Post-combustion CO_2 Capture

An overview of CSIRO activities

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Content Presentation

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  - Pilot plants
  - Lab based research projects
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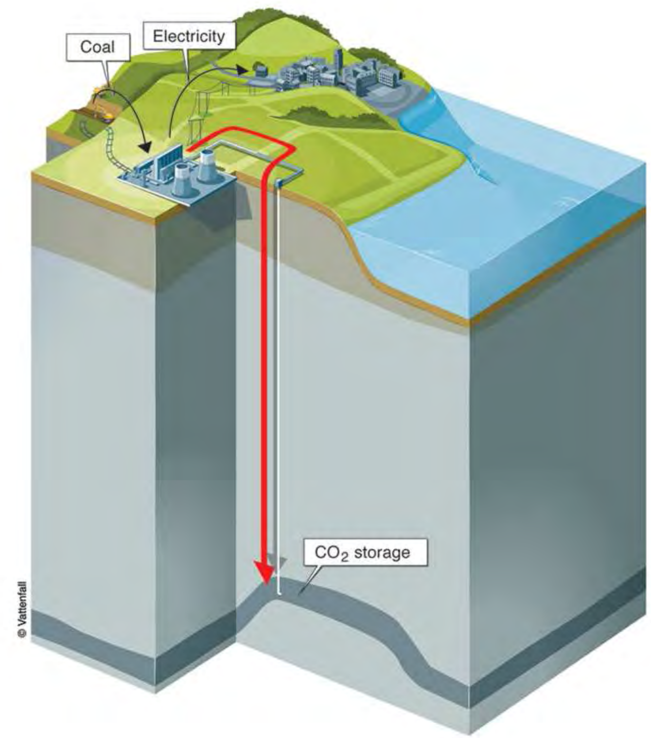
CO_2-Capture and Storage: Decarbonisation of fossil fuel chain

- CCS = Capture+Transport+Storage
- CO_2-storage least understood, hence main R&D topic
- CO_2-transport: Available technologies, but requires infrastructure
- CO_2-capture technologies available, but relatively expensive



Coal is important for Australia

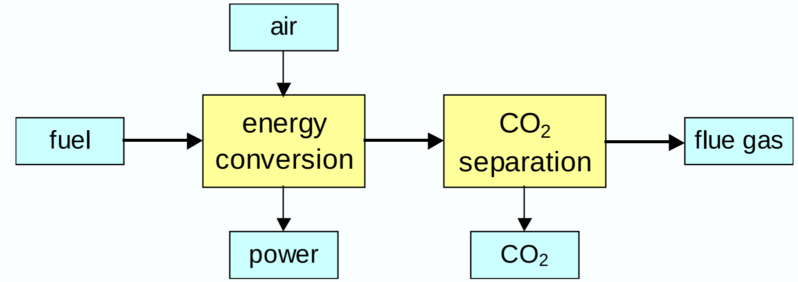
➢Australia is the world's largest coal exporter & coal is Australia's 2nd largest export earner (B$ 45 in 2010-11)

➢Most of Australia's electricity is produced from pulverised coal fired boilers (52% black coal, 23% brown coal in 2009-10)

- Generation capacity ~ 28 GW
- Electricity production ~ 170 TWh/a
- Average generation efficiency
  - Black coal: 35.6% - 0.9 tonne CO_2/MWh
  - Brown coal: 25.7% - 1.3 tonne CO_2/MWh
- CO_2-emissions ~ 170 Mtonne CO_2/a from ~ 60 flue gas streams

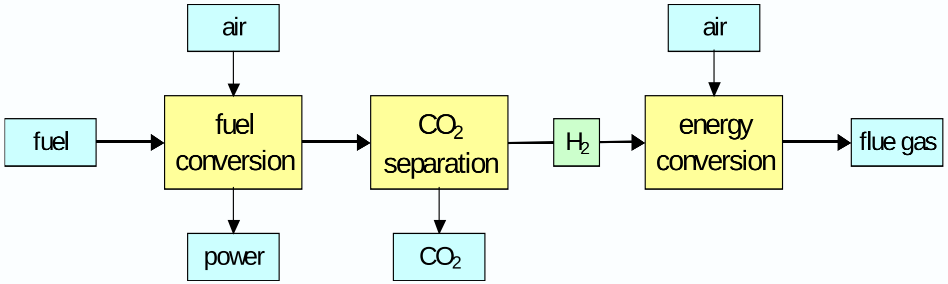
Overview of PCC programme at CSIRO

Decarbonisation routes for power plants



Post-combustion

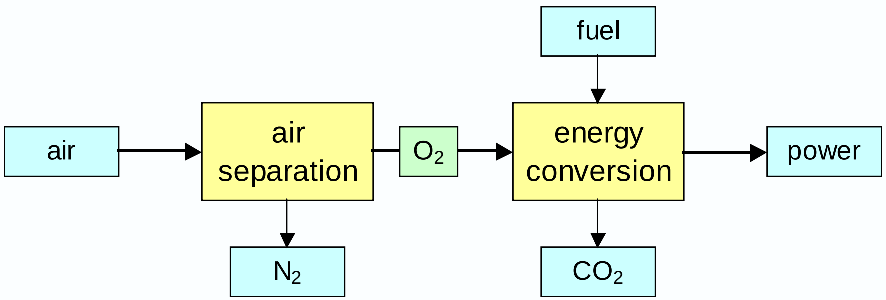
CO_2-N_2 separation



Pre-combustion

CO_2-H_2 separation

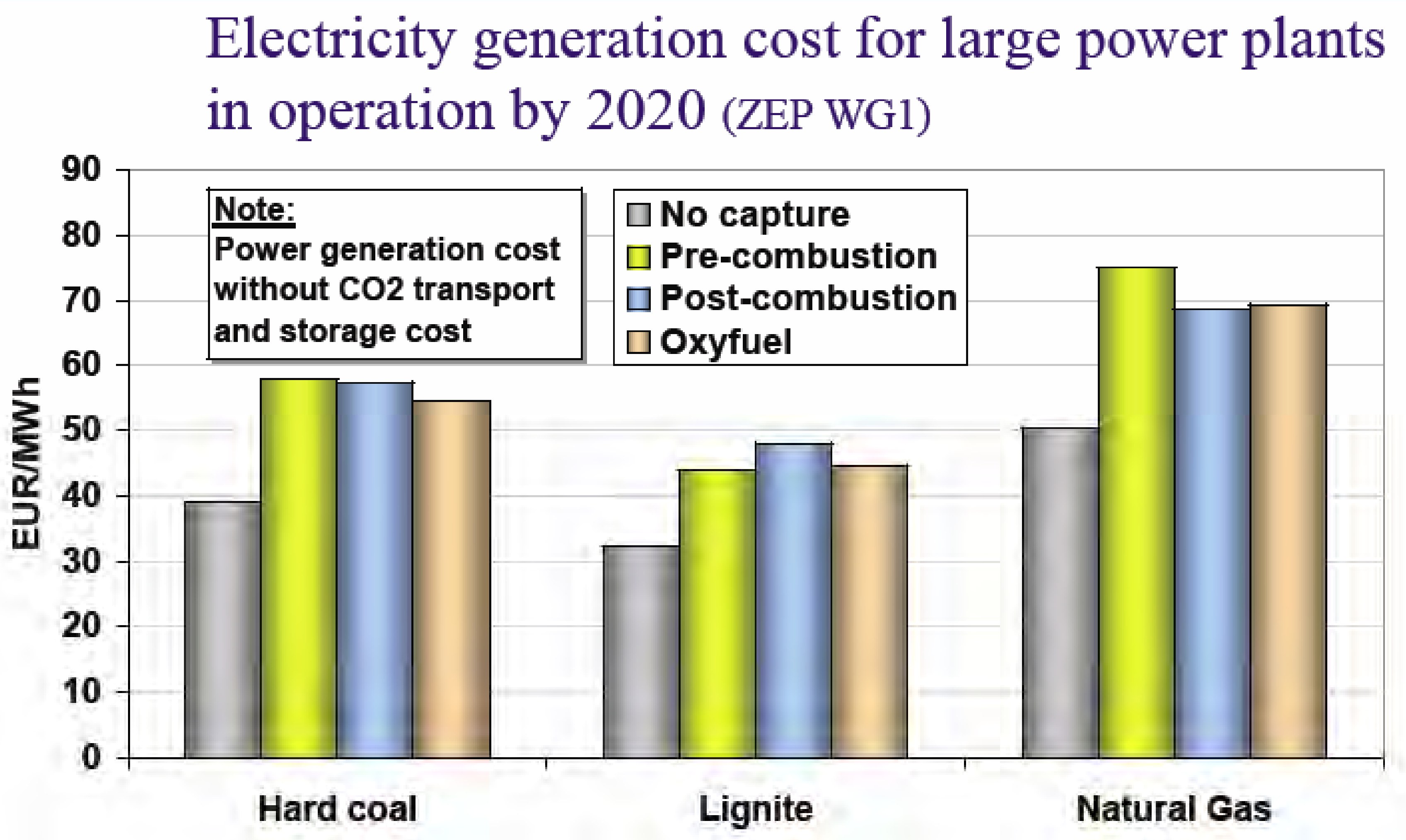
H_2-CO, O_2/N_2 separation



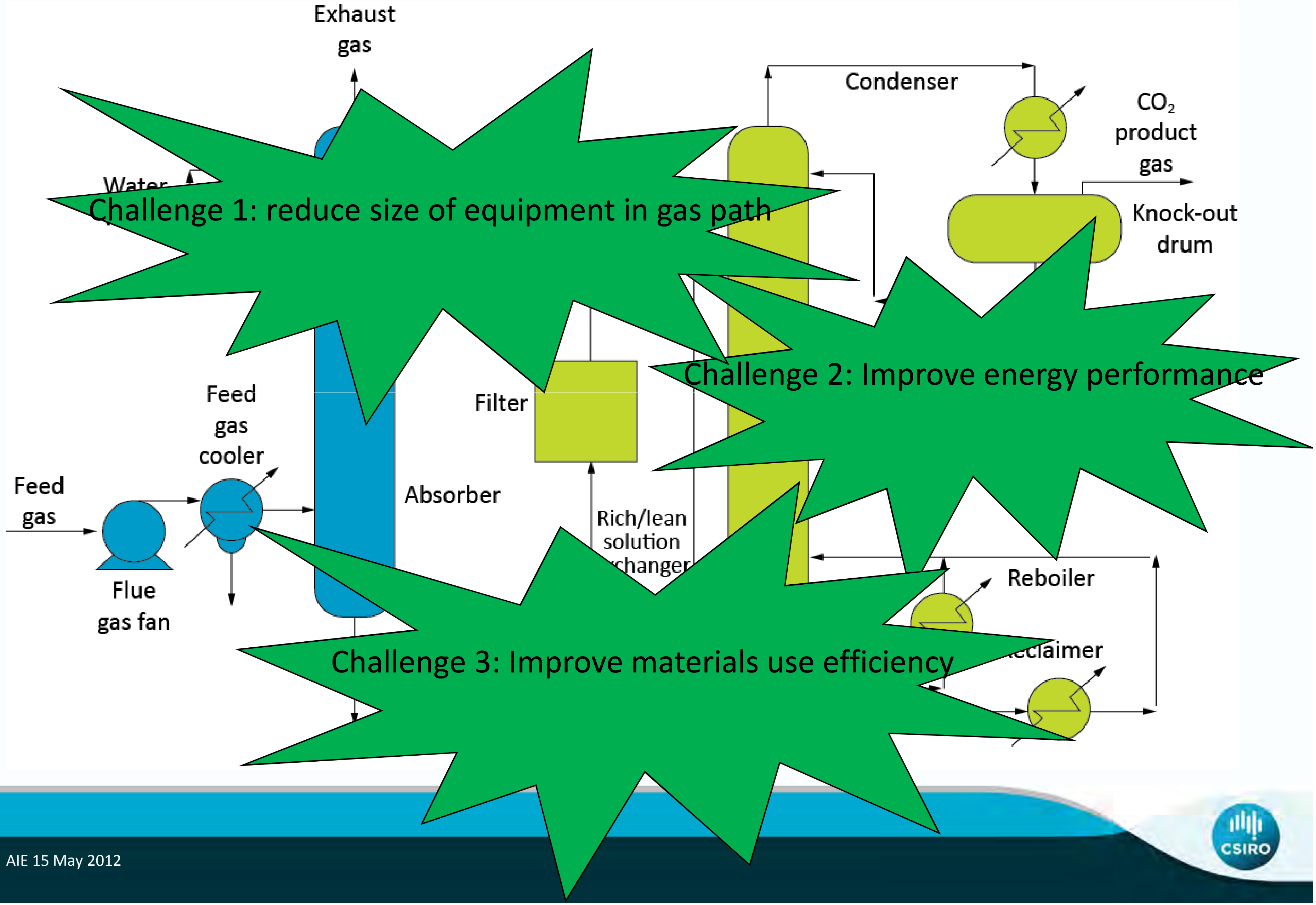
Denitrogenation

O_2/N_2 separation

Cost of CO_2 capture – not much difference between options



Leading PCC technology is liquid absorbent based

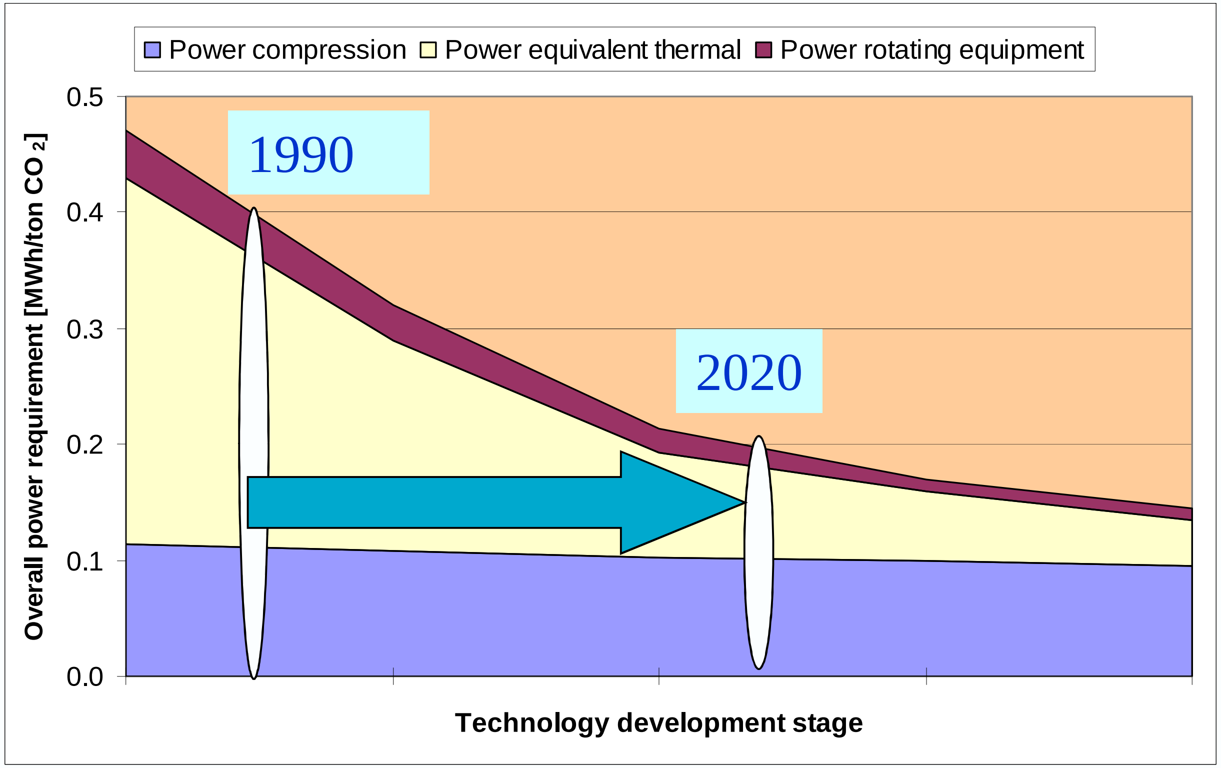


Why liquid absorbent based PCC process?

PRO	CON
Low technology risk	High cost
Flexible operation, in tune with market requirements	Loss of generation efficiency
Ability to adopt technology improvements	Not demonstrated in integrated power plants scale
New and retrofit applications	Sensitive to O_2, SO_x and other flue gas constituents

Thermodynamic analysis shows a large improvement potential in energy performance of PCC

- Thermal energy
  - Regeneration of solvents; Extracted from steam cycle in power plant
- Electricity
  - Flue gas fans, Solvent pumps, CO_2 compressor



Derived from Feron, proceedings of GHGT-9, November 2008, Washington

Integrated PCC R&D Programme

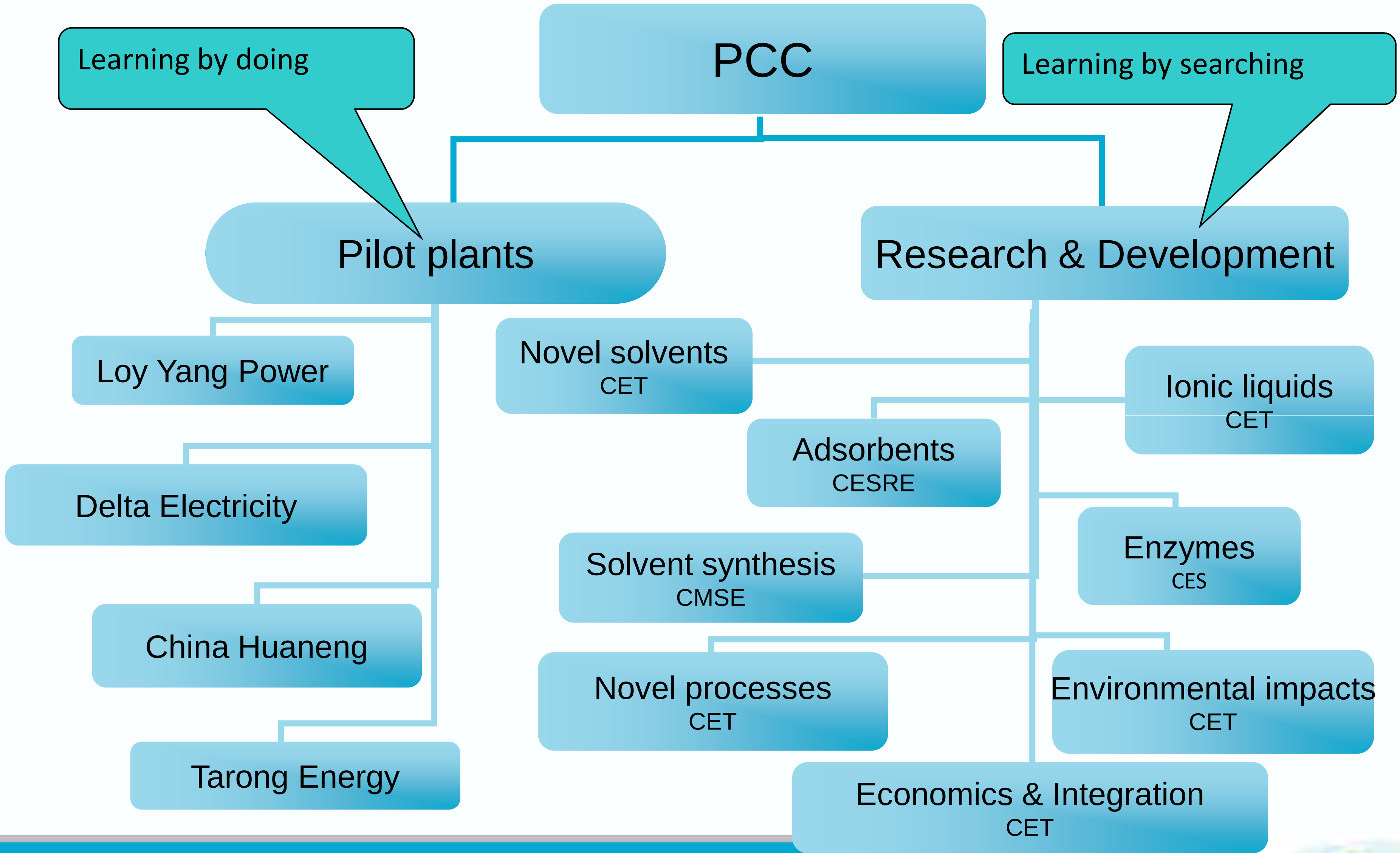
Pilot plant programme (Learning by doing)

- 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)

Key projects in CSIRO's PCC program



Established Pilot Plants in Australia

2008

2009

2010

Post-Combustion Capture Pilot Plant
China Huaneng Beijing Cogeneration plant

华能清洁能源研究院
HUANENG CLEAN ENERGY RESEARCH INSTITUTE

Results reported in Huang et al., Applied Energy 87(2010)3347–3354

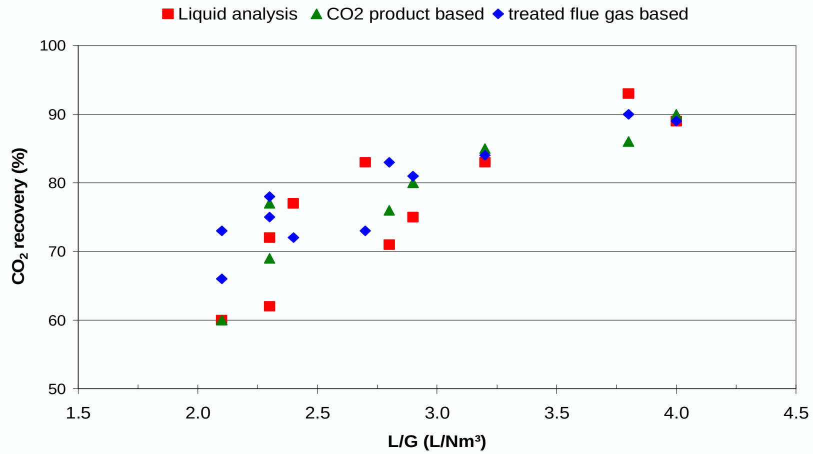
CSIRO

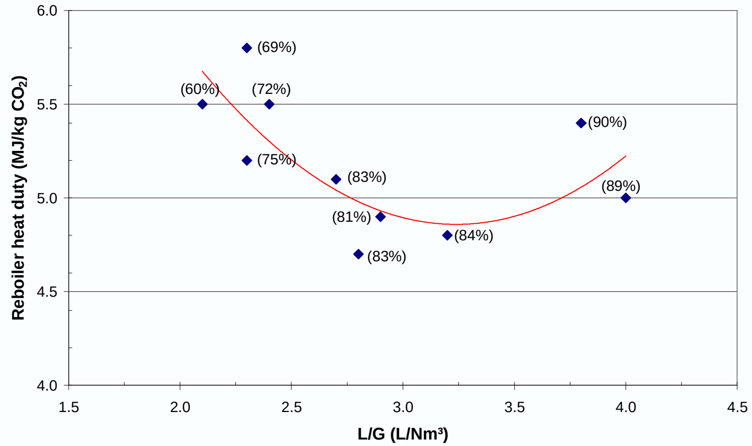
Loy Yang Power Station PCC Pilot Plant Victoria

- ➢ETIS support
- ➢Lignite
- ➢Amine based
- ➢No FGD/DeNox
- ➢Operational May 08

Research overview Loy Yang pilot plant

- 7 campaigns with different solvents completed
- Detailed investigation of PCC emissions
  - Validation of procedures for sampling and analysis
  - Contribute towards quantification of environmental impact of PCC
- Collaboration with EU consortium in the iCap project.
  - CSIRO is part of an Australian consortium (coCAPco) working with iCap
  - Aim to develop and test a combined CO_2 and SO_2 control process
- PCC process emissions assessment





Artanto, et al., 2009

Munmorah Power Station PCC Pilot Plant New South Wales

Delta electricity

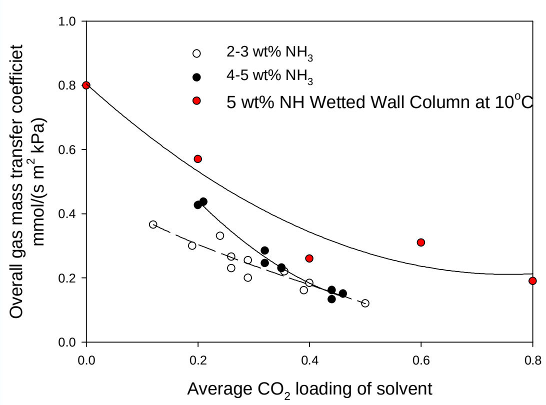
Australian Government
Department of Resources, Energy and Tourism

Asia-Pacific Partnership on Clean Development & Climate

- APP support
- Black coal
- Aqueous ammonia based
- No FGD/DeNox
- Operational Feb 09

Research overview Delta Electricity pilot plant

- Research campaigns have been completed:
  - Technical feasibility of aqueous ammonia for PCC demonstrated
  - Low absorption rates and ammonia losses are concern
- Further trials after the plant is relocated to Vales Point Power Station as part of a Coal Innovation NSW Project
  - Informing selection/design of demonstration scale PCC plant in NSW
- Trials will include:
  - Solar thermal energy for solvent regeneration
  - Impact of flue gas impurities
  - Evaluation of solid sorbents in real flue gases



Hai Yu et al., 2010

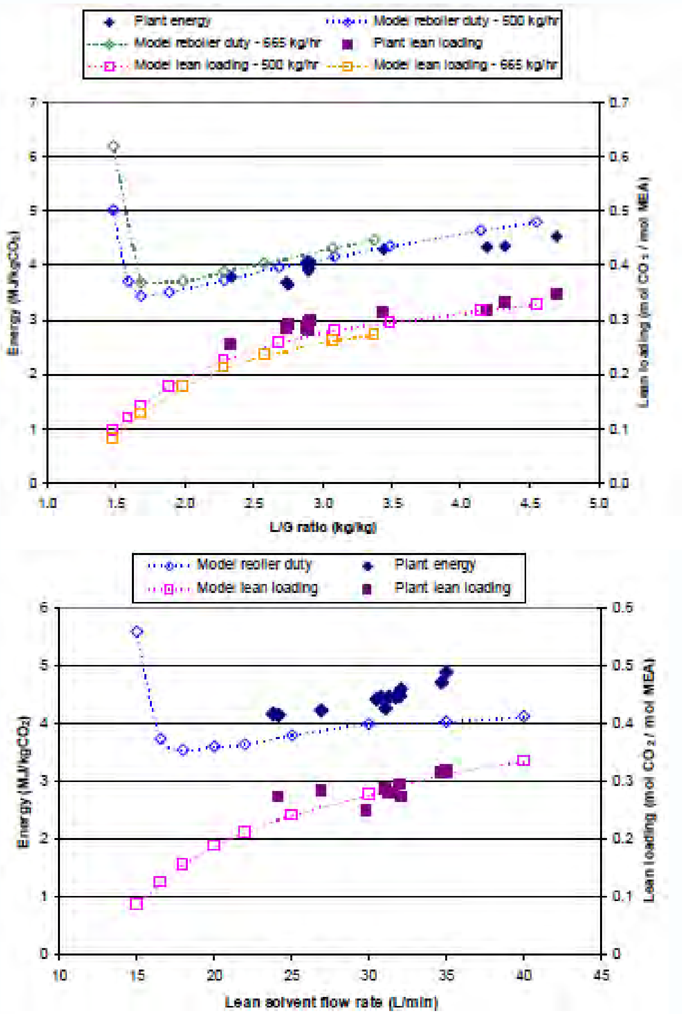
Tarong Power Station PCC Pilot Plant Queensland, Australia

- APP support
- Black coal
- Amine based
- No FGD/DeNox
- Commissioned November 2010

Australian Government
Department of Resources, Energy and Tourism

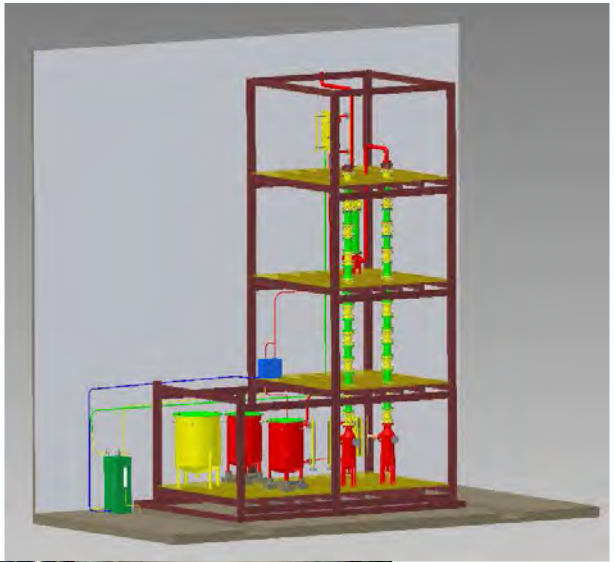
Research overview Tarong pilot plant

- Alternative process configurations tested: rich split, inter-stage cooling and split flow
- Collaboration with University of Texas and URS will enable trials with concentrated piperazine to trial high temperature and pressure regeneration
- More modifications will be tested to provide experimental evidence on process modifications to reduce the energy consumption



Cousins et al., 2012

Process Development Facility in Newcastle



Flexible
absorber/desorber rig

Absorber and desorber

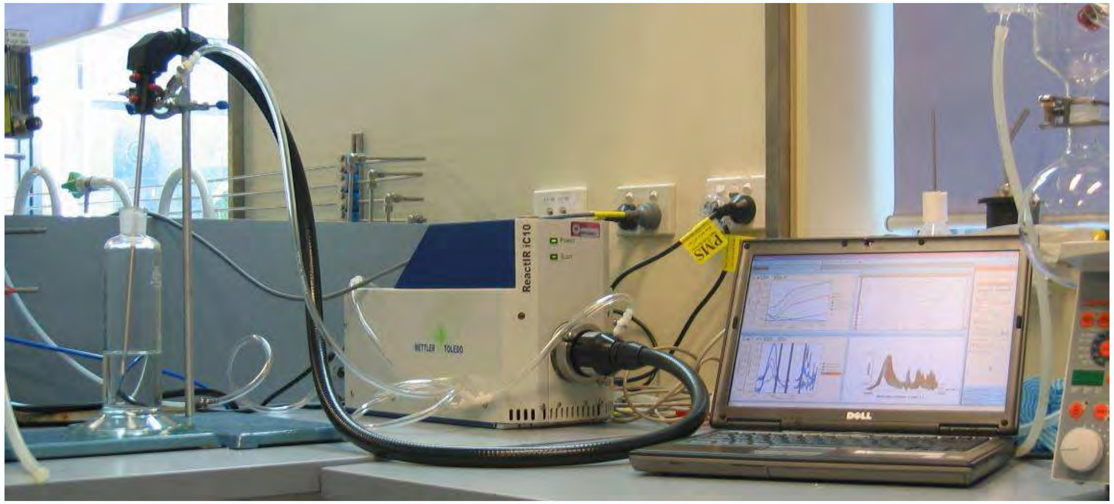
Segmented columns

Pilot plant summary

Plant	Loy Yang	Munmorah -> Vales Point	Tarong	Newcastle PDF
Solvent	Amine	Ammonia/Amine	Amine	Both
Flue gas source	brown coal	black coal	black coal	Synthetic
Scale	50 kg/hr	300 kg/hr	100 kg/hr	20 kg/hr
Focus	solvent benchmarking	ammonia operation	process optimisation	process development
Other activities	emission study	solar thermal integration	Novel solvent	cutting edge processes

- Matrix approach helps cover many aspects of PCC as well as providing quicker delivery of information

Liquid Absorbent R&D capability

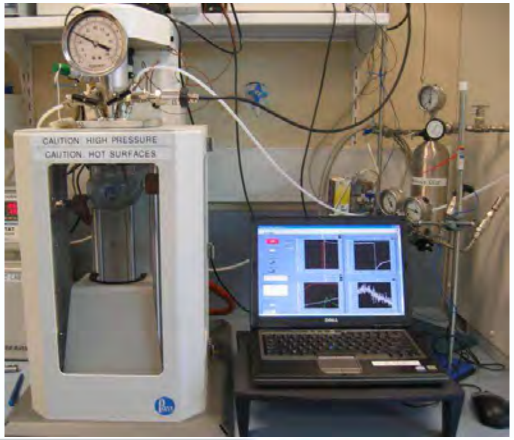


Speciation in liquid

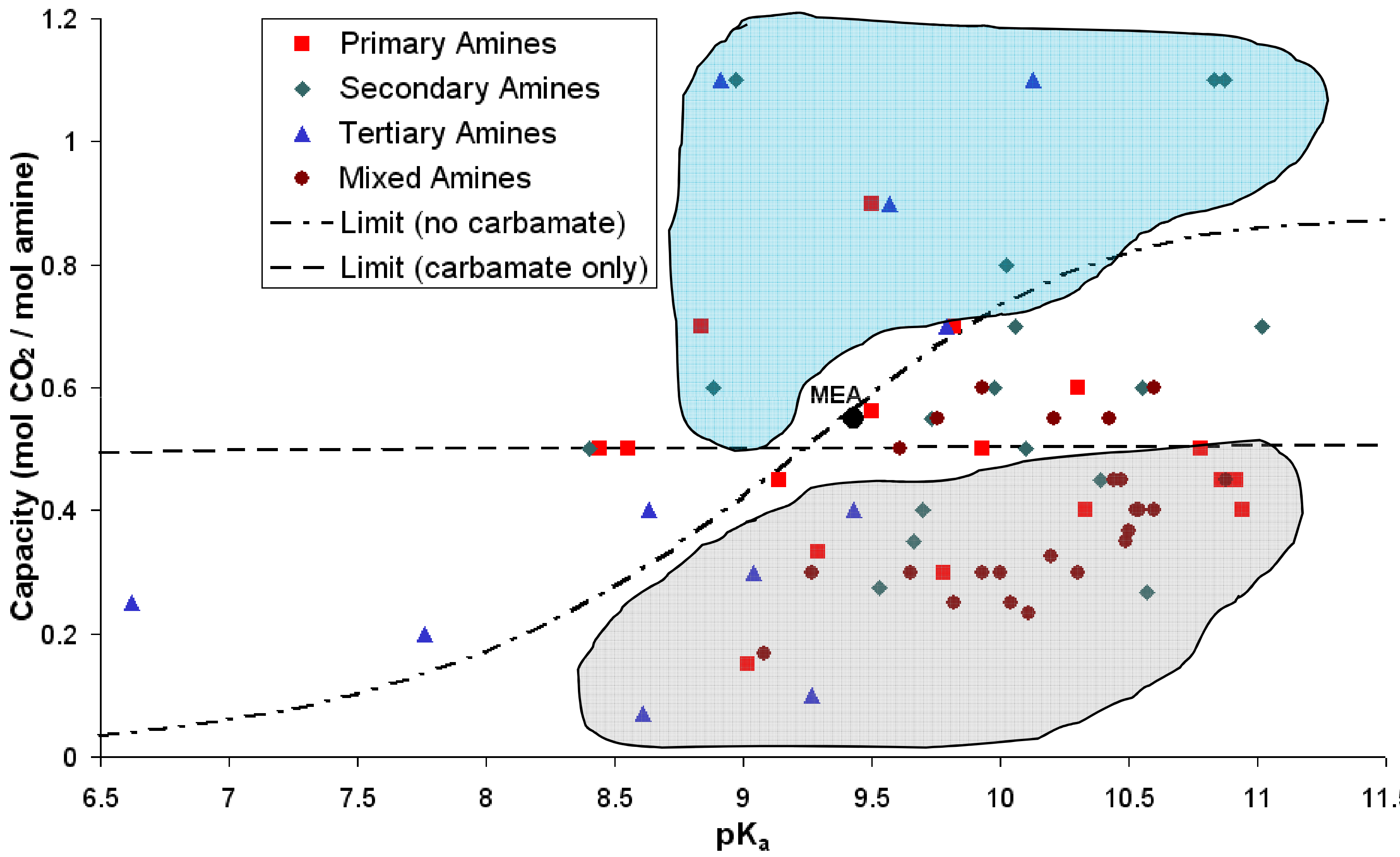
Absorption rates

Absorbent degradation

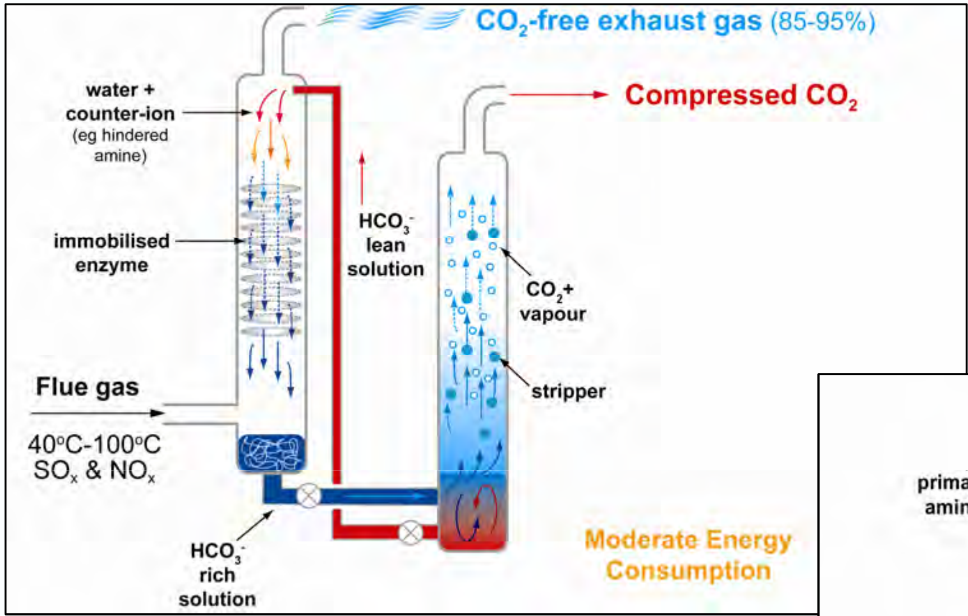
Vapour liquid equilibrium



Modelling + Screening of amines
(Puxty et al. , 2009)

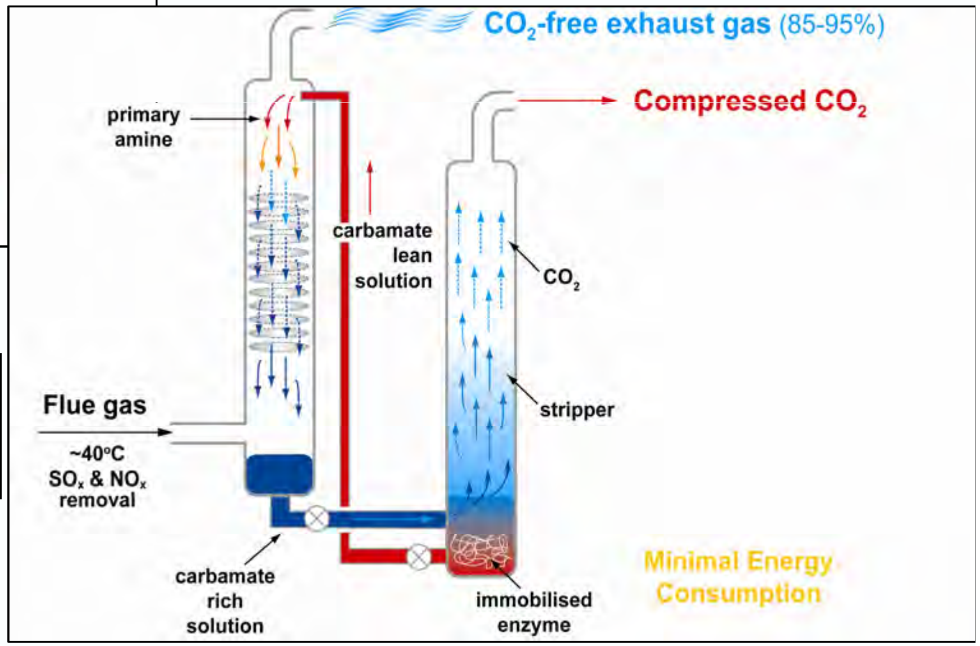


Use of Enzymes in PCC



1. Promotion of CO_2 capture using enzymes

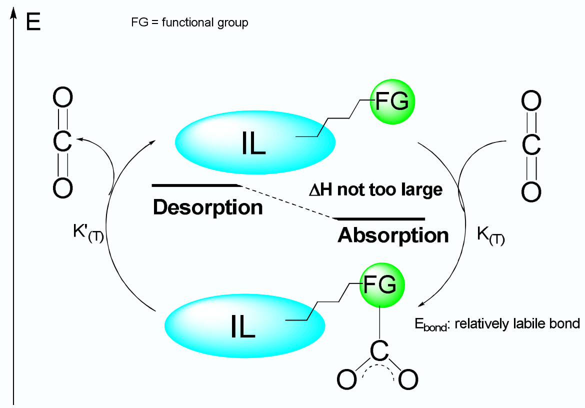
2. Low energy regeneration of CO_2 from amine carbamates using enzymes



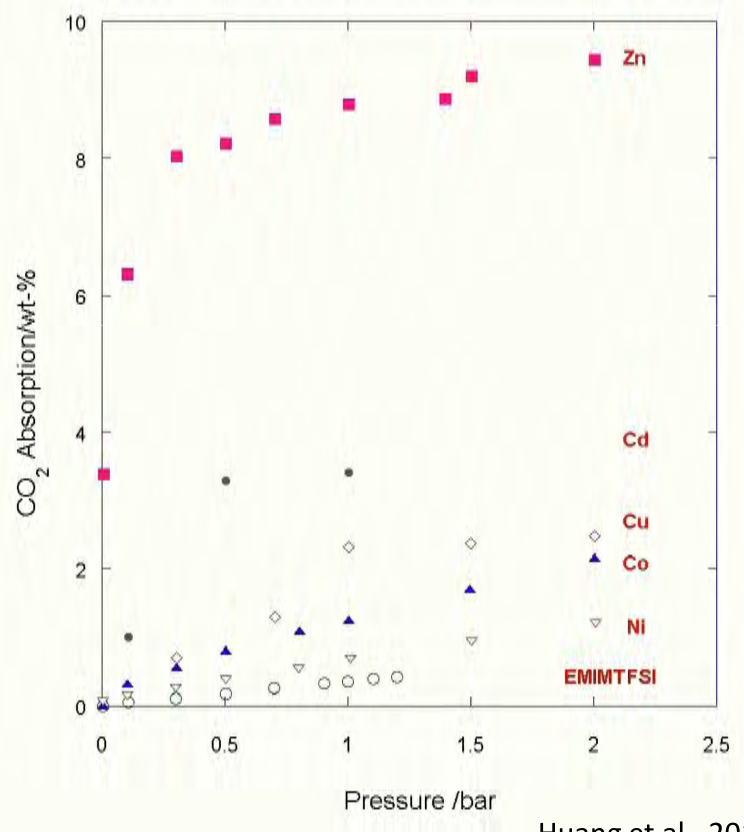
Victoria Haritos et al.

Ionic liquids for PCC

- Standard ionic liquids give low CO_2 absorption capacity similar to a physical absorbent
- Functionalised ionic liquids give higher CO_2 loadings



- Energy savings up to 70% possible:
  - Absence of water
  - Low heat capacity
  - Low binding energy
- Challenges:
  - High viscosity
  - Low absorption rates



Huang et al., 2012

Carbon based sorbents

Design, fabrication, testing and optimization of novel honeycomb monolithic carbon fibre composite adsorbents for CO_2 capture

- **Simulated Gases:** Test Gases
  - **Flue Gas**:
    - 10% CO_2, 5% O_2, N_2 balance
    - 10% CO_2, N_2 Balance
  - **Gas Mixture**:
    - 10%, CO_2 1%, CH_4 N_2 balance
    - 1% CO_2, 5%CH_4, N_2 balance

- **Operating Conditions:**
  - Flow rates: 0.2 SLM, 0.5 SLM, 1.0 SLM
  - Pressures: atmospheric pressure, 10 bar, 20 bar
  - Temperatures: room

Molding equipment

3 processing furnaces

Length: 80mm, Dia: 30mm, Number of Channels: 17, Channel Dia: 3mm

Fabricated Honeycomb Monolithic Carbon Fibre Composite (CFHM)

Adsorption isotherms (up to 80°C)

Breakthrough Test Rig with Lab Scale Adsorption Chamber (Length: 200mm, Dia: 35 mm)

Economics of PCC in Australia

Power plant base case

Subcritical

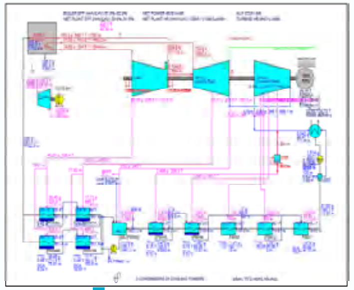
Supercritical Single Reheat

Ultra-supercritical Single Reheat

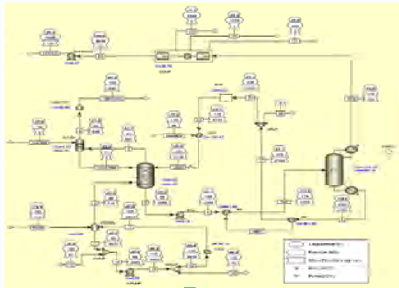
Supercritical Double Reheat

Ultra-supercritical Double Reheat

STEAM PRO Simulations



ASPEN-Plus Simulations



CO_2 capture plant model

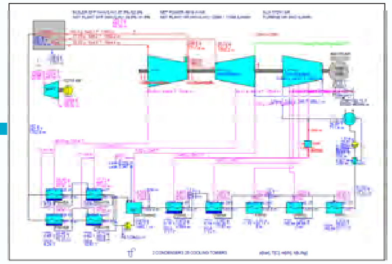
30% w/w MEA base case

Integrated plant assessment

90% CO_2 capture

CO2 capture always on and on demand.

Off-design calculations



STEAM MASTER Simulations

Cost estimates

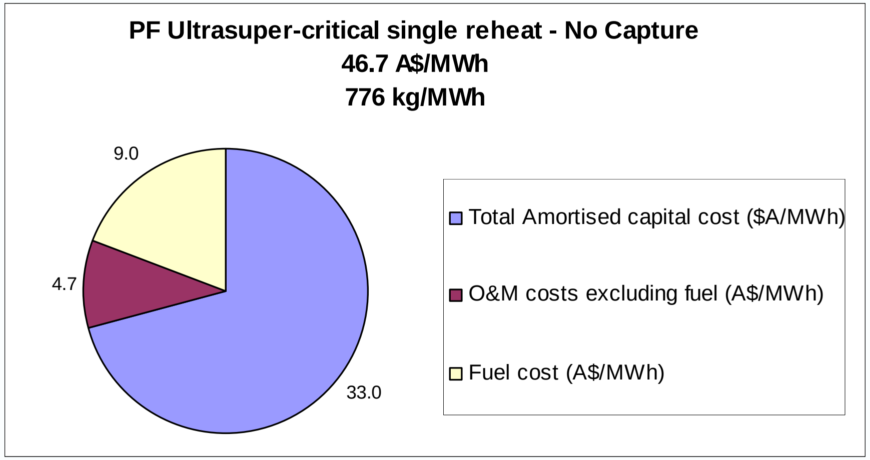
PEACE software

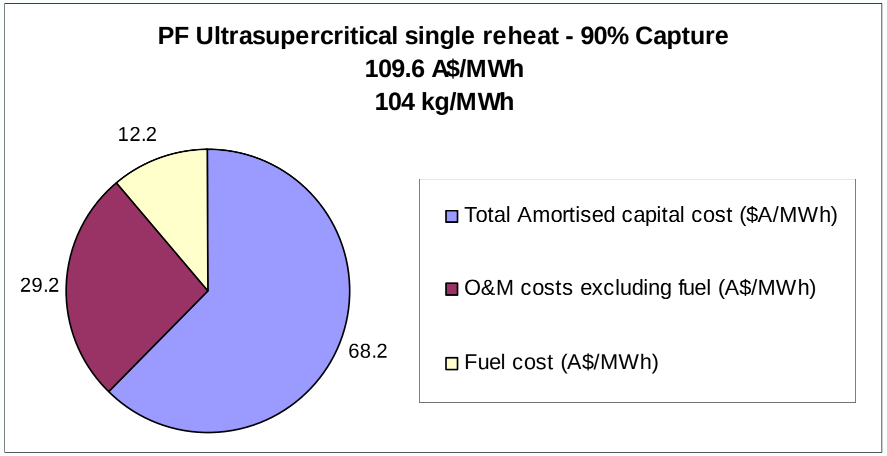
In-house cost data

Economic Modelling

Example results from economic modelling

- Supercritical and ultra-supercritical power plants with single reheat provided lowest electricity generation costs
- Example for USC-single reheat and mechanical draft cooling tower



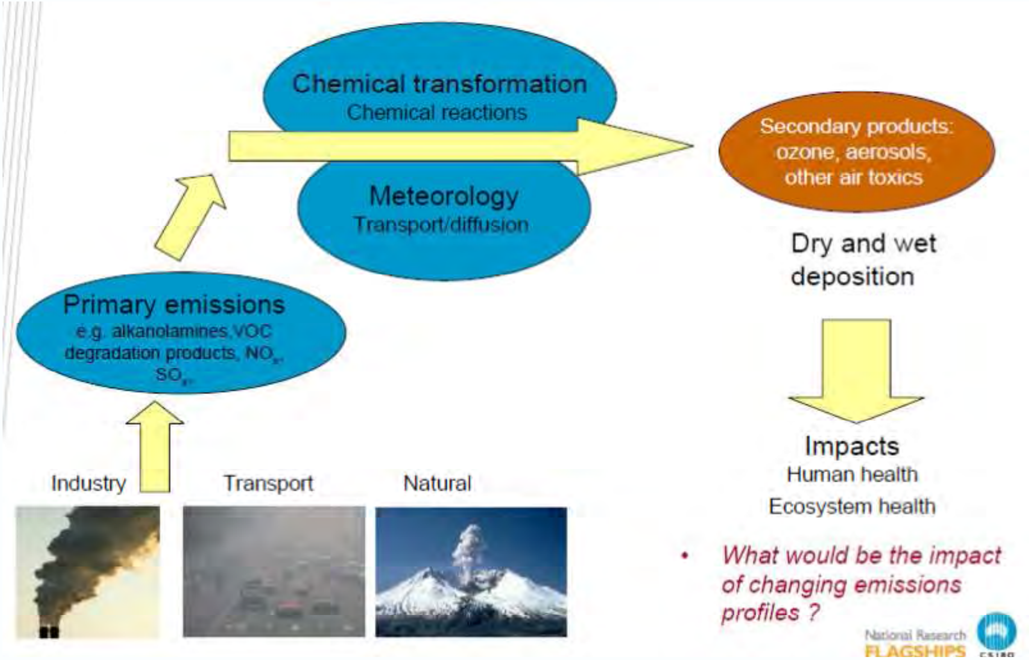


Narendra Dave et al.

- Power plant efficiency reduced from 40% to 30%
- Electricity generation cost is more than doubled with 90% CO_2-capture
- Specific capital costs are doubled with 90% CO_2-capture
- Cost per tonne avoided 94 A$/tonne CO_2 represents a worst case

Environmental challenges for PCC

- ➢ Greenhouse gas emissions reduced
- ➢ Addressing gaps in knowledge on additional emissions
- ➢ Assessing emission limits of PCC processes
  - Process chemistry
  - Atmospheric chemistry



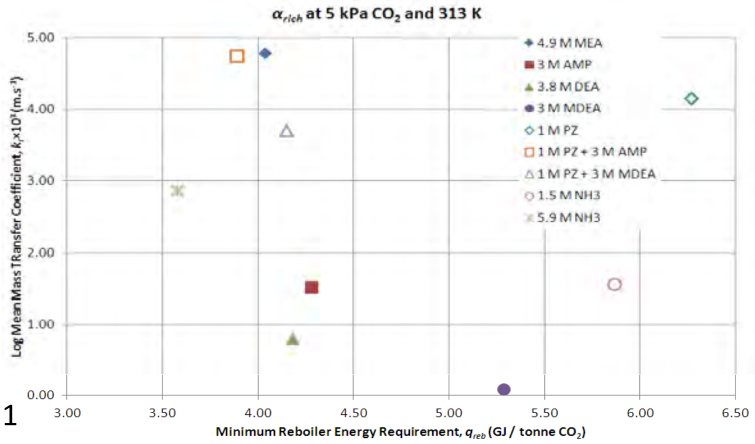
Smog chamber facility at Lucas Heights

PCC Research Summary

- ➢ CSIRO PCC Pilot plant programme is unique in depth and breadth
- ➢ Solvent screening, formulation and characterisation methods developed

➢ Liquid absorbent screening of more than 100 candidates has been narrowed down to the 2 most promising candidates

➢ Unique position in the application of enzyme technologies and ionic liquids has been realised through patent applications



Puxty, Feron,submitted, 2011

➢ More IP under development in contactors, the regeneration process and designer amines

➢ Excellent insight into the overall economics of PCC has been realised

➢ Environmental impact of PCC-processes identified as major concern and capabilities established to address this.

➢ Establishment of international links with leading groups in the APP region and Europe

Key research and engagement partners in PCC

Australian Government
Department of Resources, Energy and Tourism

Asia-Pacific Partnership on Clean Development & Climate

LOY YANG power

TRU energy

stanwell

Delta electricity

NSW GOVERNMENT

Victoria The Place To Be

BROWN COAL INNOVATION AUSTRALIA
Positioning brown coal for a brighter future

anlecr&d

华能清洁能源研究院
HUANENG CLEAN ENERGY RESEARCH INSTITUTE

RITE
Research Institute of Innovative Technology for the Earth

iCO_2ap

GASSNOVA

GLOBAL CCS INSTITUTE

CO_2 net

TNO innovation for life

Statoil

MONASH University

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

The Rochelle Lab
The University of Texas at Austin
CO_2 Capture

清华大学
Tsinghua University

Zhejiang University

Thank you

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w www.csiro.au/science/Post-combustion-capture.html