers. Little work has been done on the quantitative microstructure characterisation of deposits from full-scale utility boilers. Moreover, in most analyses conventional bulk approach were often employed, without considering the heterogeneity of the ash deposits. This study focused on quantitative characterisation of ash deposits collected from a full-scale, 330MW utility boiler.

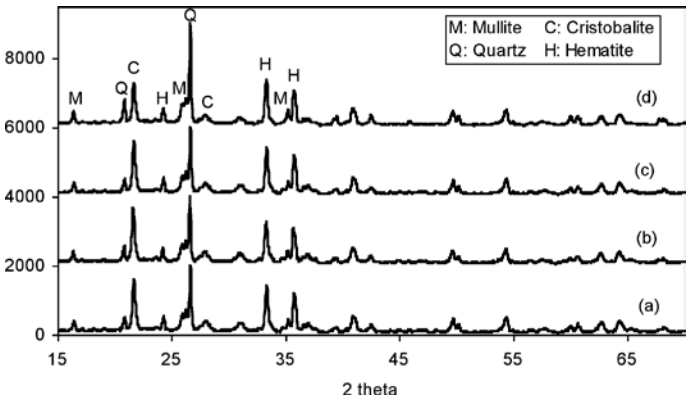


Figure 1: The XRD spectra of slices of the AB deposits away from the contact surface; (a) 0-4mm, (b) 4-6mm, (c) 8-10mm and (d) 20-22mm.

A series of thin slices of the ash deposit samples was employed to characterise the deposit heterogeneity, in terms of the deposits microstructure, chemistry and mineralogy. Thermodynamic calculations were then performed based on the chemical compositions of each deposit slices. The results did not show evidence of substantive equlibration during deposit growth.

PROJECT 2.4
DEVELOPMENT OF PF OPERATIONS

Introduction

The environmental impacts of current power generation need to be reduced with regard to greenhouse gas emissions with the substitution of biomass for coal in the energy mix. The aim of this project is to provide the technical support for options to modify existing plant, mainly for greenhouse-gas-abatement, where the focus is primarily on co-combustion technologies. In providing the Australian power generation industry with the support for full scale co-firing of coal and biomass, the Centre will produce a handbook on biomass co-firing that will include combustion behaviour of coal biomass blends and the prediction of ash behaviour for coal blends.

Achievements for the Year

The project is coming close to conclusion with the near completion of two important reports:

- *Co-Milling of Coal and Biomass in a Pilot-Scale Vertical Spindle Mill*, March 2006, M H Zulfiquar, B Moghtaderi, T F Wall.
- *Co-firing of Coal and Biomass in 150kW Pilot-Scale Boiler Simulation Furnace*, M H Zulfiquar, B Moghtaderi, C Spero, T F Wall.

Future Work

This project will conclude with providing a final assessment "Co-firing of Coal and Biomass in 150kW Pilot-Scale Boiler Simulation Furnace" in August 2006 with results from co-firing experiments in a 150kW Boiler Simulation Furnace, located in ACIRL facility in Queensland, Australia. The centre will compile this research in an application context in a coal biomass co-firing handbook.

Products for 2005/2006

TA 49 – Co-Milling of Coal and Biomass in a Pilot-Scale Vertical Spindle Mill (March 2006)

Mohammad Zulfiquar, Behdad Moghtaderi, Terry Wall

In its Technical Assessment Report 49 the Centre reported on *"Co-Milling of Coal and Biomass in a Pilot-Scale Vertical Spindle Mill"* (March 2006). The report summarises the milling constraints for coal and biomass blends that includes the results of a comprehensive study aimed at investigating the impact of biomass type, moisture content, initial feed size, and blending ratios in a pilot-scale vertical spindle mill. Three types of biomass were used: pine chips, hardwood chips and urban green waste and blended with four Australian domestic coals.

The impacts on pulveriser performance were analysed in terms of changes in: general operation of the mill, product size distribution, mill power requirement, inlet and outlet temperature, etc. Results showed that the vertical spindle mill was able to run through 5wt% of biomass without major problem (at around 60% of mill capacity). However, it was found from the mill power requirement data that the mill could not cope with 10wt% samples of pine and hardwood chips. The 10wt% urban green waste posed a different problem, where it blocked the opening of the storage hopper before milling. Generally, mill power was found to increase when biomass was introduced. This increase was non-linear with all coals. Grinding pressure also played an important part in mill power. Samples that were ground with lower grinding pressure recorded a smaller increase in mill power compared to those with higher grinding pressure. At 5wt% this increase was about 7% to 20% for low grinding pressure operation and 20% to 30% for high grinding pressure.

The abrasive wear also decreased for blends with woody biomass while for blends with urban green waste the abrasive wear increased primarily due to the soil and dirt contents of the urban green waste.

PROJECT 2.5
ADVANCED PROCESS MODELLING TOOLS FOR COAL POWER GENERATION APPLICATIONS

Introduction

To fully understand, interpret and predict a variety of processes occurring during coal power generation it is essential to know the presence, proportion and composition of the liquid slag (molten oxides) and the solid phases as a function of the minerals composition, temperature and atmosphere (reducing/oxidising). The objectives of Project 2.5 are to provide technical support to the coal industry in the form of generic predictive modelling tools. This project will address this by continuing the development of thermodynamic databases required to predict the high temperature behaviour of coal mineral matter.

In 2005-2006 the following issues were investigated:

- Viscosity models for coal ash slags; and
- Application of FACTSage/CCSD thermodynamic and viscosity models to coal slagging (entrained flow) gasifier technologies.

Achievements for the Year

The project reported on "Prediction of Ash Phase Equilibria using FACTSage Models" documenting delivery of the coal ash related databases used with the commercial FactSage software. The databases are also available in the commercial product.

A second report on "Slag Viscosity Prediction and Characterisation Al_2O_3-CaO-'FeO'-SiO_2 and Al_2O_3-CaO-'FeO'-MgO-SiO_2 Systems" also provides the models by which slag viscosity may be predicted using phase equilibria information. The melting and flow behaviour of the mineral matter (slag) present in the entrained flow gasifier and iron blast furnace is regarded as a key issue in process design, operation and in coal selection. This research enables better understanding of the development status and reduces the risks associated with, the implementation of advanced, high-efficiency power generation technologies based on coal gasification systems.

Future Work

The project will conclude in the following year with a new, accurate structurally-based viscosity model developed for liquids in the 7 component system Al_2O_3-CaO-'FeO'-MgO-K_2O-Na_2O-SiO_2. In contrast to the existing coal ash slag viscosity models the new model is valid over the whole compositional range including all unary, binary and higher-order subsystems of this 7 component system. The slag viscosity model is on schedule for completion by December 2006.

Products for 2005/2006

RR 54 – Prediction of Ash Phase Equilibria using FACT Models (July 2005)

Eugene Jak, Dmitry Saulov

As a part of a strategic plan the Cooperative Research Centre for Coal in Sustainable Development (CCSD) and the Australian Coal Association Research Program (ACARP) funded the development of a capability to calculate and predict the high temperature stability of the major coal ash constituents from fundamental thermodynamic principles. This was accomplished by constituting a database of high temperature properties from which a suitable computational engine can compute thermodynamically stable species. The Centre has implemented delivery by both improving the commercial FACTSage software engine and developing the requisite database for the major eight components of coal ash.

The database development was carried out through thermodynamic optimisations. Thermodynamic optimisations involve the thermodynamic model selection / development and then fitting the parameters of the model to ensure all available experimental data are described within experimental errors. In the thermodynamic "optimisation" of a system, all available thermodynamic and phase equilibrium data for the system are evaluated simultaneously to obtain one set of model equations for the Gibbs energies of all phases as functions of temperature and composition. From these equations, the thermodynamic properties and the phase diagrams can be back-calculated.

The large number of important modifications and improvements in the thermodynamic model of the slag phase have been introduced since the previous version of the database for this five-component system Al_2O_3–CaO-FeO-Fe_2O_3-SiO_2 was released in 1999. In particular, re-optimisation was a necessary step to ensure consistency with the new databases of MgO-containing systems. This re-optimisation has enabled the FactSage database for this system to be significantly improved and prepared a more accurate and robust basis for extention to the Mg-, Na- and K-containing systems.

All binary and higher order sub-systems in the higher-order systems Al-Ca-Fe-O-Si-Mg, Al-Ca-Fe-O-Si-Na and Al-Ca-Fe-O-Si-K have been optimised. Necessary solid solutions were modified or incorporated. The best possible agreement was achieved between predictions and existing experimental data.

The new database introduces significant improvement in accuracy and reliability of the predictions. In addition, in a number of systems calculations were previously not possible at all. The predictions with the new database were crosschecked with all available experimental information and the best possible fit was found in the course of the database development. The new database provided in FACTSage is now state-of-the-art for its content and consistency.

RR 58 – Slag Viscosity Prediction and Characterisation Al_2O_3-CaO-'FeO'-SiO_2 and Al_2O_3-CaO-'FeO'-MgO-SiO_2 Systems (February 2006)

Alex Kondratiev, Eugene Jak, Peter Hayes

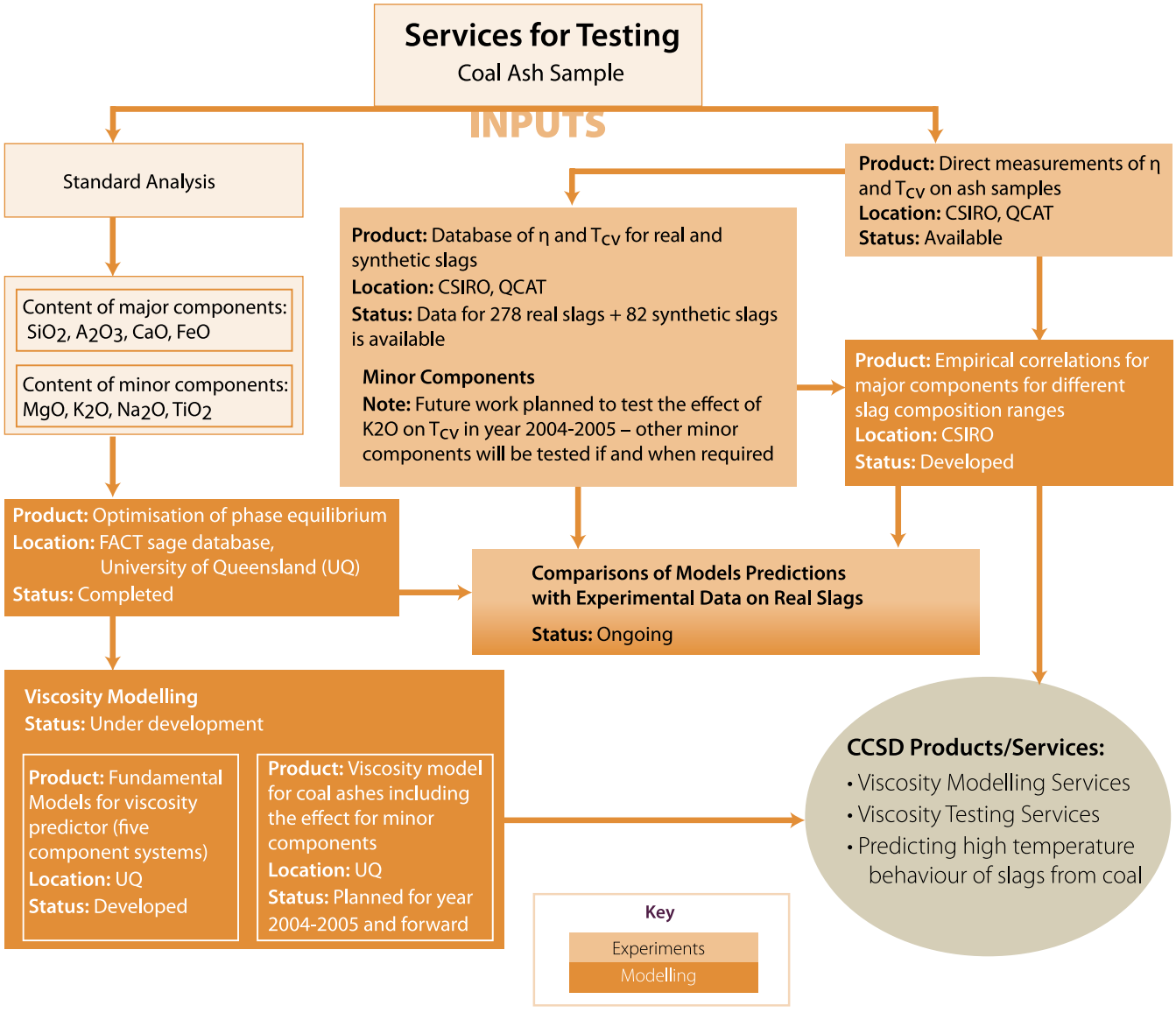
The technical objective of this task is to provide accurate and robust viscosity models that can be used to assist the selection and marketing of coals and coal blends, and in the optimisation of actual slagging gasifier and iron making operations. The viscosity models are developed in conjunction with the FactSage thermodynamic package and new CCSD thermodynamic database developed in prior CCSD research. The major focus of the project is to provide support for decision-making and technical development.

The report describes work completed on the development of a viscosity model for the system and sub-systems Al_2O_3-SiO_2-CaO-FeO-Fe_2O_3-MgO at metallic iron saturation.

Whilst these are fundamentally-based models they are particularly significant because they describe slag behaviour in the conditions encountered in coal entrained flow gasification technologies. The models make it possible to predict:

- Coal compositions suitable for entrained flow gasification technologies; and
- The extent of build up of slag deposits within the gasifier as a function of gas composition and operating temperature.

Understanding of Slag Flow Behaviour in Coal Gasification



PROJECT 3.1
ENTRAINED-FLOW GASIFICATION

Introduction

Knowledge of coal gasification science and technology is also important for technology selection and implementation in Australia. An integrated research program is being conducted by CCSD to provide the necessary technical information required to understand the development status of, and reduce the risks associated with the implementation of advanced, high efficiency power generation technologies based on gasification systems.

Project 3.1 provides the necessary fuel performance data and interpretive modelling capability for entrained flow gasification. The pressurised-entrained flow reactor (PEFR) at Pinjarra Hills is one of the few reactors available internationally that can generate such data and is a major asset. Supporting equipment includes a drop tube furnace and a single particle reactor.

Issues investigated in 2005-2006 include:

Carbon Conversion

- Gasification behaviour of Australian coals at high temperatures (1400°C) and pressures (20 bar) in environments containing $O_2/H_2O/N_2$;
- Reaction rates of 'practical' coal chars with CO_2 at high pressures (20 bar) and temperatures (1100–1400°C);
- Fundamental studies of intrinsic (low-temperature) gas–char reaction kinetics in high pressure mixtures of CO_2 and H_2O; describing these reactions in terms of their kinetics and the implications for use in models etc; and
- Fundamental studies of gasification reactions in environments containing products (CO and H_2).

Mineral Matter in Gasification

- Experimental determination of effects of potassium in coal mineral matter on slag viscosity and the temperature of critical viscosity.

Modelling

- Integration of bench scale pyrolysis and reactivity data with higher temperature PEFR measurements to develop a working 2D axisymmetric model of the gasification process and to assess the performance of this model against PEFR data.

Achievements for the Year

"RR 60 – A Review of Mineral Matter Issues in Coal Gasification" examined the effects of mineral matter in coal on slagging gasification technology. It provides a summary of the science with respect to slag flow, slag-refractory interactions and slag stability
and disposal.

"RR 59 – Gaseous Nitrogen and Sulphur Emissions from Coal Gasification" summarised the work performed, as part of the Centre's research program to examine gaseous emissions from coal gasification. The report documents emissions of nitrogen and sulphur compounds measured under O_2 gasification conditions in the PEFR at 1100 and 1400°C. Two chars, were studied in the bench scale fixed bed reactor to examine the effects of pressure, temperature and gasification medium on emissions.

Future Work

The project will continue a PhD program on "Gasification Reaction Rates of Coals at High Pressures and Temperatures" which is due for completion in December 2008.

Bench scale investigations of char reactivity fundamentals will also continue to understand how high pressure gasification reactions occur in the presence of other gasifying agents and rate-inhibiting product gases.

Results from the CCSD Pressurised Entrained Flow Reactor (PEFR) test program will be finalised to deliver a thorough assessment of the gasification behaviour of Australian coal at high temperatures.

Products for 2005/2006

RR 60 – A Review of Mineral Matter Issues in Coal Gasification

Nikolai Kinaev

Integrated Gasification Combined Cycle (IGCC) based power stations combine the advantages of relatively cheap fuel with the efficiency and environmental performance of gas turbines. Due to the high temperature of operation of entrained flow gasifiers, coal mineral matter is required to melt and flow out of the gasifier. Whilst the requirements of the coal mineral matter in pf power stations is well known, the issues of mineral matter related to coal gasification technologies are less well understood and are the subject of recent and ongoing research interest. This report reviews the state-of-the-science in an industrial context. It suggests that CCSD research to predict and control slag flow behaviour through coal fluxing or blending strategies have been adequately addressed for Australian coals. It identifies the need for further research to validate existing slag flow models with existing experimental data and commence consideration of slag refractory interactions that will be an issue for refractory lined gasifiers.

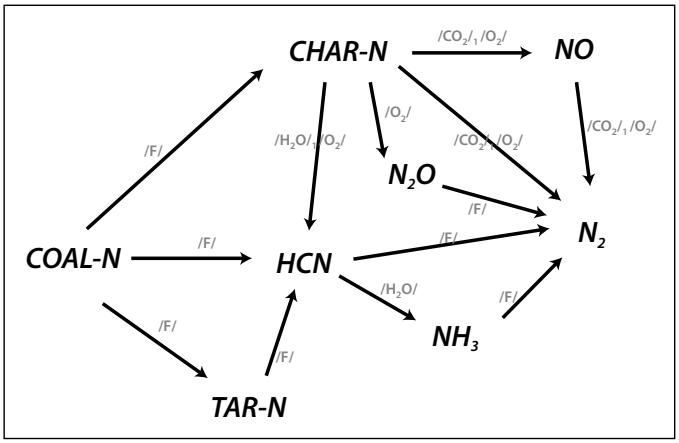
RR 59 – Gaseous Nitrogen and Sulphur Emissions from Coal Gasification

Stuart J Day, Peter F Nelson, Dongchan Park

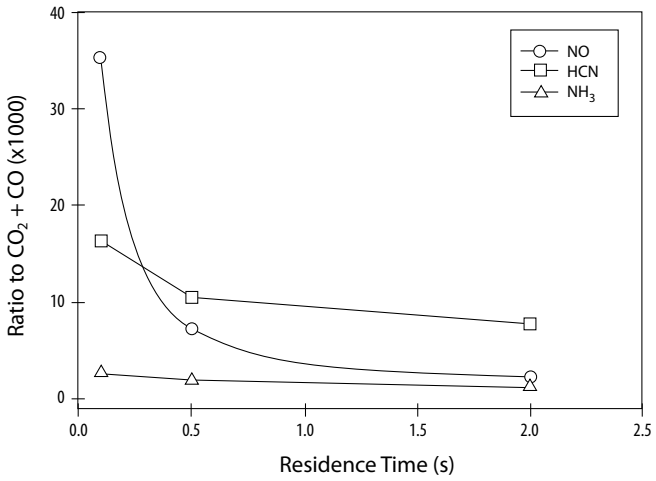
There are few large scale IGCC plants operating in the world and hence emissions of potentially adverse compounds from these processes are not well understood. To widen the amount of information available on the nature of gaseous emissions from gasification processes, this project was developed with the specific aims to identifying and quantifying the gaseous N and S containing compounds produced during coal and char gasification; determine the effect of gasification temperature and residence time on the emission of these compounds; and determine the effect of the gasifying medium on N and S emissions.

The main findings of the study included:

- During O_2 gasification of a Queensland bituminous coal using the PEFR, HCN and NH_3 were the only nitrogen products observed (although N_2 was also likely to have been produced under some conditions). Hydrogen sulphide was the main sulphur species with lesser amounts of COS also produced. The PEFR runs showed that about 50 percent of coal N was released as HCN and NH_3 under these conditions. Approximately 50 percent of the S in the coal was released during the PEFR reaction at 1100°C whereas at 1400°C, essentially all of the S was released;
- The experimental program identified the main gaseous sulphur and nitrogen products from char gasification in a fixed bed reactor. In relation to nitrogen, the species produced were N_2, NH_3, NO and HCN depending on the reactant gas. With O_2 gasification, N_2 and NO were produced whereas in CO2, N2 was the dominant product with very high selectivity over a wide range of pressures and CO_2 concentrations. Steam gasification produced mainly HCN, NH_3 and N_2;
- In the fixed bed reactor, SO_2 was the only sulphur compound identified. With O_2, the evidence suggested that this was the only compound produced, however, in CO_2, mass balance deficiencies indicated that other compounds, possibly H_2S and/or COS may also have been produced. Analytical difficulties prevented this from being confirmed; and
- The large matrix of experiments performed enabled mechanistic pathways for the formation of the various nitrogen and sulphur compounds in the effluent gas to be postulated.



Possible nitrogen transformation routes during gasification. Note that /F/ indicates that the pathway is dependent on experimental conditions apart from the gasification atmosphere.



Effect of residence time on the release of nitrogenous species.

PROJECT 3.2
FLUIDISED BED COMBUSTION

Introduction

Advanced coal combustion technology offers higher efficiency and lower emissions for power generation. Pressurised Fluidised Bed Combustion (PFBC) provides a competing low-emission, high-efficiency transitional power generation technology, with plants already in operation in Japan and France. Unburned carbon, elutriation, and bed agglomeration have been identified as major areas of interest in PFBC. A model supported by experimental data generated at the UNSW has been developed to predict these parameters. This simplified model includes allowance for particle size distribution in the coal feed, particle fragmentation, attrition and elutriation, and uses coal-specific properties obtained in earlier research at UNSW. It was benchmarked with data from the Wakamatsu Demonstration Plant in Japan, firing Australian coals.

Achievements for the Year

RR 52 – *"Predicting PFBC Efficiency for Australian Black Coals"* summarised research into combustion efficiency of Australian coals in pressurised fluidized bed combustion (PFBC). This research incorporates the results of the earlier fundamental coal performance research into a combustion efficiency predictor for commercial-scale PFBC plant.

The problem of bed agglomeration has occurred with some Australian black coals in industrial Pressurised Fluidised Bed Combustion (PFBC) in Japanese power plants. A doctoral thesis study shows the extent to which factors such as the distribution of coal ash and ash components between bed ash and fly-ash and the ash formation process under PFBC conditions and the temperature at which char particles burn in PFBC may be used as indicators of coal performance.

Future Work

The project concluded during the year.

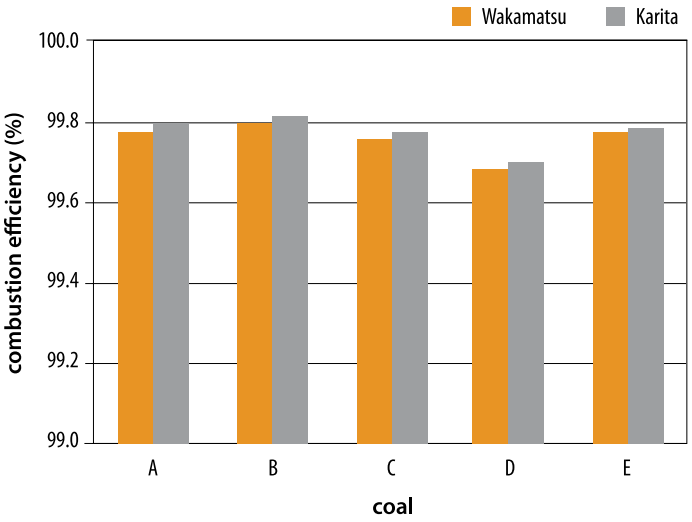
Products for 2005/2006

RR 52 – Predicting PFBC Efficiency for Australian Black Coals

John Stubington, Emi Ikeda, Alan Wang, Yongbin Cui

The research commenced in the preceding Centre to support the international marketing of Australian coals into PFBC plant, by providing performance predictions and coal selection criteria for PFBC applications of export Australian coals. The continuing work focused on developing a combustion efficiency prediction model for combustion of Australian black coals in large-scale industrial pressurised fluidized bed combustors.

The capability to predict combustion efficiency has been established and the project final report delivers a PFBC combustion efficiency advisory capability with validation against industrial-scale results from the 71MWe Wakamatsu demonstration PFBC in Japan firing Australian coals. It shows that combustion efficiencies predicted for the largest PFBC (360MWe at Karita) firing five Australian coals were satisfactory at 99.7–99.8%.



Coal combustion efficiencies in Wakamatsu and Karita PFBC combustor.

PROJECT 3.4
OXY-FUEL SCIENCE AND TECHNOLOGY

Introduction

The basic idea behind oxy-fuel combustion is to conduct pf combustion in oxygen and re-circulated fluegas (CO_2) rather than air (oxygen and nitrogen). This technology can be used in conventional pulverised fuel (pf) boilers including both supercritical (SC) and ultra-supercritical (USC) units as a way of increasing the concentration of CO_2 in a low volume flue gas stream amenable to storage.

Achievements for the Year

The CCSD oxy-fuel research program has continued a highly visible international presence and CCSD researchers now have a role in coordinating international collaborative research as reflected by:

- Development of collaboration with CS Energy, IHI and Vattenfall;
- Developing the science of radiative heat transfer in oxyfuel, where simple furnace models show oxygen supply sensitivity to heat transfer; and
- Developing the science of coal combustion in oxyfuel environments, with studies of devolatilisation and char reactivity and their effect on burnout.

During the year, the project provided the first published literature review on oxy-fuel and a report on gas quality and oxygen requirements. Research progressed heat transfer in oxy-fuel fired furnaces by using the wide-band model to predict gas emissivity ~ beam length functions for oxy-fuel environments, and the development of related grey gas models and the interpretation of laboratory coal burnout measurements in terms of coal reactivity models.

Future Work

Two PhD theses will deliver consideration for optimal heat transfer and oxygen utilisation efficiency during combustion. Project 3.4 has been planned to research combustion and emission issues. The project will continue to establish the science underpinning oxy-fuel technology, with involvement and interpretation of pilot-scale experiments in Japan completed 2005/06 in Project 3.5. Collaboration with Vattenfall on their new pilot-scale facility with a new reactivity related proposal is intended.

PROJECT 4.4
MEMBRANE REACTOR FOR WATER GAS SHIFT REACTIONS

Introduction

The project endeavours to develop specialised membranes that promote the water-gas shift reaction and simultaneously separate its products.

The water gas shift (WGS) reaction is an important reaction in gasification processes where hydrogen has to be generated or CO has to be converted. The product of coal gasification (syngas, CO + H_2) and water is fed to a membrane reactor where the WGS reaction takes place. The catalyst on the top of the membrane allows for the reaction to occur while the membrane allows hydrogen molecules to permeate (i.e. diffuse). Such membrane reactors have three major advantages. Firstly, the MR separates H_2 and CO_2, thus minimising downstream processing and associated capital and operational costs. Secondly, it shifts the CO in the syngas at high conversion rates, resulting in higher efficiencies. Thirdly, the membrane reactor reduces the H_2 concentration in by-product CO_2 streams allowing for potentially easy CO_2 capture for sequestration. The project involves the development of small lab scale platelets membrane substrates using silica derived membranes and scale up to small ceramic tubes. In addition, studies on performance parameters such as permeation, temperature, reaction kinetics, pressure, separation and regeneration are carried out.

Achievements for the Year

In August 2005, a literature review and initial experimental work was completed canvassing the current and relevant literature on WGS reactions and membranes technology. Initial experimental work also commenced to facilitate the development of membrane reactor substrates for a doctoral study.

Future Work

The study will continue as a PhD thesis which will be due for submission in December 2007.

PROJECT 5.1
COAL USE IN BLAST FURNACES

Introduction

Reducing the carbon intensity of the ironmaking process is best targeted by initiatives that reduce or replace carbon fuel in the blast furnace process. The project aims to contribute towards developing new ironmaking processes such as innovative Japanese Low Temperature Blast furnace operation and European N_2 free BF process (ULCOS), which are expected to provide step change reduction in emissions. Ongoing collaboration with developers of such innovative blast furnaces technologies has made this CCSD project an international nucleus for expertise in coal utilisation in future ironmaking.

Achievements for the Year

In Research Report 57 *"Pilot Scale Evaluation of the Co-Injection of Pulverised Coal and Non-Chlorinated Plastic Waste"* (November 2005), the combustion behaviour of two Australian PCI coals and their blends containing polyethylene was tested in the BHP-Billiton test facility and drop tube furnace and University of NSW. Promising results wre found for combustion efficiency with the co-injection of up to 10% plastic. Further studies were recommended extending to wider plastic ranges, sizes and mixing ratios.

Future Work

The project will finalise several doctoral theses that include assessments of:

- the influence of coal rank, maceral composition and mineral matter on coke properties and gasification;
- the effect of coke minerals on gasification and graphitisation; and
- the use of coke in step-change blast furnace technologies, in particular, characterization of coke quality and their implications on coke performance in blast furnaces.

Products for 2005/2006

RR 55 – Extended Characterisation of World Cokes (August 2005)

Richard Sakurovs, David French

The work showed improved characterisation of commercial cokes produced around the world would provide a more detailed benchmark for what is currently deemed an acceptable coke. This report includes the first characterisation of cokes using SIROQUANT; the results have elucidated the nature of the mineral matter in coke. This quantification of mineral matter in cokes and how it evolves during gasification, thermal annealing and reaction with molten iron is now a focus of the projects research as a consequence of the results presented in this study.

RR 57 – Pilot Scale Evaluation of the Co-Injection of Pulverised Coal and Non-Chlorinated Plastic Waste (November 2005)

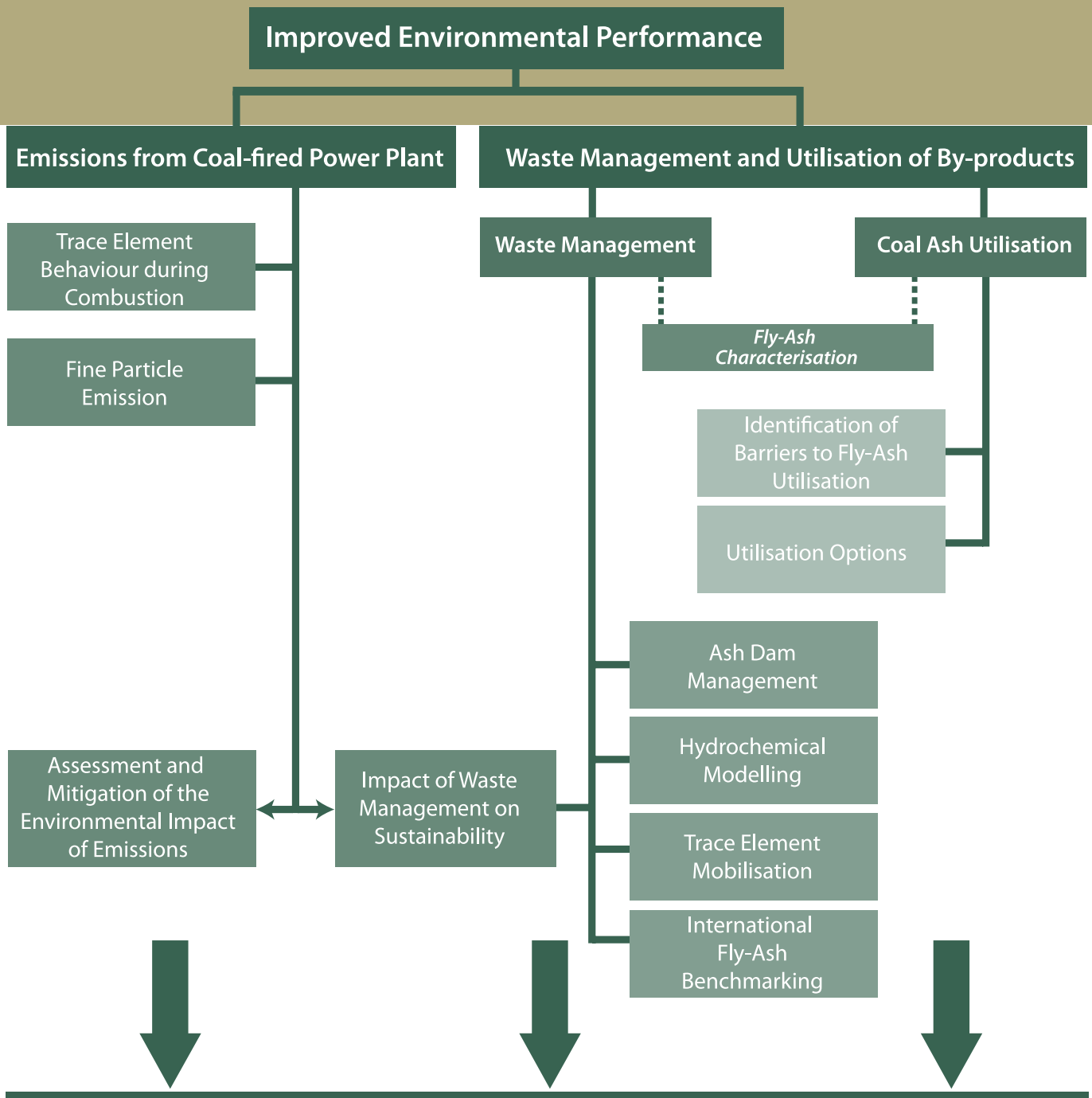
Veena Sahajwalla, Harold Rogers, Brian England, Mark Mason, John Mathieson, Sushil Gupta, Narendra Saha-Chaudhury

The study targeted blends of a high volatile coal (~ 34%(db) Volatile Matter) and low volatile/ULV type coal (~ 13% (db) Volatile Matter) with virgin polyethylene at 10 weight per cent. Both coals are marketed as, or potential, blast furnace PCI coals. Combustion performance of the blends was similar, or marginally lower under very fuel lean conditions, than that of the constituent coals alone in the case of the high volatile coal. For the blends with the low volatile coal the combustion performance was lower over the full range of the test conditions. The proximate volatile matter content of the centre-line char samples from the combustion tests with the pulverised coal – polyethylene blends were variable, but in the majority of cases in excess of the values (limited number at equivalent test conditions) for centre-line chars of the constituent coals combusted under similar conditions.

SEM investigation of the centre-line chars from the tests with aim test conditions of an Equivalent Injection Rate of 150kg/t-HM and 3% blast oxygen enrichment did not give unequivocal support to the presumption that the chars contained unburnt polyethylene. However, the ejection of partially fused, or surface fused, coarse grains of polyethylene from the combustion test section points to the presence of polyethylene in the combustion chars as a real possibility. The lack of combustion of the coarse polyethylene grains is most likely due to slow heating times to the peak pyrolysis temperature of such grains, relative to the injected coal, in the transit time available between the point of injection and the sampling position, and more over, to the time of ejection from the combustion test section.

The inspections of the chars and the polyethylene ejecta gives no indication of significant agglomeration of coal/char to the surface of the partially, or surface, fused polyethylene grains under the conditions of these specific tests.

Improved Environmental Performance



PROJECT 2.1
EMISSIONS FROM CURRENT POWER GENERATION

Introduction

Trace element and fine particle emissions during combustion of Australian coals form the core research focus of the project. The targeted outcome from this work is to improve environmental performance through the identification, assessment and mitigation of the environmental impact of emissions.

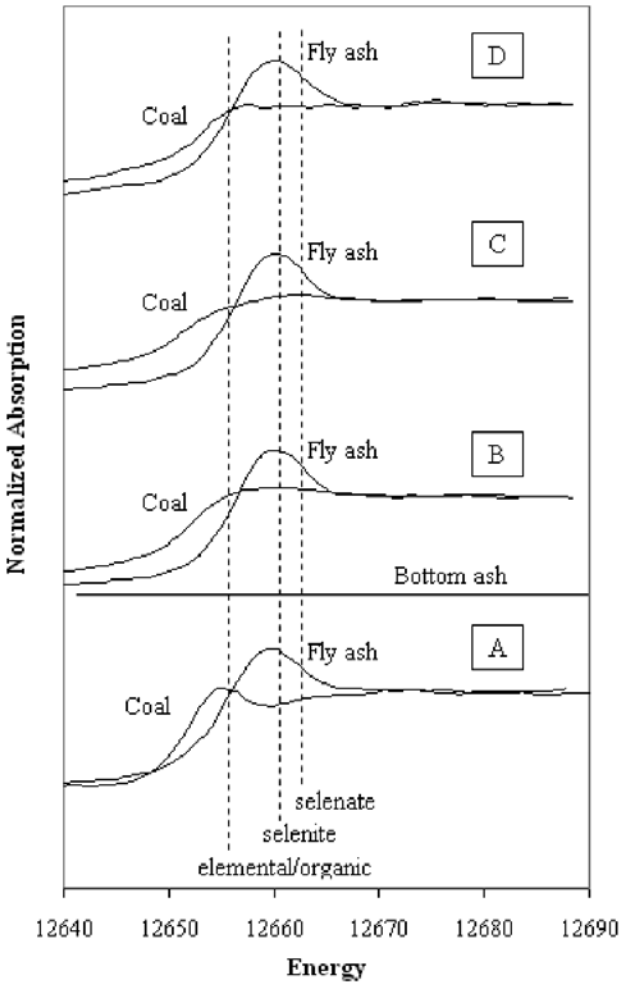
Other research in CCSD specifically address the implications for coal of a carbon constrained world, where there will be increasing pressures to reduce emissions of greenhouse gases. However, emissions and waste disposal issues associated with coal mining, preparation, and combustion, present significant, and more immediate challenges, to the social and environmental acceptability. There are also a number of emerging air quality issues that have the potential to impact on existing and future markets for thermal coals. These include emissions of fine particles and toxic compounds, and impacts of industrial NO_X on regional air quality.

Uncontrolled emissions of acid gases (NO_X and SO_2) and trace toxic species, such as Hg, Se, Cd and As, from coal combustion may have significant impacts on the environment, and have resulted in the development of stringent emission controls. The measurement, estimation, and reporting of these emissions, and an assessment of their possible environmental impacts is of significant interest to the local power industry. The issues raised by these emissions will also impact on the coal export industry, particularly in markets with exacting environmental standards and expectations. This project is providing data and techniques to enable the reporting and assessment of these emissions, including the following components:

- a database of pollutant emissions (gas, particulate and trace toxic compounds) from Australian power stations, utilising validated sampling and analytical procedures;
- Experimental studies of trace element release and transformations from selected Australian coals, and a comparison of the behaviour of Australian coals with other international coals;
- Extension of these techniques to include the co-firing of waste or biomass;
- Development of computational techniques to predict the distribution of trace elements in the waste products from combustion processes;
- Development of techniques to assess the potential environmental impacts of these emissions to land, air and water, and an evaluation of possible reduction strategies for any identified environmental impacts; and
- Development of an online power station emissions handbook undertaken as a vehicle for effective technology transfer.

Achievements for the Year

1. Completed and demonstrated the prototype chapter on legislation for web-based power station emissions handbook.
2. Reviewed and adopted potential methodologies to evaluate economic and social effects of implementation of improved pollutant mitigation strategies.
3. Obtained initial results on trace metal speciation in fly-ashes using XANES and surface science techniques in Japan, supported by Australian Institute of Nuclear Science and Engineering (AINSE) Funding.
4. Completed report on Mercury and Legislation (ACARP C14009), demonstrating the current state of knowledge of mercury emissions and control, and the market implications of low mercury content coals.
5. Representation at MEC2 Mercury Emissions from Coal – Second International Experts' Workshop, held in Ottawa 24-25th May 2005. MEC2 was organised by the IEA Clean Coal Centre as the second international experts forum for the discussion of the most pressing issues concerning mercury emissions from coal.



Selenium XANES spectra of power station coal and ash samples.

Future Work

Foreshadowed results from this research in the following years include reporting on the contribution of coal ash emissions in atmospheric particulates, modes of occurrence of trace elements in Australian coals and their speciation, assessment of the economic and social effects of implementation of improved pollutant mitigation strategies task.

Products for 2005/2006

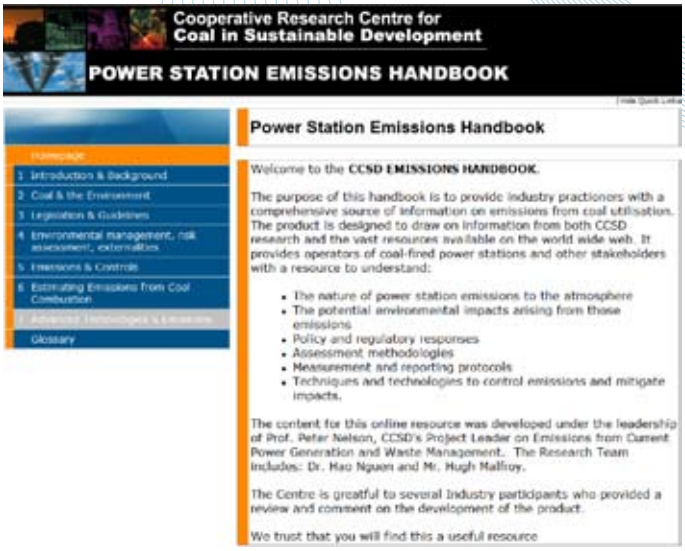
Impacts of New Legislative Controls on Mercury Emissions on Markets for Australian Coals (ACARP contract C14009)

Peter Nelson, Kitty Dong

Coal properties, especially chlorine and calcium content, and carbon in ash levels can have significant influences on mercury emissions at full scale. It is also clear that these coal properties affect the levels of reductions in mercury emissions observed in air pollution control devices (APCDs) such as De-SO_X and De-NO_X plants.

This study was designed to review world-wide legislative developments in mercury control, analyse the relevant properties of Australian and competitor coals to establish their likely behaviour in a range of APCDs with respect to mercury emissions, survey the costs of add-on mercury control techniques, develop a simple economic model to investigate the potential advantage of low mercury content coals under various pollution control regimes (eg, MACT, cap and trade), and review existing methods for mercury sampling and analysis.

The report concluded that it is probable that low mercury content coals will not have a significant market advantage where stringent air quality guidelines, leading to controls on SO_2 and NO_X emissions, are applied.



Power Station Emissions Handbook Prototype

PROJECT 6.1
WASTE MANAGEMENT

Introduction

Coal mining and preparation generate waste materials, which can affect water quality and undergo spontaneous combustion. Coal utilisation generates large amounts of waste that is disposed of in repositories such as ash dams, dry ash disposal systems and landfill. There is therefore a need to address the issue of waste generation comprehensively, and to provide the information enabling the most cost-effective methods for waste management. The project investigates the technical issues in the management of liquid and solid wastes associated with coal mining, preparation and utilisation.

Achievements for the Year

Batch leaching tests were completed on fly-ashes collected from four Australian power stations fuelled by chemically different coals. Two acidic and two alkaline fly-ashes were subjected to long-term (144h) leaching tests, and the behaviour of As, B, Mo and Se was investigated to obtain data on their potential for mobilisation during fly-ash–water interactions. The most mobile of the four elements leached were Mo from alkaline fly-ashes and B from acidic fly-ashes. The pH of the leaching solution is the key factor affecting the mobility of these trace elements in these fly-ashes.

The development of hydro-geochemical modelling to explain laboratory results was also completed the results of which were reported in detail.

Future Work

Complementary to the Centre's research on the trace element mobility of fly-ash, the Centre will also report on an international benchmarking of fly-ashes and their properties together with a preliminary assessment of the physical and chemical variation of selected Australian fly-ash.

Products for 2005/2006

RR 61 – Modelling Element Mobility in Water/Fly-ash Interactions (March 2006)

Maria Dubikova, Jerzy Jankowski, Colin Ward, David French

This report documents hydro-geochemical modelling used to obtain information about the chemical processes in leached solutions obtained during batch leaching tests on a range of Australian fly-ashes, in an endeavour to explain more fully the resulting element mobility effects.

The code PHREEQC was used for hydrogeochemical modelling to study fly-ashes with both acidic and alkaline pH levels. The models showed that calcites and strontianites were the most important carbonate phases precipitated out of the solutions. The mobility of Mn and Al were limited by the formation of oxides and hydroxyoxides. Among the sulphates, only barite and ettringite showed supersaturation. Arsenic mobility is also found to be limited by the formation of arsenic apatite. The modelling revealed that Ca and Sr carbonates appeared to be the most important carbonate phases precipitated out from these solutions. The mobility of Mn and Al was found to be limited by the formation of oxides/oxyhydrides.

PROJECT 6.2
UTILISATION OF SOLID WASTE BY-PRODUCTS

Introduction

The use of coal as the major fuel for power generation in Australia creates a large waste stream of fly-ash material that is currently mostly dumped at a cost to industry. Fly-ash is already a valuable input into the manufacture of cement and other products, however its use is limited in scale. This project addresses technical, environmental and economic issues associated with beneficiation and utilisation of coal-derived solid wastes.

Achievements for the Year

- During the year a doctoral thesis study on the use of ash in the production of low grade zeolites for potential applications in agriculture was completed and submitted; and
- The first stage report on matching coal ash to aggregate manufacturing processes was also delivered.

Future Work

Four major milestones are scheduled to be achieved in future work. Following assessment of the sintering method for aggregate production, the following research will reports on the suitability of the various ash types to aggregate production using cementitious binding, and geopolymerisation bases.

Products for 2005/2006

Aggregate Manufacture from Coal Ash by Sintering Method (Progress Report)

Hamzah Fanruri, Hongming Yan, Dong-ke Zhang (to be printed with other parts of the project)

The report detailing the work and outcomes of making aggregates using the sintering method was completed. Fly-ash samples used in the tests were collected from power stations in Western Australia (Muja Power Station), New South Wales (Mt Piper and Wallerawang Delta Electricity) and Queensland (Tarong energy, CS Energy and Swanbank). The tests showed that three fly-ashes Mt Piper, Wallerawang, and Callide are suitable for making aggregates with good compressive mechanical strength .15–27 MPa. With 2.5% of lime addition this can be increased to 40MPa by the sintering method at 1150°C.

PROJECT 6.3
ENVIRONMENTAL ASSESSMENT OF FLY-ASH USE IN MINE BACKFILL APPLICATIONS

Introduction

Over its present term the Centre has developed a capability to underake hydro-geochemical assessment of ash emplacement in rock and water environments. Mine backfilling with coal combustion products (CCPs) is an application of growing interest. The Centre's capability to assess such interactions are a direct technology application of the CCSD hydro-geochemical assessment capabilitity that has been developed. The Centre's research will form an important contribution to developing robust assessment methods and protocols for managing the longer term environmental risks which are not currently available.

This two-year project commenced in 2005-2006, developed in collaboration with the power and coal industry. The three key objectives are:

1. Identify key environmental, technical, and regulatory barriers to use of coal ash as mine backfill;
2. Provide a scientifically sound basis for removing some of the potential regulatory and perceived environmental risk issues that might otherwise act as impediments to economic use of coal ash in mine backfill applications;
3. Develop a generic protocol (a standard guide) to be used for evaluating coal combustion products for use in mine backfill applications (to match individual ashes with specific mine-site requirements).

Achievements for the Year

During the year a comprehensive literature review of Australian and overseas experience was completed. Progress has been made on a review of the regulatory framework and samples of ash and mine materials were collected from one Australian site, with laboratory analysis in progress.

Future Work

Phase one of the study will be completed with a report on the review of regulatory requirements and systems for mine backfill applications and a preliminary analysis of the initial sample set with respect to trace element mobility in ash, rock, water systems. This will be extended to a more detailed study on the basis of results from the first phase.

Products for 2005/2006

RR 62 – Use of Coal Ash in Mine Backfill and Related Applications

Colin Ward, David French, Jerzy Jankowski, Ken Riley, Zhongsheng Li

The review noted that regulatory barriers in Australia, under which ash could be considered as an industrial waste, tend to inhibit further beneficial ash usage. The environmental effects of the use of ash for mine backfill are also somewhat uncertain. Although most reviews have indicated ash use as backfill to be environmentally beneficial, or at least have no negative effect, some authors have suggested that negative effects do occur, and may result in contamination of water resources.

The main beneficial use of ash for mine backfill has traditionally been derived from the interaction of alkaline ash with mine solids, mine waters or in mining voids to ameliorate acid mine drainage conditions. Significant research has been carried out on the behaviour of different ashes in such applications, with a focus on the extent to which the ash may release or adsorb any potentially toxic elements in conjunction with the neutralisation process. Ash is also, however, routinely emplaced in open-cut mines as part of void infill programs in the western USA, without necessarily an AMD treatment objective in mind, and this may provide a better parallel for Australian conditions.

Although backfilling is common in underground metalliferous mines, only limited use has been made of backfill in underground coal mines, especially in Australia. Apart from its role in acid neutralisation, the ash-based backfill in underground mines is mainly used for ground support and subsidence control, for which the critical factors are geotechnical properties, such as flowability, density, porosity, abrasiveness, strength and pozzolanic or cementitious properties. Most Australian studies on the use of ash in underground coal mines have therefore focussed on the relation of ash characteristics to the geotechnical properties of the fill, rather than on any environmental issues which may arise. Fly-ash has also been used for the control of mine fires, as a contaminant barrier to reduce the escape of waterborne contaminants from potentially toxic mine products such as preparation tailings, and as an additive to enhance the fertility of mine soils in reclamation programs.

The study recommended that two different test routines be investigated as a basis for evaluating ash behaviour in mine backfill systems, using ash, water and relevant rock samples from selected mine sites. One of these is a two-step routine, in which the ash and mine water are brought together to produce a leachate, after which that leachate is brought into contact with samples of the mine rock materials. The leachates from both stages of the process to be analysed, and the results evaluated in the light of the solid phase and water characteristics and, to the extent possible, hydrogeochemical modeling techniques. The second routine involves the use of leachability tests directly on appropriate mixtures of the ash and rock materials. This may provide a more rapid basis for testing, but will need to be evaluated in the first instance against results from the two-stage process.

Acronyms

ACARP	Australian Coal Association Research Program
ACIRL	Australian Coal Industry Research Laboratories Ltd
AINSE	Australian Institute of Nuclear Science and Engineering
APCDs	Air Pollution Control Devices
AMD	Advanced Micro Devices
CCPs	Coal Combustion Products
CCSD	CRC for Coal in Sustainable Development
CCSEM	Computer-Controlled Scanning Electron Microscopy
CCUJ	Centre for Coal Utilisation
CO2CRC	Cooperative Research Centre for Greenhouse Gas Technologies
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CY	Calendar Year
FACTSage	Commercial Thermodynamics Software
GDP	Gross Domestic Product
GGE	Greenhouse Gas Equivalent
GJ	Gigajoule
IDGCC	Integrated Drying Gasification Combined Cycle
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IHI	Ishikawajima-Harima Heavy Industries
LCA	Life Cycle Analysis
LNG	Liquefied Natural Gas
MACT	Maximum Achievable Control Technology
MPa	Megapascal
MWe	Megawatt (electrical)
MWh	Megawatt Hours
NG	Natural Gas
PCI	Pulverised Coal Injection
PEFR	Pressure Entrained-flow Reactor
PF	Pulverised Fuel
PFBC	Pressurised Fluidised Bed Combustion
PHREEQC	Computer program for speciation
QEMScan	Proprietary Analysis Technique
SC	Super-critical
SIPS	Species Identification Program
SIROQUANT	Proprietary Analysis Technique
SMHEA	Snowy Mountains Hydro Electric Authority
SWIS	South West Interconnected System
ULV	Ultra Low Volatile
USC	Ultra Super Critical
WGS	Water Gas Shift
XANES	X-ray Absorption Near Edge Structure
XRD	X-ray Diffraction

improved environmental performance

CCSD

Cooperative Research Centre for Coal in Sustainable Development

Technology Transfer Centre
Queensland Centre for Advanced Technologies
Technology Court
Pullenvale QLD 4069

T: +61 7 3871 4400

F: +61 7 3871 4444

E: administration@ccsd.biz

W: www.ccsd.biz

CCSD acknowledges its participant organisations

ACARP Australian Coal Association Research Program
bhpbilliton
COAL & ALLIED
cs energy
CSIRO
Curtin University of Technology
Delta electricity
GRIFFIN COAL
Macquarie University
Premier Coal
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