Post-Combustion Capture (PCC) R&D and Pilot Plant Operation in Australia

IEA GHG 11th Post Combustion CO₂ Capture Network Meeting

Vienna, Austria, 20-21 May 2008
Overview

- Clean Coal Technologies in Australia

- PCC in Australia
  - The Need
  - The Issues

- PCC programme at CSIRO
  - Pilot plant activities
  - Research activities
Australia’s Greenhouse Gas Emissions

- Australia emitted 559 M tonnes CO₂ equiv. (2005)

- Australia has signed the Kyoto Protocol. Committed to the Kyoto target of a 108% increase over 1990 emissions (to 2012) – currently on track

- Australia’s greenhouse gas intensity (per capita) at ~27 tonnes CO₂ – equiv. per capita is among the highest in the world

- Australia’s greenhouse gas intensity (per $ of GDP) is 0.7 kg CO₂
Importance of Coal to Australia

- Black coal is Australia’s largest commodity export and is worth $25 billion (AUD) per annum
- Australia is the world’s largest exporter of coal
- Electricity generation accounts for ~35% of Australia’s net GHG emissions
- Australia’s electricity derives mainly from coal (57% black coal, 30% brown coal)
Emission reduction pathway for Australia

Source: Energy Futures, Paul Graham, CSIRO
Australian Research Organisations in CCT

- Cooperative Research Centre for Coal in Sustainable Development (CCSD)
- Centre for Low Emission Technologies (cLET)
- Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)
- Australian Coal Association Research Program (ACARP)
- Energy Transformed Flagship of the Commonwealth Scientific and Industrial Research Organisation (ETF-CSIRO)

- Until 2006 there was also a CRC for Clean Power from Lignite
Clean Coal Technology Pilot and Demonstration Projects

1. IDGCC (HRL)
2. Monash Energy - Gasification/ GtL/ CSS
3. Stanwell IGCC/ CSS - ZeroGen Project
4. CS Energy Oxyfuel Project
5. International Power - Lignite Power Repowering, Drying and Capture
6. Gorgon
7. Zero Carbon - Fairview
8. CO2CRC Otway Basin Project
9. Kwinana Project
10. Latrobe Valley PCC Project
11. Moombah Carbon Storage
12. APP - Post Combustion Capture Project
13. APP - Enhanced Coal Bed Methane Project
The Need for PCC in Australia

- Potential for substantial impact on very high GHG intensity of nations with a heavy reliance on coal for power generation.
- Offers ultimate long-term objective of near-zero CO₂-emissions.
- Addresses the risk of having major stranded generation assets (if a high cost is applied to carbon emissions).
- PCC potentially offers cost competitive route to low GHG emission electricity from coal for existing and new power stations.

80% of energy from burning coal.
PF Power Plant

Coal → Boiler → Steam turbine → Alternator → Electricity

Air → Flue gas 13-15% CO₂

Particulate removal → Flyash

Coal Type | Thermal Efficiency (%) | CO₂ Emissions (kg/MWh)
--- | --- | ---
Black | 36 - 41 | 1000 - 800
Brown | 28 - 32 | 1300 - 1100

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PF Power Plant with Post Combustion Capture

Thermal efficiency 28 - 33%
CO₂ emissions <100 kg/MWh

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PCC application in Australian coal fired power stations

- Generation capacity ~ 28 GW
- Electricity production 170 TWH/a
- Average generation efficiency
  - Black coal: 35.6% - 0.9 tonne CO₂/MWh
  - Brown coal: 25.7% - 1.3 tonne CO₂/MWh
- CO₂-emissions ~ 170 Mtonne CO₂/a from ~ 60 flue gas streams
- SO₂ levels:
  - Black coal: 200 - 600 ppm
  - Brown coal: 100 - 300 ppm
- NOₓ levels:
  - Black coal: 300-700 ppm
  - Brown coal: 100-200 ppm
- Flue gas temperature
  - Black coal: 120 °C
  - Brown coal: 180 °C
- Cooling water: 1.5-3.0 m³/MWh

Data used from CCSD – technology assessment report 62
Known issues with PCC

- High cost: around $30/t CO₂ captured
- Electricity cost increase from $30/MWh to $50/MWh for an 85% reduction in GHG
- Loss of generation efficiency around 20-30% to capture 90% of CO₂
- Not demonstrated in integrated power plants scale
- Sensitive to O₂, SOx and other flue gas constituents
- Large increase in cooling water requirement
PCC programme at CSIRO
Integrated PCC R&D Programme

Pilot plant programme (Learning by doing)
- Hands-on experience for future operators
- Identification of operational issues and requirements
- Testing of existing and new technologies under real conditions

Lab research programme (Learning by searching)
- Support to pilot plant operation and interpretation of results
- Develop novel solvents and solvent systems which result in lower costs for capture
- Addressing Australian specifics (flue gases, water)
Confirmed Pilot Plants

- APP support
- Munmorah Power Station
- Black coal
- Ammonia based
- No FGD/DeNox

- APP support
- Gaobeidian Power Station
- Black coal
- Amine based
- FGD/DeNox installed

- ETIS support
- Loy Yang Power Station
- Lignite
- Amine based
- No FGD/DeNox
Pilot plant locations

Gaobeidian power station

Tarong power station

Munmorah power station

Loy Yang power station
Latrobe Valley Post-Combustion Capture Project

Energy Technology Innovation Strategy
Project activities and actors

- New solvent development research – CSIRO/CO2CRC
- Membrane research 10 tpa – CO2CRC
- Adsorbent research at 100 tpa – CO2CRC
- Solvent testing in 1000 tpa test facility – CSIRO/Loy Yang Power
- Solvent testing in 10000 tpa demonstration plant – CO2CRC/International Power Hazelwood
- Process and energy integration studies - all
- Technical and economical studies - all
Scope of pilot plant experiments at LYP

- Technical and economical scale-up information about CO₂ capture plant based on operation on flue gas from brown coal combustion

- This includes determining the following interrelationships:
  - CO₂ capture energy consumption
  - CO₂ capture efficiency
  - Solvent CO₂ loading
  - Solvent and flue gas flow rates
  - Regeneration temperature and pressure
  - Absorption temperature
  - Solvent consumption and degradation rates
  - Fouling and corrosion
  - Effectiveness of the conditioning stage
  - Reagent loss rate both to acid gas and to release with flue gas
  - System water consumption
Loy Yang Power Station, Victoria

- The power station is capable of generating 2,200 megawatt.
- Loy Yang mine is the largest producing open cut brown coal mine in the southern hemisphere.
- Loy Yang Power supplies one third of Victoria's electrical energy needs.
- The Loy Yang open cut coal mine excavates approximately 30 million tonnes of brown coal each year.
- There are 168,000 million tonnes of accessible brown coal beneath the Latrobe Valley, or in excess of 1,300 years supply at current rates of usage.
LYP Pilot plant design

- Use of two columns with a specified single column design CO₂ capacity of 100 kg/hr as a minimum (85% removal)
- Based on local flue gas composition (11% CO₂)
- Based on the use of MEA (30%)
- Operate with reboiler temperatures 100 - 120°C
- Operate with stripper pressures 1 - 2 bar
- Be able to determine thermal and electrical energy requirements of the pilot plant
- Be able to determine emissions to atmosphere and CO₂-product quality
Pilot plant design process

- Process modelling based on Winsim and Aspen Plus providing heat and mass balance -> basis for design
- Sizing and costing of major equipment both internally and by external contractors
- Frame/skid design
- Detailed design including piping
- Process and Instrumentation
- Control logic
Simplified Pilot plant flow sheet
Two absorbers for added flexibility

Single column operation with other column on standby or changed out for new experiment

Series operation for higher packing heights

Parallel operation for larger equivalent column diameter

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Gas analysis will be performed at 5 points throughout the pilot plants.

Diagram adapted from MHI.
Loy Yang Pilot Plant Program

**Collaboration Partners**
- Loy Yang Power
- Victorian Government (Energy Technology Innovation Strategy - ETIS)

**Project Milestones**
- Establishment of pilot plant on site Jan 2008
- Official opening 29 April 2008
- Pilot plant operational - May 2008
Munmorah Pilot Plant

• Collaboration Partners
  • DELTA Electricity
  • Department of Resources, Energy, & Tourism (Asia Pacific Partnership program)

• Project Milestones
  • Detailed design complete – Feb 2008
  • Construction complete – June 2008
  • Commissioning and experimental program – July 2008 – July 2010
Development Pathway for PCC

Generation I: MEA (chemicals)

Generation II: Improved “MEA” (EOR, chemicals)

Generation III: Novel solvents (PCC-CS)

Generation IV: Novel capture systems (PCC-CS)

Focus of the lab research

Current best technology

$/t CO_2
PCC Technology Development Scenario

- Contribution CO2 binding
- Contribution steam stripping
- Contribution solvent heating

Thermal energy requirement [GJ/ton CO2]

State of the art

Improvement Potential
Efficiency and CO₂ Emissions

- Efficiency and CO₂ emissions for different technologies (G1, G1/2, G2/3, G3/4, G4).
- Graph showing efficiency reduction due to capture and CO₂ emission reduction with capture.
- State of the art indicated.

Technology development arrow pointing towards lower emissions and higher efficiency.
Research: Solvent system development

A holistic approach is essential!

- Solvent - chemistry
- Process design - flow sheet
- Equipment - hardware
- Integration - thermodynamics

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PCC Research programme overview

1. Solvent development focuses on new chemicals or chemical formulations for reversible binding of CO₂
2. Solvent process development involves the development of alternative processes, novel process flow sheets, inclusion of other separation processes such as membrane technology to improve the solvent process performance
3. Equipment development is particularly aimed at reducing the equipment sizes and the physical footprint of capture technology and hence reducing investment costs
4. Optimal power plant integration is required to have minimal impact of the capture process on the power plant, including the usual of solar energy
Solvent development programme

- Commercially available amines
- Amine synthesis
- Screening of CO₂ absorption capacity and initial rate
- Modelling of CO₂-amine interactions
- Identification of outstanding performers
- Absorption kinetics (wetted-wall)
- Vapour-liquid equilibria and kinetics (stirred batch reactor)
- Solution phase reactions and speciation (NMR and FTIR)
- Reaction enthalpies (calorimeter)
- Identification of outstanding performers
- Laboratory pilot-plant testing
- Corrosion
- Oxidation
- Impact of SO₂ and NOₓ
- Pilot-plant testing

Over 100 amines
Screening of Capacity and Initial Rate

Gravimetric method used to measure CO₂ absorption and initial absorption rate on μL scale

Traditional absorption method used on the mL scale
Modelling + Screening

![Graph showing capacity vs. pKₐ for different types of amines, including primary, secondary, tertiary, and mixed amines. The graph includes limit lines for no carbamate and carbamate only.](image-url)
Advanced amines
  • Formulated mixtures, multiple amine groups

Non-aqueous solvents
  • Ionic liquids

Phase change solvents
  • Slurries, emulsions

Modified process concepts
  • Intervolving, heat exchange integration in stripper, integration of compression, split flow

Novel process components
  • Membrane contactors, heat pumps

Robust solvents
  • Ammonia, carbonates

Biomimetic approaches
  • Enzymes for solvent process improvements
Thank you

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