Queensland Centre for Advanced Technologies (QCAT)

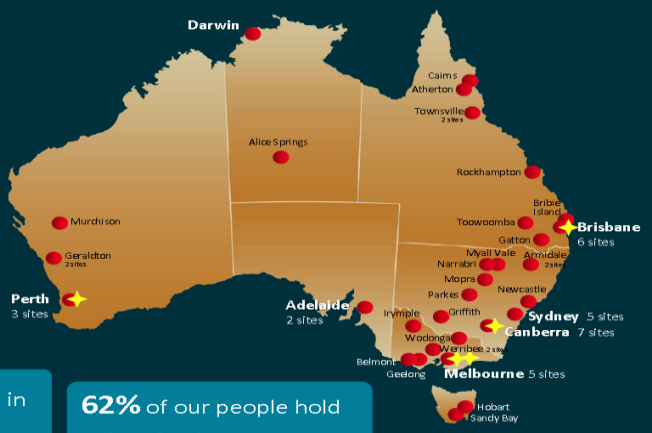
Welcome, safety and CSIRO

24 October 2016

CSIRO ENERGY
www.csiro.au

CSIRO

People	~5500
Locations	58
Business units	8
Budget	$1B+



Top 1% of global institutions in 14 of 22 research fields

Industry focus: **1600** Australian companies, **350+** Multi-nationals

62% of our people hold university degrees
2000 doctorates
500 masters

$500M+ annual revenue generated from external sources

Current portfolio, CSIRO's lines of business

Impact Science – R&D Business Units

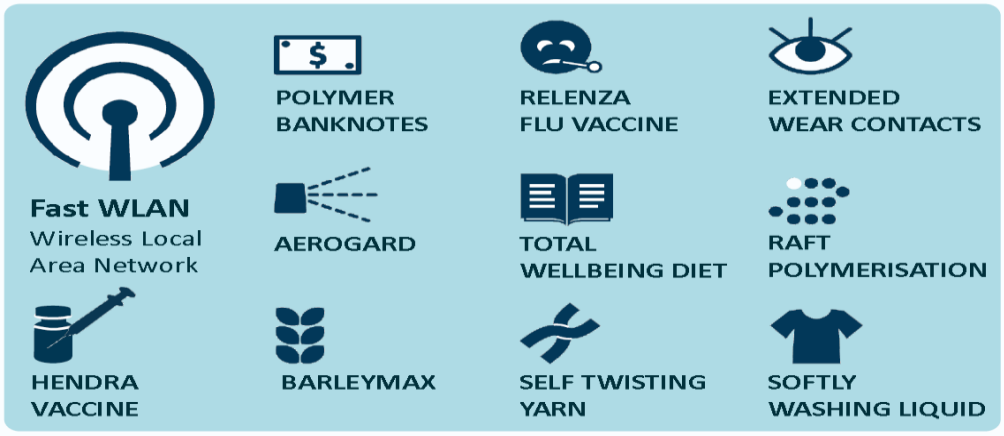
- HEALTH & BIOSECURITY
- ENERGY
- DATA61
- MANUFACTURING
- MINERAL RESOURCES
- AGRICULTURE & FOOD
- LAND & WATER
- OCEANS & ATMOSPHERE

Lines

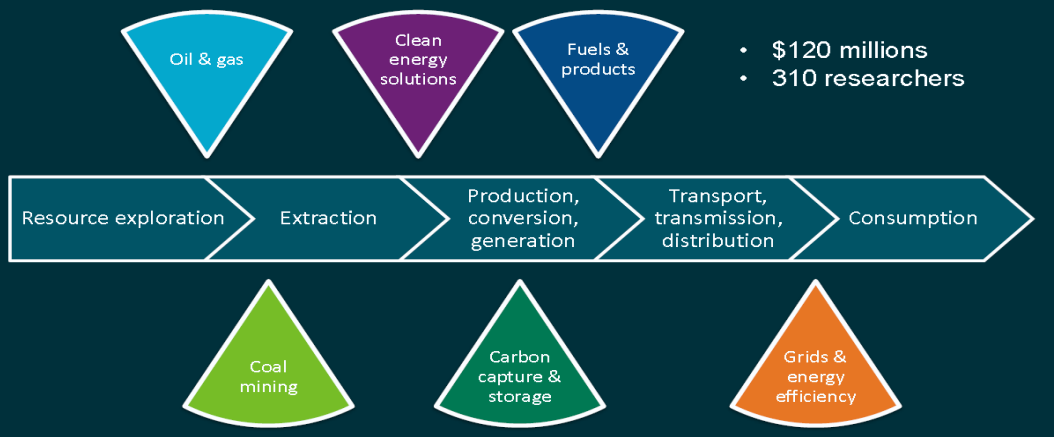
- SERVICES
- NATIONAL FACILITIES & COLLECTIONS

One CSIRO support functions

Our track record: top inventions



CSIRO Energy



Site water trial

Gasification, H2 production, and 'Pre-combustion Capture' R&D

Daniel Roberts | Research Group Leader

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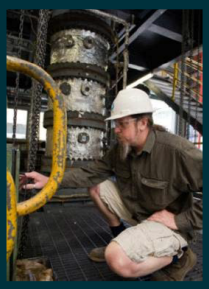
Gasification of coal, biomass, and waste



CSIRO Gasification Research

Fundamental science supporting industrial application

Feedstocks

- Urban Waste
- Coal
- Biomass
- Agricultural Waste
- Lignites

→

Science & Research Areas

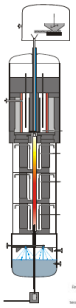
- **Gasification reaction science:** devolatilisation, char formation, heterogeneous kinetics, high temperature processes
- **Inorganic chemistry:** slag formation and flow; mineral matter and trace element transformations, speciation, and behaviour; chemistry of residues and ash
- **Modelling:** Gasification, gasifier, and process models
- **Scale:** Technical and pilot-scale studies of feedstock behaviour

→

Applications

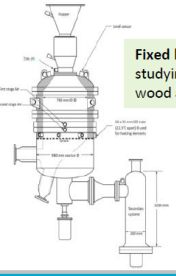
- Supporting pilot-scale R&D and commissioning studies
- R&D in support of technology development
- Matching feedstocks to gasifiers, feedstock requirements
- Supporting gasifier design, optimisation, troubleshooting
- Developing solutions for remote or off-grid applications

CSIRO Gasification Research



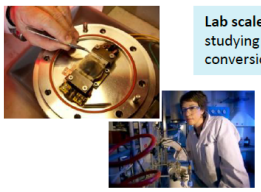
Gasification behaviour data under relevant gasification conditions

Entrained flow reactor for studies of fuel gasification behaviour at high temperatures and pressures.

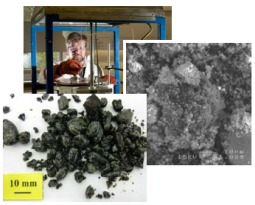


Fixed bed biomass gasifier for studying gasification characteristics of wood and other biomass wastes

Supporting experiments allowing detailed interrogation of the gasification process



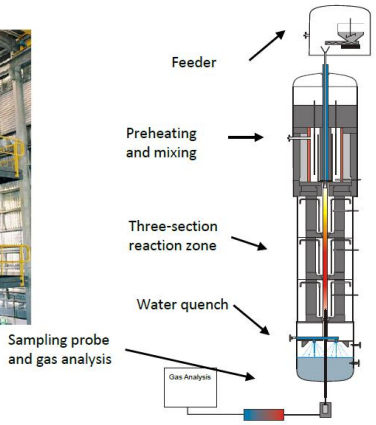
Lab scale facilities for studying feedstock conversion behaviour



Characterisation of inorganic species to troubleshoot gasifier operation and manage disposal or reuse of residues

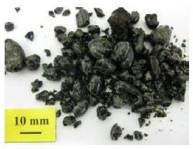
High Pressure Entrained Flow Reactor (PEFR)

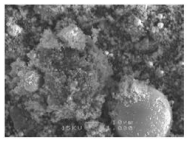
- Entrained-flow reactor
- Capable of 20 bar pressure, 1500°C wall temperature
- Coal feed rate of 1-5 kg/hr
- Gas mixtures of O_2, CO_2, H_2O and N_2
- Adjustable sampling probe - char and gas samples collected at different residence times (0.5-3s)

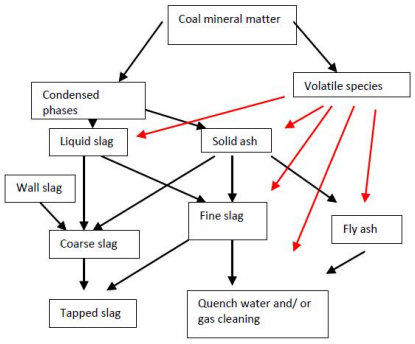


Mineral Matter in Gasification

Slag viscosity, trace elements, and their impacts







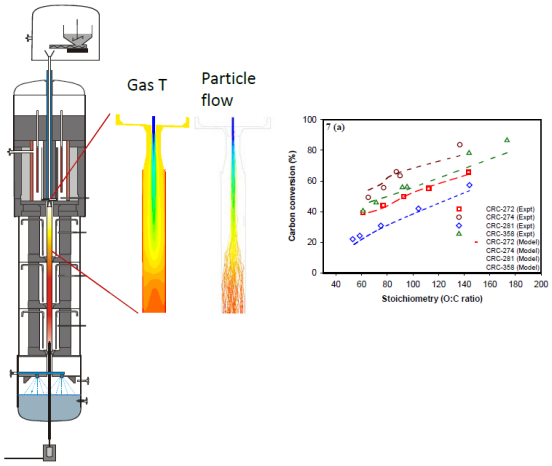
Volatile species (in syngas):

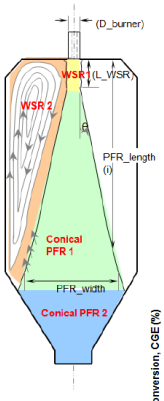
- requirements for syngas cleaning

Condensed phases (slag, fly ash):

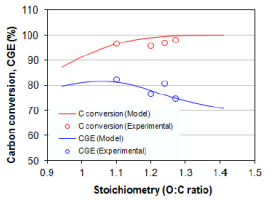
- Syngas cleaning
- Operational: slag viscosity
- Utilisation/handling of waste
- Physical & chemical properties: trace elements, leaching

Gasification modelling





Application to real gasifiers using simplified flow models supported by detailed and accurate fundamental models.



Biomass and waste gasification

New facility for studying gasification behaviour of biomass

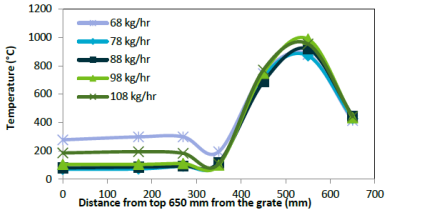
- Designed for forestry waste
- Well-suited for green waste

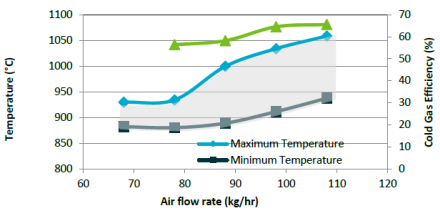
Research gasifier

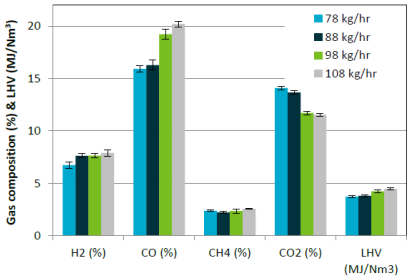
- Can be integrated with gas-to-liquid test facilities
- Can be integrated with a 25kW microturbine for power generation

Gasifier operation

Top air	Primary air	Secondary air	Total air (kg/hr)
0	39	29	68
0	44	34	78
0	48	40	88
0	53	45	98
0	58	50	108



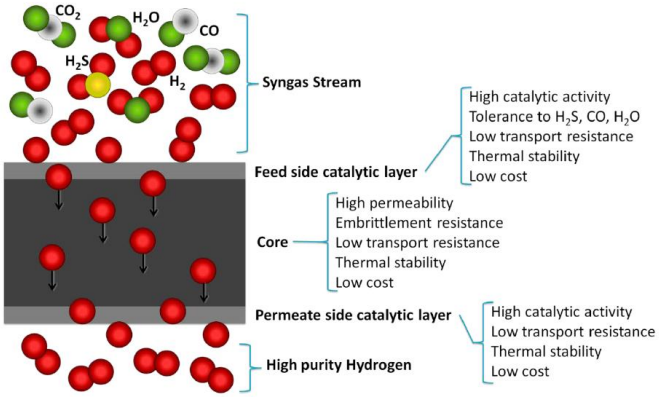




Metal membranes and membrane reactors

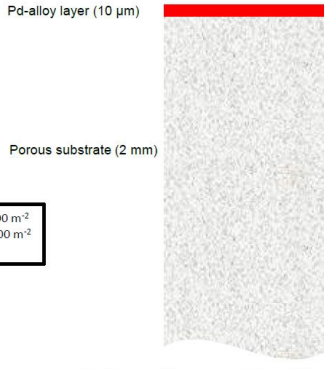
Metal membranes

Separation of H_2 from gasification, reforming or ammonia-derived mixed gas streams



Supported Pd membrane

- Pd layer provides gas-tightness and H_2 separation
- Porous substrate provides strength

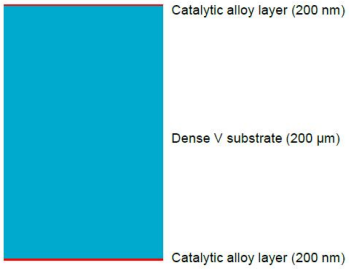


Pd in outer layer: USD 2400 m^{-2}
Porous substrate: USD 5000 m^{-2}
plus manufacturing costs

Must be >>10 µm to meet ISO14687

Layered V membrane

- Pd layer provides H_2 separation
- V provides gas-tightness and strength

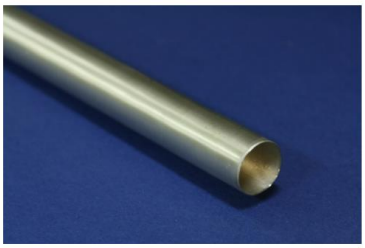


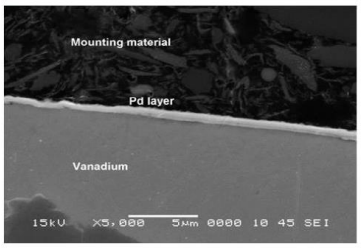
100% H_2 purity

V in substrate: USD 180 m^{-2}
Catalytic layers: USD 100 m^{-2}
plus manufacturing costs

Layered V-based membranes

- Embrittlement-resistant V-based alloy tube (patent pending)
- 9.5 mm (3/8") OD
- Catalytic surface coatings
- 300-350°C
- Very low cost (< $2000/m^2 plus vessel), much cheaper than competing Pd-based membranes
- 100% pure H_2 (fuel cell compatible)





Industrial trials: Gas Reforming

Coregas plant at Port Kembla

BLUESCOPE

NATA

Issued: 6th April, 2016
Page 1 of 1

Reference No.: P00740-16

Coregas
Cryogenic Plant
c/o Bluescope Steel Limited
Five Islands Rd
Port Kembla NSW 2505
Joe Bongiolatti
Phone: (02) 4275 7250
Fax: (02) 4275 7283
Charged to: 931442

For enquiries please contact:
Nina Oosthuizen
(02) 4275 3410

CERTIFICATE OF ANALYSIS

Hydrogen Purity ex CSIRO Trial Hydrogen Plant

This certificate has been issued without any alterations or corrections and shall not be reproduced except in full.
The following samples collected by the laboratory have been analysed with the following results.

Laboratory Number:	16-018318
Date of Sampling:	16/03/2016
Sample Identification:	CSIRO Trial Plant 90:30 am
	Hydrogen Product
Acetylene (ppm)	<0.020
Carbon Dioxide (ppm)	5
Ethane (ppm)	0.01
Ethylene (ppm)	<0.01
Propane (ppm)	<0.01

Report Comments:
Note: Sampling not covered by Scope of Accreditation

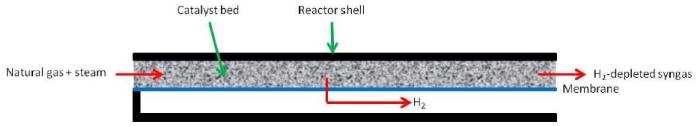
Analysis Methods Used:
MA-LABS-AC-109:5104

Lignite gasification trials, 2015

- Assessment of membrane performance for IGCC-CCS at EERC, Grand Forks ND
- Lignite-derived syngas
- 30 bar, 350°C
- US DOE program

Solar reforming, 2015

- Low temperature membrane reformer for solar-assisted H_2 production
- High methane conversion at 20 bar, 550°C (*c.f.* 800°C)
- In situ H_2 extraction (no downstream separation required
- Solar-thermal integration
- Partnership with ARENA



$$CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2$$

Carbon dioxide storage

Lincoln Paterson | CSIRO Fellow
24 October 2016

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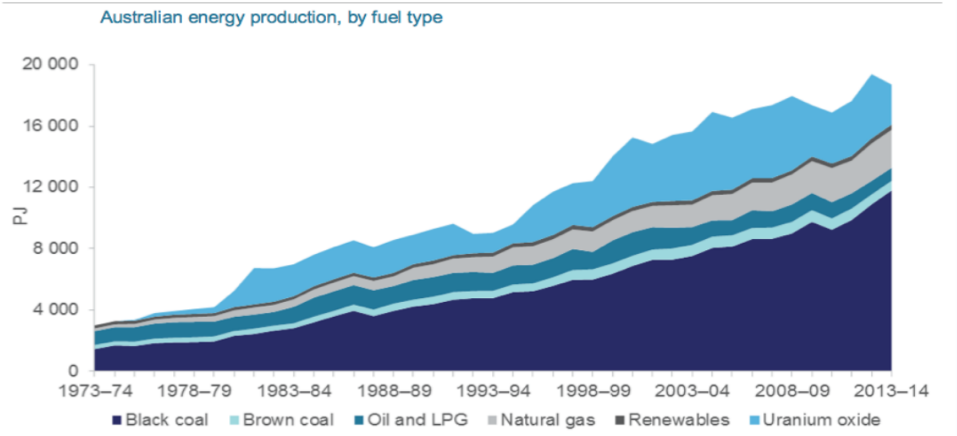
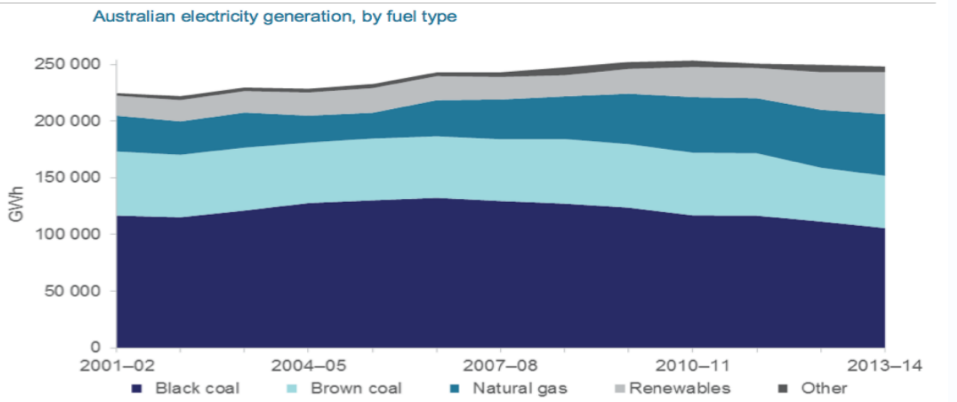
Australian energy production



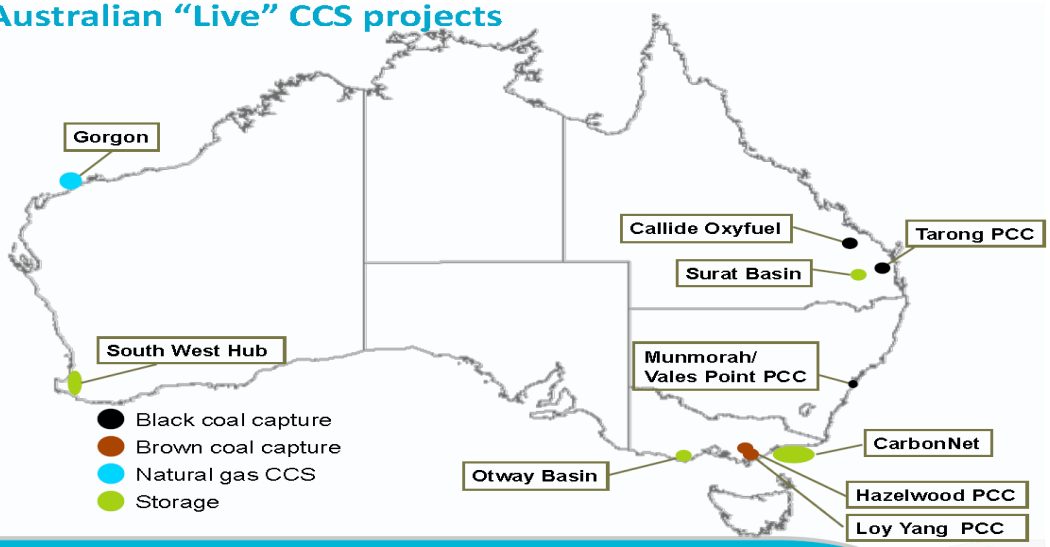
Source: Department of Industry and Science (2015) *Australian Energy Statistics*, Table J.

Australian electricity generation



Source: Department of Industry and Science (2015) *Australian Energy Statistics*, Table O.

Australian "Live" CCS projects

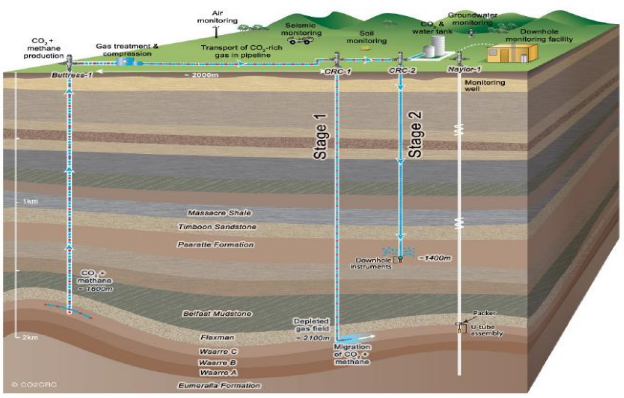


Carbon dioxide storage

- CSIRO is currently working on:
  - Supporting the evaluation of Australian storage sites (especially the SW Hub, CarbonNet, and Surat Basin sites).
  - Modelling the injection of injected CO_2 plumes.
  - Devising and applying methods to monitor the injected CO_2 to ensure it remains safe and secure.
  - Examining movement of groundwater in the vicinity of potential storage sites.
  - Engaging in international collaboration on CO_2 storage.

- CSIRO is a core research participant in the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) and the National Geosequestration Laboratory (NGL).

CO2CRC Otway Project



CO2CRC

CO2CRC Otway Project

Carbon dioxide storage | Lincoln Paterson

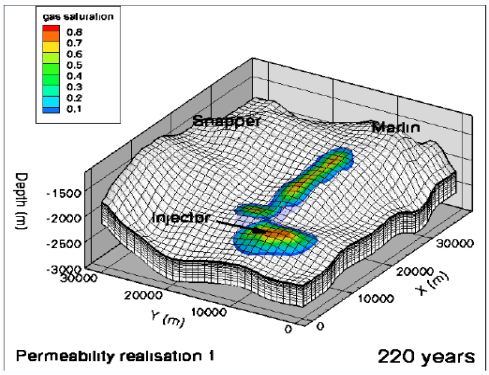
Example of a CO_2 well

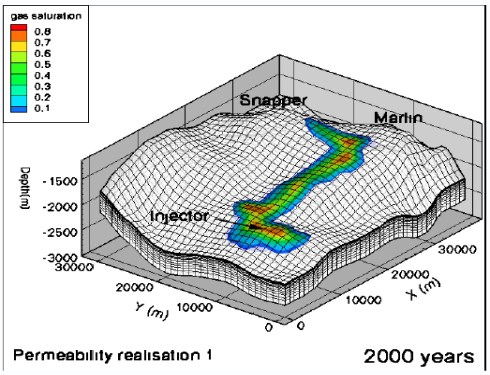
Carbon dioxide storage | Lincoln Paterson

Enhanced coal seam gas recovery with CO_2 at Liulin

Carbon dioxide storage | Lincoln Paterson

Reservoir simulation of injected CO_2

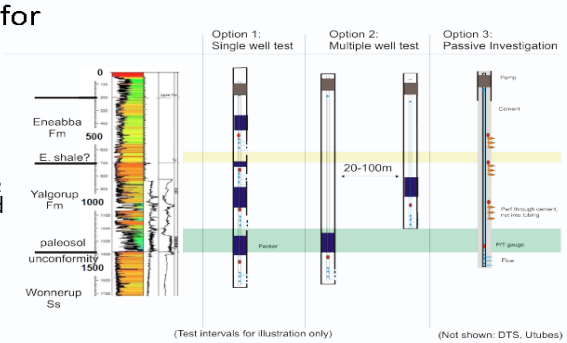




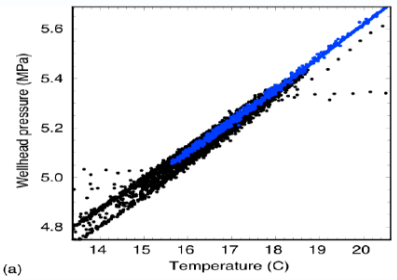
Designing CO_2 wells

Developing recommendations for well location, testing and instrumentation options for:

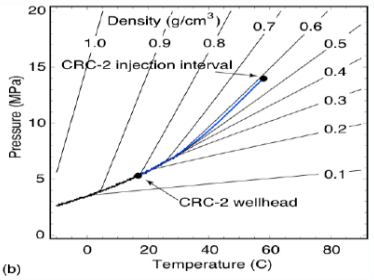
- Risk reduction and site characterisation, to define the CO_2 storage complex (containment and reservoir).
- Research and middle to long-term monitoring (e.g. deploy new instruments, implement new testing program, implement new injection techniques).



Wellbore conditions

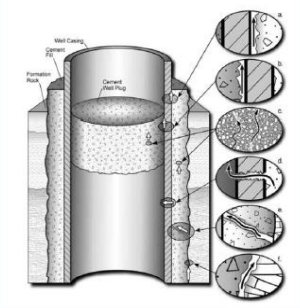


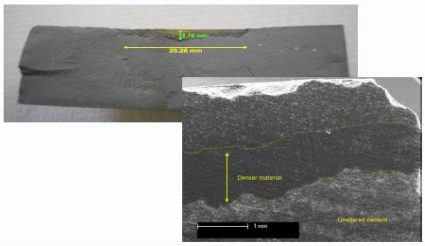
Wellhead (surface) conditions



Pressure and temperature in a CO_2 well

Integrity of wellbore cement



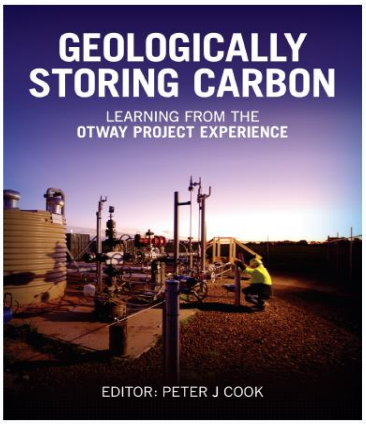


Cement degradation

Cement (portlandite) → Calcium Carbonate → Amorphous silica gel

- Laboratory experiments of cement degradation
- Reactive geochemistry simulations
- Predictions of well cement degradation under reservoir conditions

Otway project experience book



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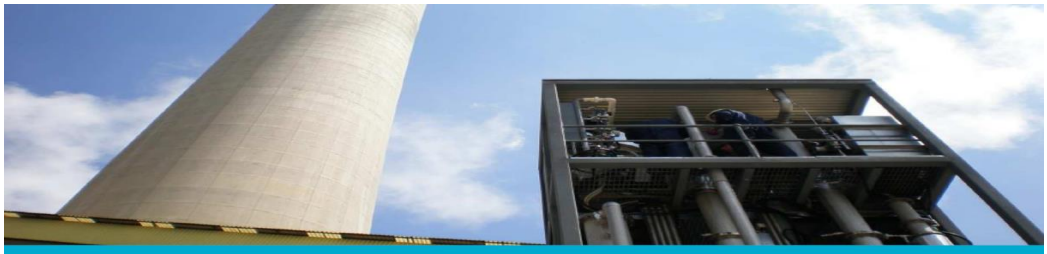

An overview of Emissions Management and CO_2 Capture research at CSIRO

Ashleigh Cousins

24 October 2016

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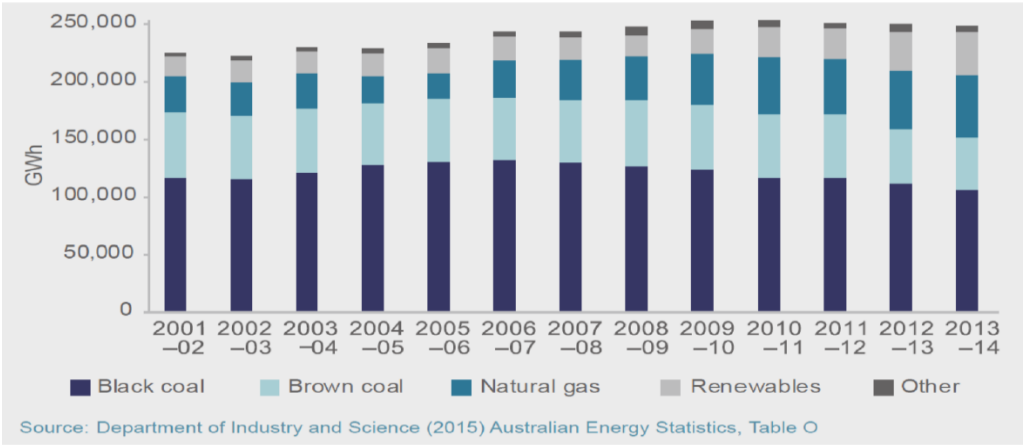
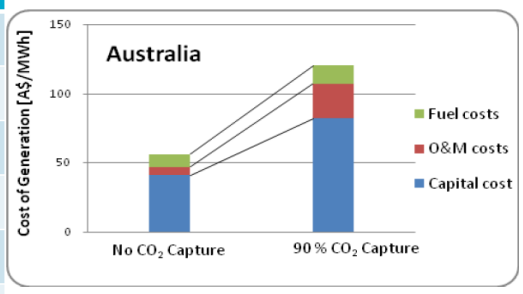
Electricity production in Australia



Source: Department of Industry and Science (2015) Australian Energy Statistics, Table O

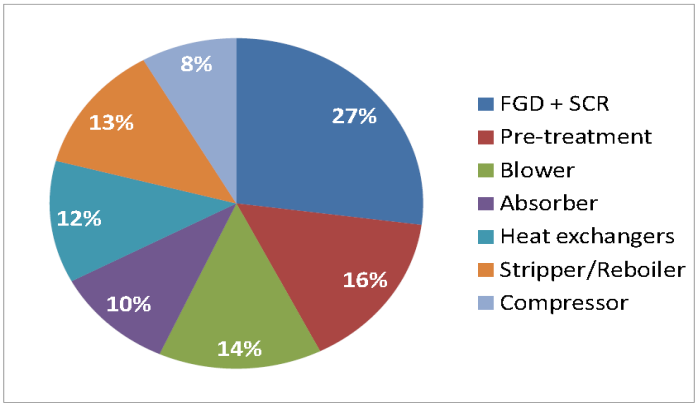
Australian coal fired power stations

	Black coal	Brown coal
Average efficiency [% HHV]	35.6	25.7
CO_2 emission [tonne/MWh]	0.9	1.3
SO_2 concentration [g/m^3]	0.5 – 1.7	0.2 – 0.7
NO_x concentration [g/m^3]	0.4 – 1.5	0.2 – 0.4
Particulate matter [mg/m^3]	10 – 100	10 – 60
Flue gas temperature [°C]	120	180

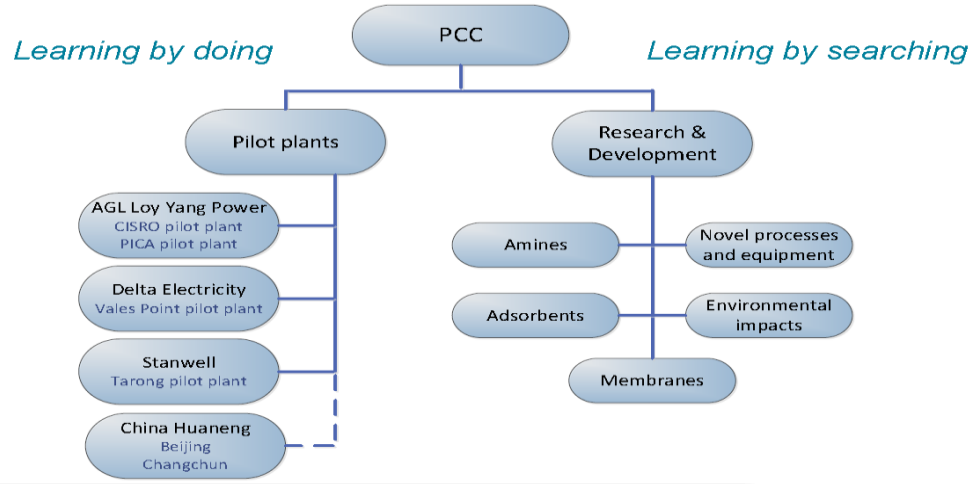


Data derived from CCSD – technology assessment report 62

PCC equipment costs overview

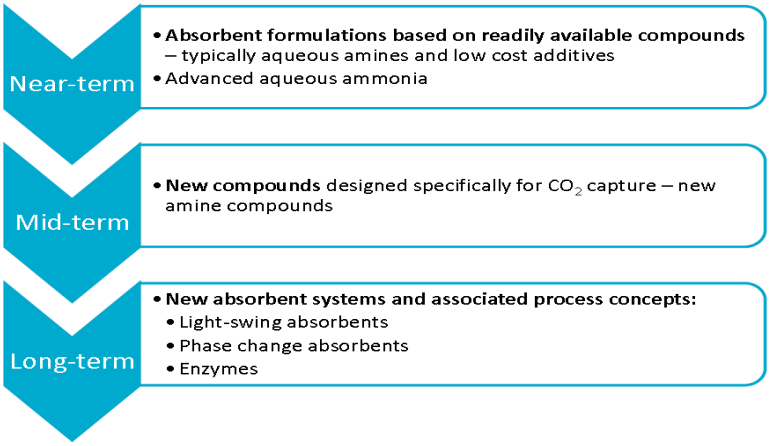


CSIRO's PCC program



CSIRO's chemical absorbent research program

Graeme Puxty



Rotating liquid sheet contactor

Leigh Wardhaugh

Basic principles

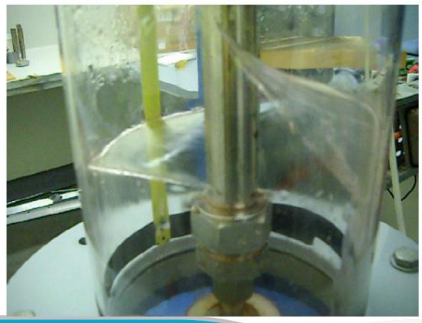
- Surface area of stabilized liquid sheet greater than that resulting droplets
- Rotating liquid surface proven experimentally to pump gas
- Centrifugal + liquid pumping force creates interfacial area

Advantages

- Higher gas velocities possible
- Liquid entrainment significantly reduced
- Suitable for viscous solvents

Challenges

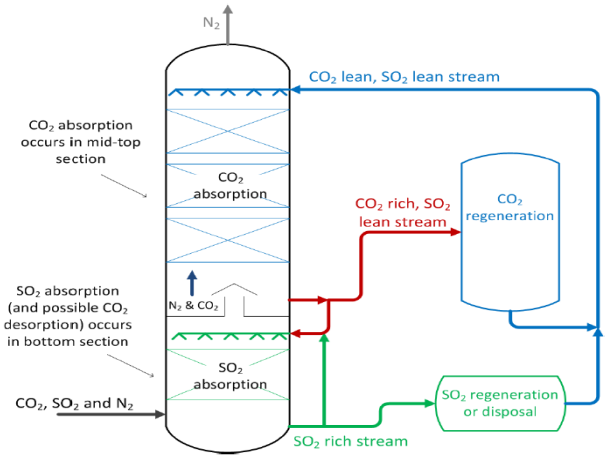
- Scale-up to commercial scale
- Liquid residence time low

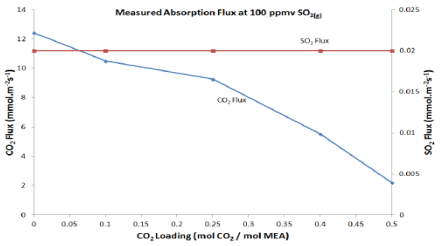


Wardhaugh et al, Greenhouse Gas Sci Technol. 5:198–209 (2015)

Integrated single stream SO_2 and CO_2 capture

Ashleigh Cousins





Beyad et al., International Journal of Greenhouse Gas Control 31 (2014) 205–213

Puxty et al. 2012, WO2012_097406

Aqueous ammonia

Hai Yu

- Indestructible liquid absorbent
- Chemical well-known to electricity industry
- Suited for "contaminated" feed gases
- Fertiliser by-product
- Product CO_2 at elevated pressure
- Technical feasibility demonstrated in pilot plant but no cost advantage
- Addressing challenges:
  - Mass transfer promotion, temperature increase
  - Vapour suppressors
  - Further integration of pretreatment and water wash
  - Process design

Li et al., Environ. Sci. Technol. 2015, 49, 10243−10252

Solid sorbent CO_2 capture unit at Vales Point

Ramesh Thiruvenkatachari

- **Objective**
  - Evaluate the stability of honeycomb CF composite monolithic adsorbents using the real flue gas
  - Understand the effect of real flue gas characteristics on the operation and performance of the CO_2 capture unit

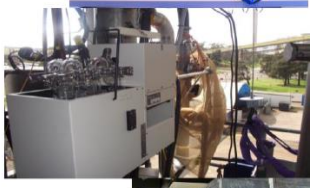
- **Results**
  - Excellent stability to real flue gas over 200 experiments
  - CO_2 adsorption efficiency consistently over 98%
  - CO_2 desorption efficiency between 90-95%
  - Near complete removal of SO_2 and NO_x
  - Could be pretreatment unit for amine based PCC

Thiruvenkatachari et al. IJGGC 42 (2015) 415–423

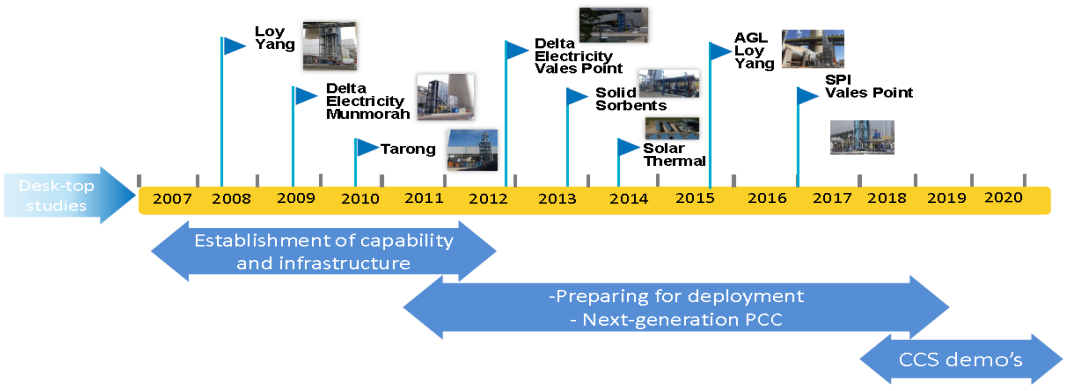
Emission issues addressed via integrated approach

Merched Azzi

1. **Formation of potentially harmful components**
   - Absorbent degradation in absorber
   - Absorbent degradation in desorber
2. **Emission analysis**
   - Estimation of concentrations using process models
   - Actual measurements in pilot plants
3. **Dispersion**
   - Smog chamber to investigate atmospheric degradation
   - Updating dispersion models with atmospheric chemistry



Piloting PCC Technologies in Australia



Pilot plant summary

Aaron Cottrell

Plant	Loy Yang	Vales Point	Tarong	PICA
Solvent	Amine	Ammonia/ Amine	Amine	Amine
Flue gas source	Brown coal	Black coal	Black coal	Brown coal
Scale	50 kg/hr CO_2	300 kg/hr CO_2	100 kg/hr CO_2	50 kg/hr CO_2
Focus	Solvent benchmarking	Ammonia operation	Process optimisation	Duration evaluation
Other activities	Emission study Combined CO_2/SO_2 capture	Pressurised absorption Solar thermal integration	Pressurised stripping Corrosion Degradation	

Solar thermal energy for absorbent regeneration

James McGregor

- Avoiding interface with existing steam cycle
- More effective in terms of CO_2-emission reduction
- Introduction of flexibility into the capture process

Pilot plant at Vales Point power station

- Integrated with existing PCC pilot plant
- 65 kW_{th} solar array

http://arena.gov.au/files/2015/08/3-A006-Final-Report-and-Lessons-Learnt.pdf

PICA project

Aaron Cottrell

PCC
IHI
CSIRO
AGL

Project aims:

- 40% lower cost compared to the MEA base case
  - Advanced packing materials, liquid absorbent and process
- Long-term performance evaluation both IHI Corporation and CSIRO developed technologies
- Supporting large-scale CCS as an affordable, secure and environmentally benign option for power generation

http://www.csiro.au/en/News/News-releases/2016/PICA-powers-up-to-improve-CO2-capture

Process Development Facility

Dan Maher

- Located at Newcastle Energy Technology Labs
- Scale between Lab bench scale and Pilot scale
- Modular design
- Flexible operation
- Ventilated & bunded space
- "Controlled" environment

Outlook for PCC in Australia – Next steps

- Qualification of new liquid absorbents towards deployment
  - Formulations and designer amines
  - Optimisation of process design
- Development of SO_2/CO_2 process concept
- Focus on process and equipment innovation
- Solar thermal integration demonstration
- Continued efforts in next-gen technologies
  - Adsorbents, membranes
  - Advanced liquid absorbent systems