
The site of the Callide Oxyfuel Project – Callide A Power Station in central Queensland, Australia.

Callide Oxyfuel Project (COP)

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28 & 29 October (Wuhan China)

Callide Oxyfuel Project

Presentation Overview

- Project background and history
- Project objectives and project description
- Project achievements and learnings
- Final steps

Callide
OxyFuel Project

Callide Oxyfuel Project

Callide Oxyfuel Boiler (add-on)

Oxygen plant and CO_2 capture plant

Callide Oxyfuel Project

Australian Energy Policy

- The Callide Oxyfuel Project was formulated under the Commonwealth Energy White Paper in 2004 – the aim was to support low emissions technologies
- In 2014 the Commonwealth launched its Direct Action Plan committing some $2.55 billion over 4 years through the Carbon Emissions Reduction Fund to support a GHG emissions reductions target of 5% below Yr 2000 levels, by Yr 2020
- The Commonwealth has proposed a further target for the Conference of Parties (COP21) in Paris from the end of November 2015, of 26 – 28% reduction in GHG emissions below Yr 2005 levels, by Yr 2030
- Australia's Yr 2005 baseline is 612 MT CO2-e (all sources)

Emissions Reduction Fund

The Emissions Reduction Fund is the centrepiece of the Australian Government's policy suite to reduce emissions.

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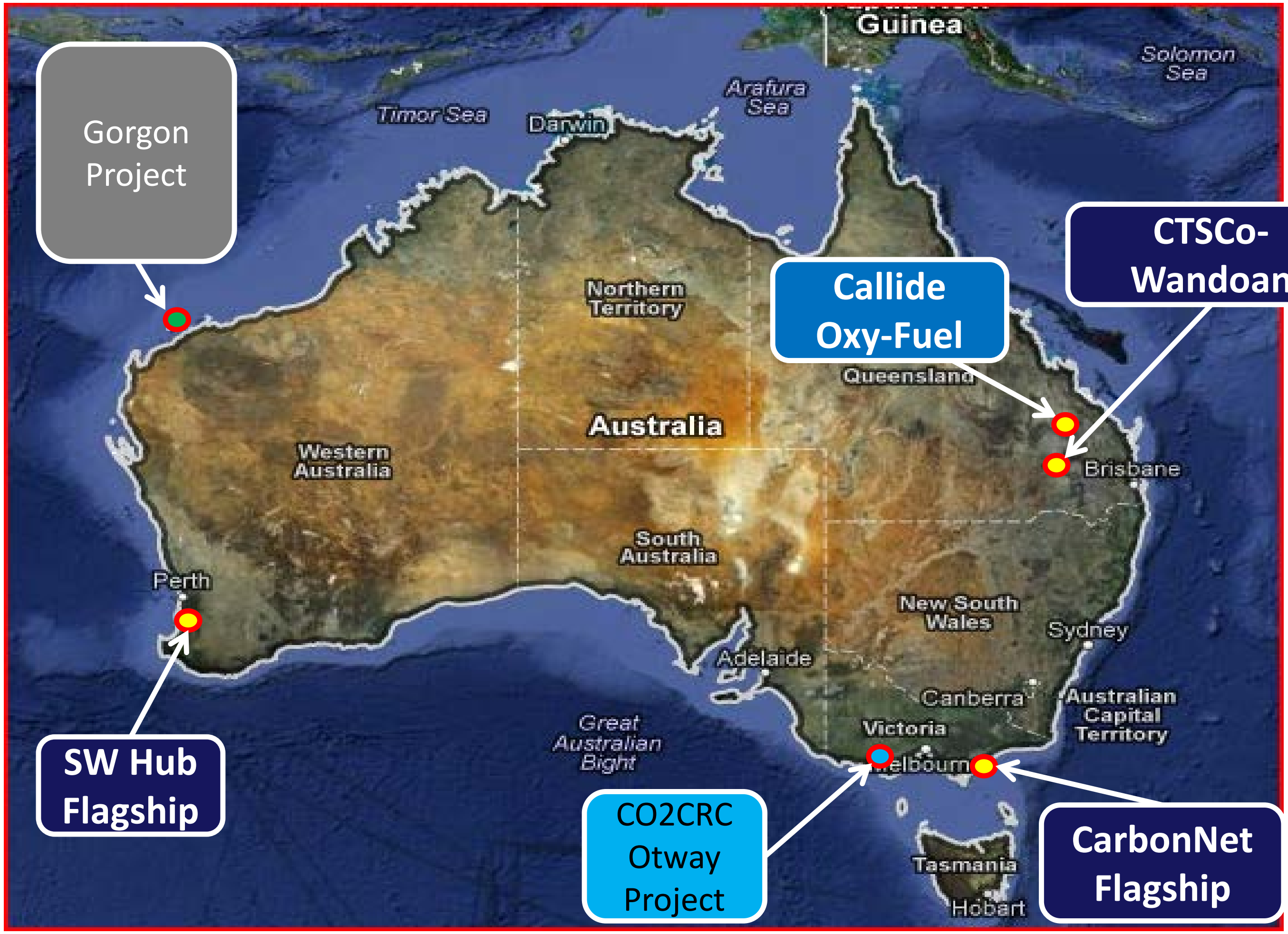
Active CCS Projects in Australia



Courtesy - ANLEC

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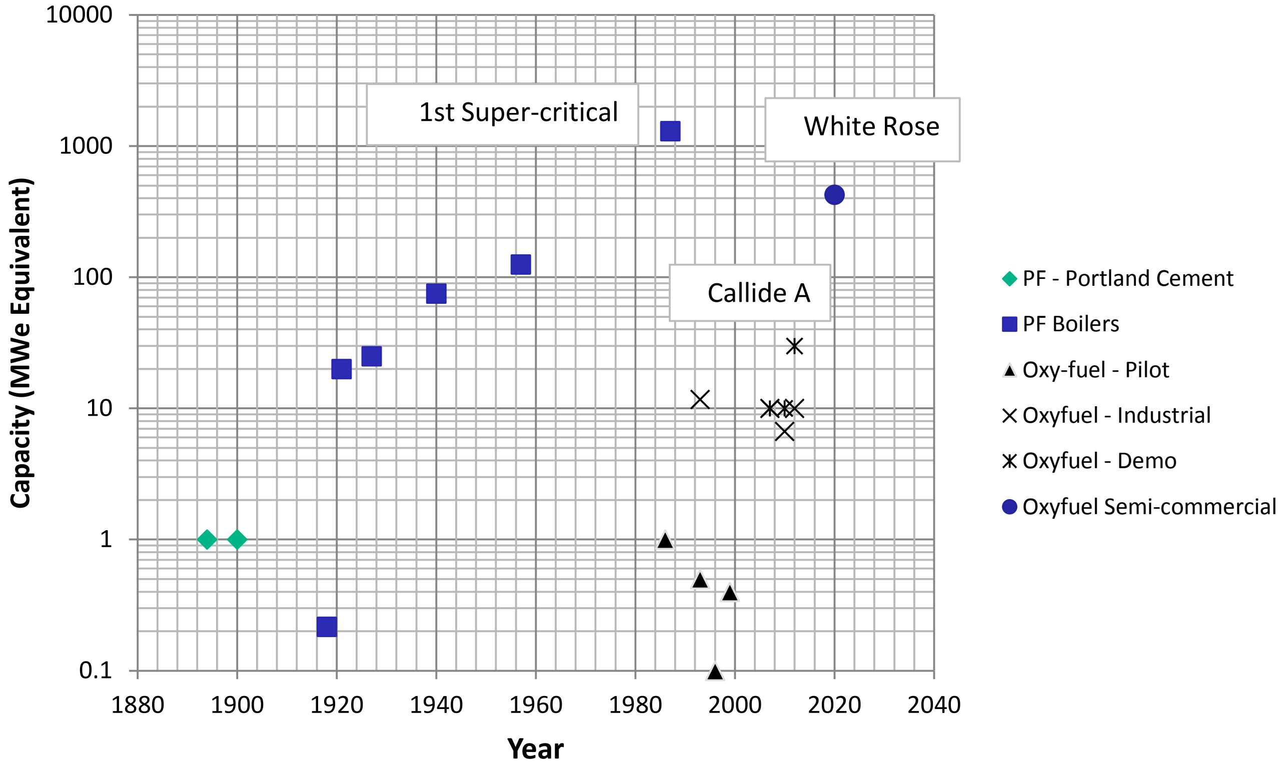
Development of Oxyfuel technology



Callide Oxyfuel Project

Project History

- Project idea –September 2003
- COAL 21 (Australian) Road Map – March 2004
- Japan-Australia Oxyfuel MOU and Feasibility Study – September 2004 to April 2006
- Commonwealth Low Emission Technology Development Fund and COAL21 Fund – October 2006
- FEED study conclusion and Financial Investment Decision – March 2008
- Oxyfuel boiler operational June 2012
- CO_2 capture Plant operational December 2012
- Operations concluded March 2015

Project Goals & Objectives

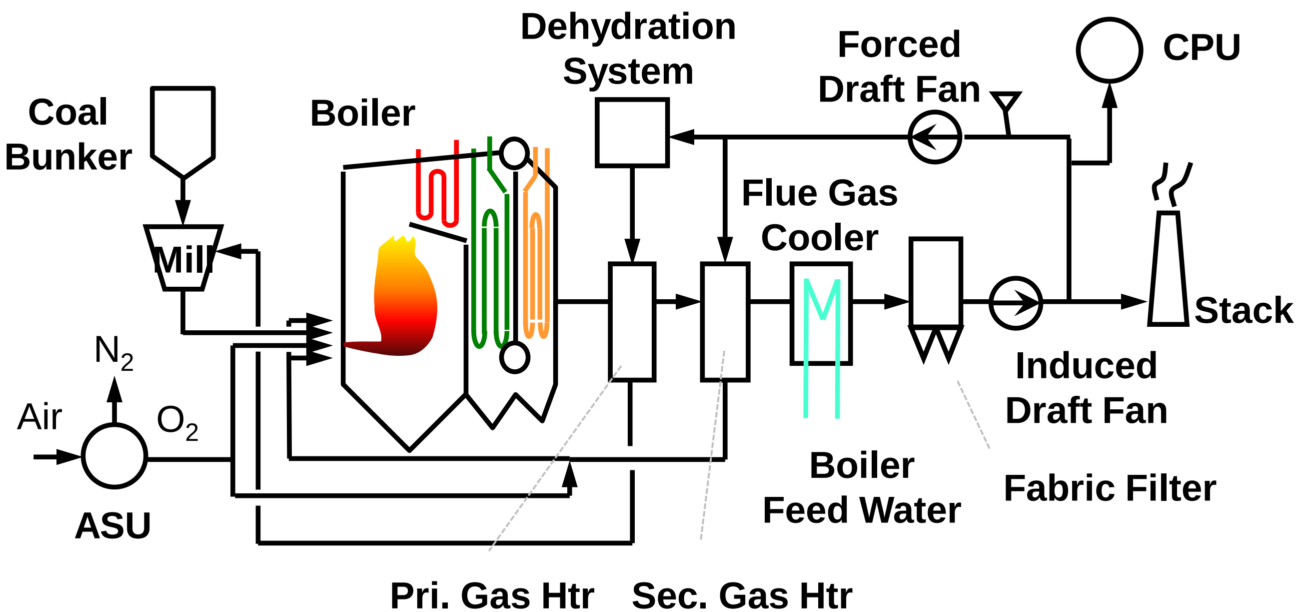
Overarching goals:

- Maintaining industry competitiveness and coal-based asset value
- Care for the environment
- Providing a framework for decision makers (especially Government) about which technology paths to pursue

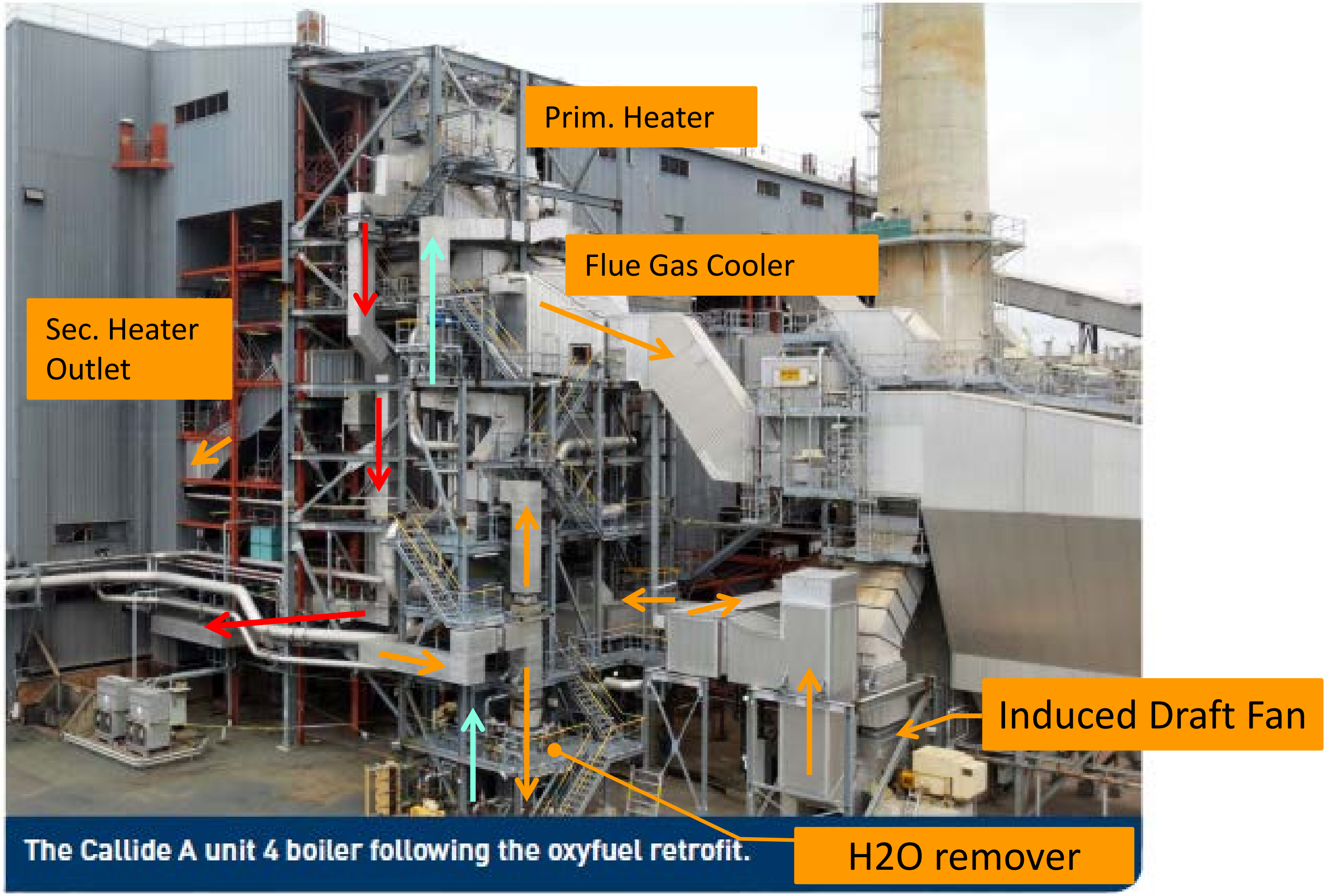
Project scope & objectives:

- Demonstrate oxy-combustion boiler, CO_2 capture and near zero emissions of NOx, SOx, Mercury and other heavy metals
- O&M data to under-pin commercial development
- Support CO_2 storage trials and demonstrations

Callide A Oxy-fuel boiler



COP - Boiler works



The Callide A unit 4 boiler following the oxyfuel retrofit.

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COP – Air-mode/Oxy-mode comparison

	Air-Mode (General)	Oxy-Mode (General)
O_2 required (kg/h)	32,000	32,000
Net flue gas (kg/h, wet)	169,300 (to Stack)	52,100 (to Stack + CPU)
Flue gas CO_2 (mol. %, dry)	15	70
Net flue gas CO_2 (kg/h, wet)	35,400	35,400

Actual data					
Flue Gas Composition		**Air-Firing mode**	**O2 Sequence**	**RFG Mode**	**Oxy-mode**
O2	vol %, dry	4.5	6.0	6.8	5.4
CO2	vol %, dry	15.0	16.2	59.9	72.2
CO	ppm, dry	20	20	12	12
SO2	ppm, dry	220	230	800	890
NO	ppm, dry	550	720	1195	965
NO2	ppm, dry	9	10	45	46
H2O	vol %	8	8.5	20.5	21.6
NOx	ppm, dry @ 7% O2	474	681	1223	907
NOx	ppm, dry @ 12% CO2	447	541	248	168
Flue Gas to Stack	kg/s (wet)	54	59	15.4	14.0
	Nm3/s (dry)	40.9	40.6		
NOx	**g/s**	**43**	**61**	**21**	**15**

Air-firing mode means normal air firing

O2 sequence means increased O2 to the boiler via O2 injection nozzles but no recirculation of flue gas

RFG mode means that the recirculated flue gas sequence has been completed

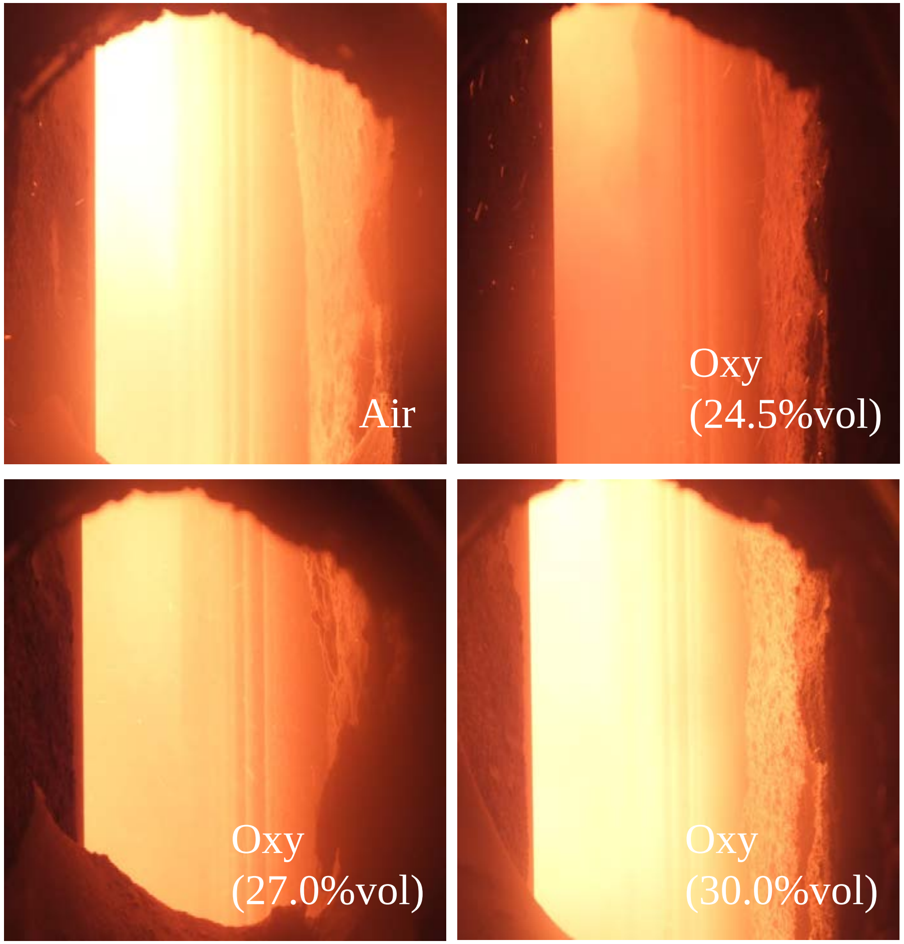
Oxy-mode means that on completion of the RFG sequence the overall O2 is reduced to normal levels and full oxy-mode is achieved

Oxyfuel boiler performance

1. Optimisation of mode transition Air → Oxy, Oxy → Air, stable Oxy-mode operation
2. Trials completed with a range of bituminous coals and semi-anthracite/Callide blend

   Fuel Ratio (Fixed Carbon/Volatile Matter) ranging from 1.8 to 2.8
3. Combustion Efficiency: 50 – 60% decrease in unburnt Carbon
4. NOx emissions: typically a 60% reduction in specific emission rate. E.g. for Callide coal, reduction from ~ 4.7 g NOx/kWh down to ~ 2 g NOx/kWh

   Note within the CPU, the 2 gNOx/kWh is reduced down to < 5 mg/kWh equivalent.
5. Particulates: slight reduction Air (0.3 – 0.375 mg/kWh) →Oxy (0.25 – 0.34 mg/kWh)



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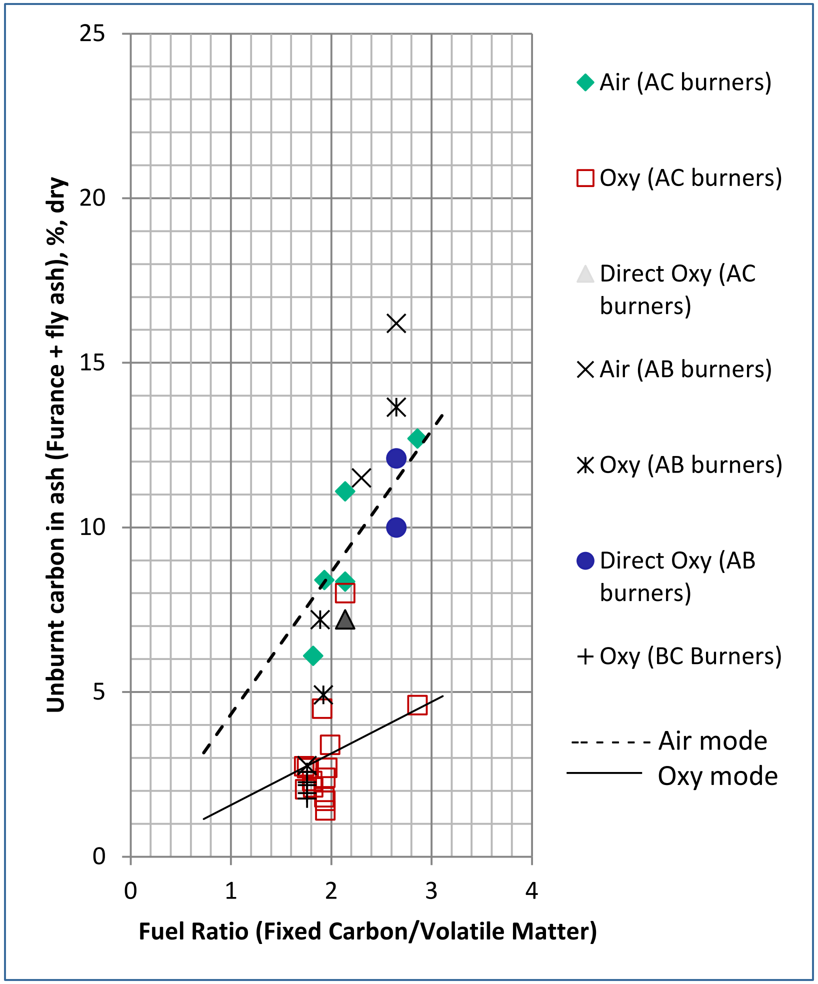
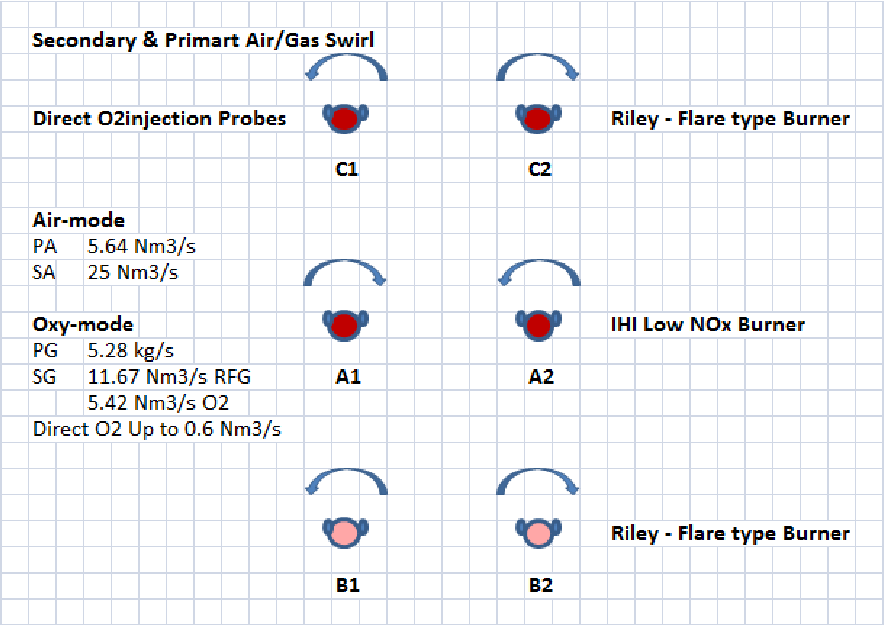
Combustion





- Significant improvement in combustion efficiency in OF mode with test burners including low NOx burners
- Residence time in Boiler OF/AF ~ 1.3
- Injection of direct O_2 (up to 10% of requirement) slightly improves combustion efficiency but also increases flame temperature and reduces flame length with some impact of furnace heat adsorption.

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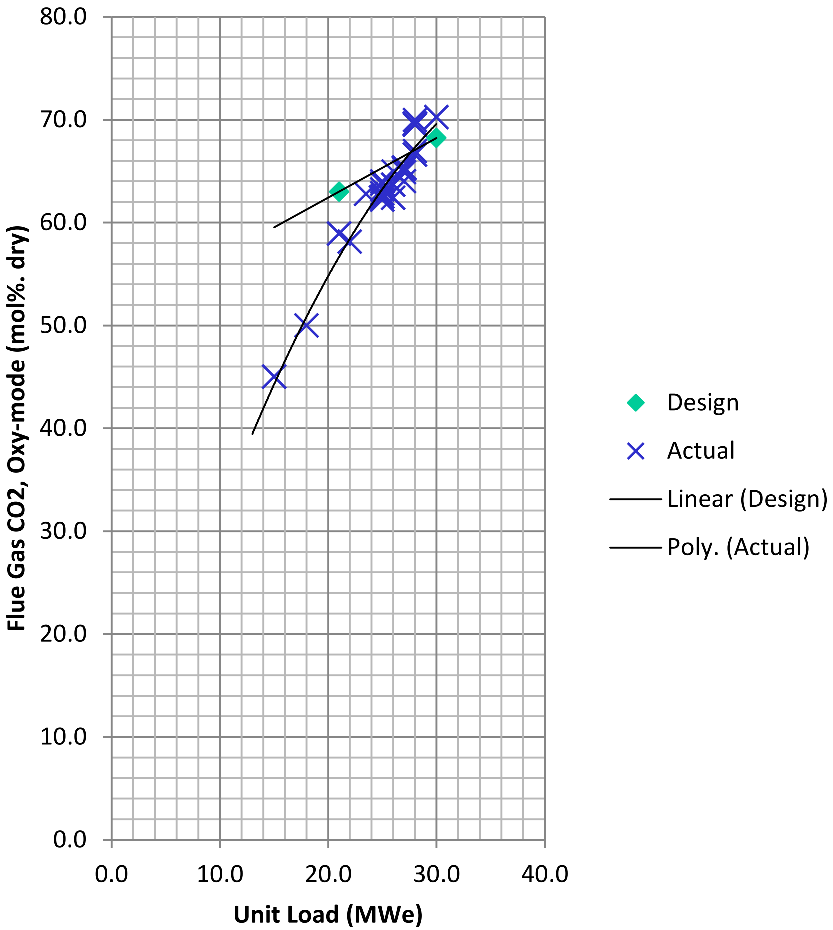
Callide A Oxy-fuel flue gas quality

- Boiler inlet O_2 range 24% to 30%
- Boiler exit O_2 range 2.0 to 3.5 vol% (wet) at 28-30 MWe
- Boiler exit O_2 on average is a little higher than set point
- Boiler exit O_2 increased with decreasing load (as usual)
- Overall air ingress design rate was 6 mass %
- Max CO_2 achieved ~ 71 mol % (dry), limited by 98% purity O_2, higher actual boiler exit O_2 than set point, small level of air ingress through ID and GRF fan seals, air used to pulse fabric filters
- Minimum turndown achieved in oxy-mode was 50% (15 MWe) yielding a CPU feed gas of 45 % CO_2 (dry basis)



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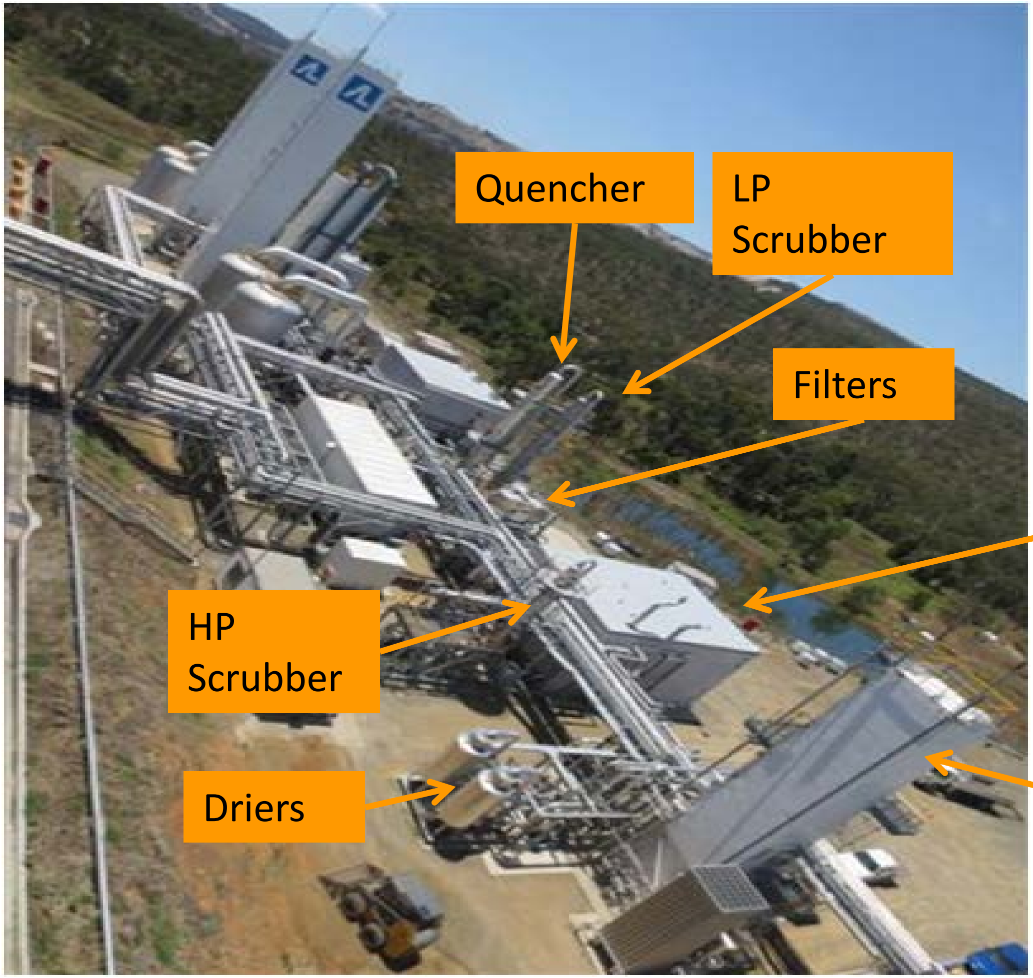
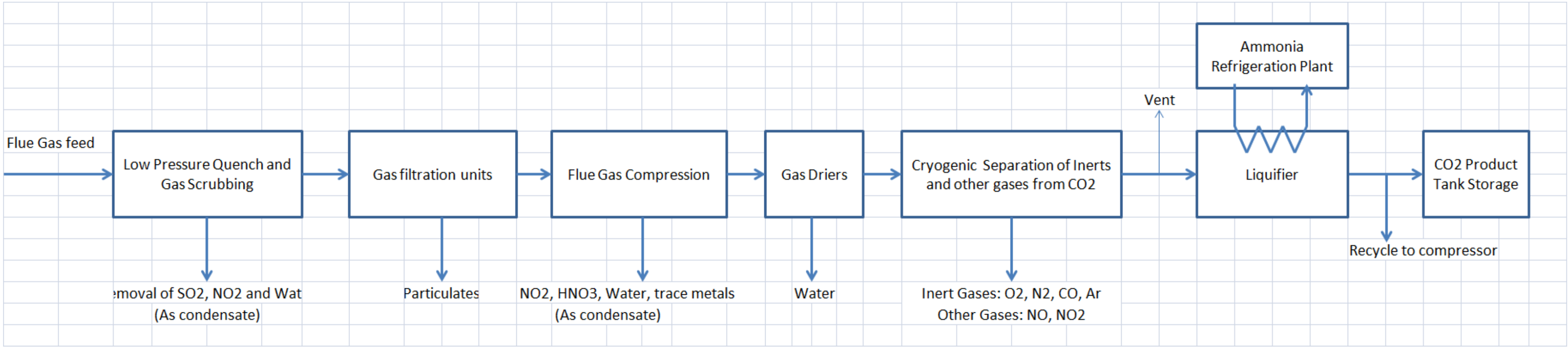
ASU & CO_2 capture plant



CO_2 Capture Plant



- Callide A Feed CO2 is only 68 – 70 (mol%, dry) at boiler loads.
- CPU consists of Low Pressure flue gas pretreatment + High Pressure CO_2, NOx and inerts separation
- Overall design capacity is 75 t CO_2/day under optimised conditions
- The main purpose of the CPU demonstration was to evaluate centrifugal flue gas compression and the capture rate achievable in the Coldbox.
- Capture rate (Coldbox only) was generally around 85%, as expected under normal conditions.
- Product was 99.99% CO_2 (with 5 – 15 ppm NO_2).
- The next development for the cryogenic distillation method is based on Feed CO2 of > 85%, which avoids CO2 recycle for adequate cold production, and membrane separation of CO_2 from the Coldbox vents and recycle to the compressor train; to achieve global CO_2 capture rates > 90%.

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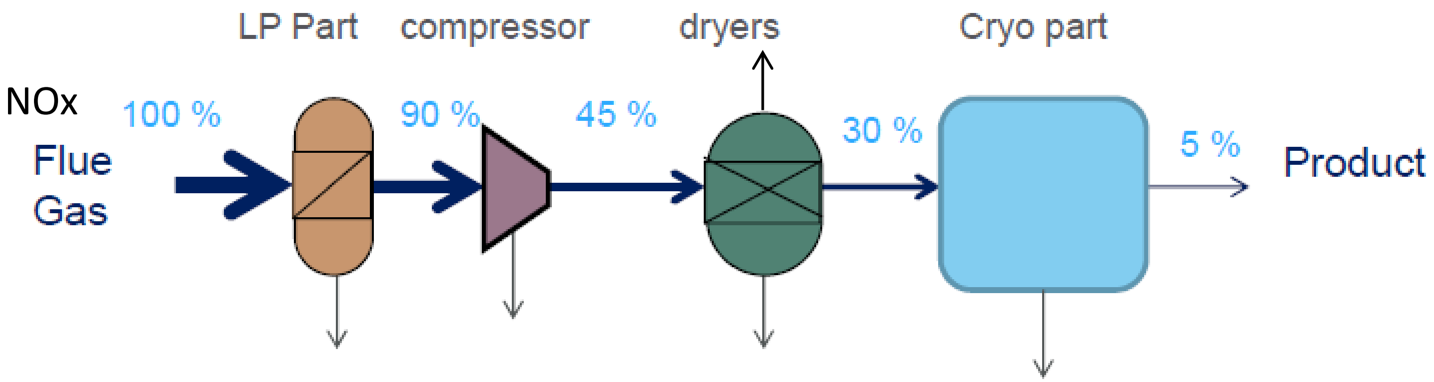
CPU – Environmental performance

- Low pressure scrubbers utilise a caustic soda wash to remove SO_2 from the gas stream (< 10 ppm in gas phase).
- Nitrous Oxide (NO) passes through the LP scrubbers but is largely converted to NO_2 and then Nitric Acid (as condensate) during flue gas compression.
- Downstream, the balance of the NO_2 is removed in the coldbox as vapour (NO_2 and HNO_3).



- Trace elements in the gas phase are also effectively extracted from the gas phase in the Low Pressure section of the CPU.
- The net result is near zero emissions to atmosphere.

Courtesy Air Liquide

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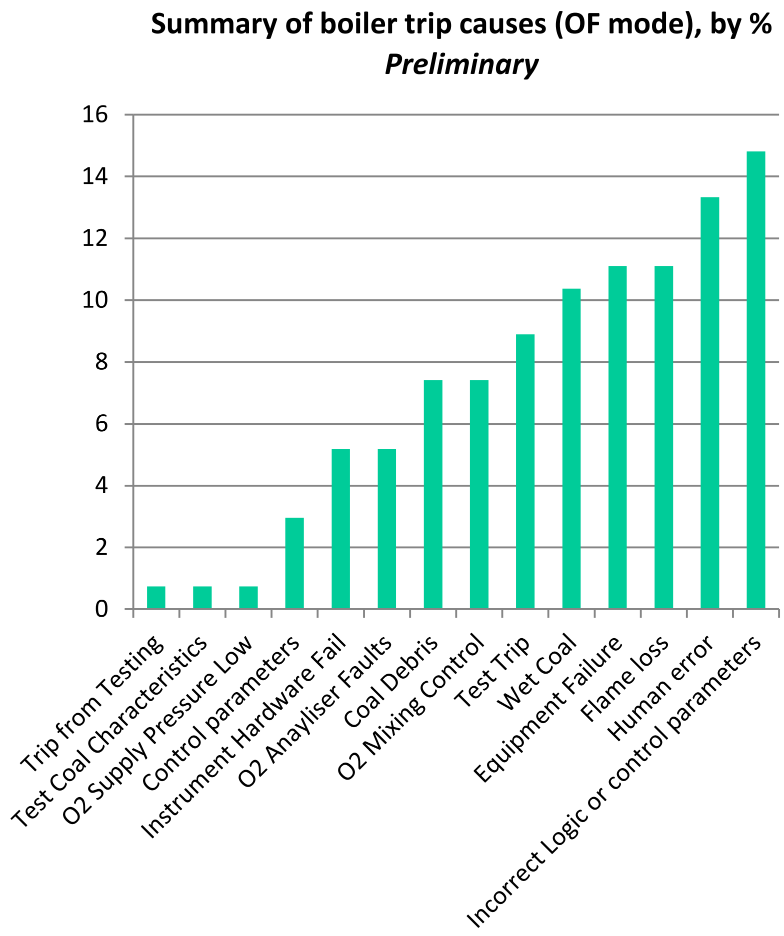
Oxy-fuel and CPU plant – reliability assessment

- Graph shows causes of boiler trips in oxy-mode (% out of 100).
- Boiler originally designed for HHV 20 MJ/kg (16% Ash); actual coal burned was 17 – 18.5 MJ/kg (24 – 27% ash).
  - ➢ *This had a significant impact on reliability, especially in oxy-mode*
- Other causes associated with oxy-firing mode were certain equipment failures, human error, O_2 flow control issues and incorrect logic.
- Logic issues significantly resolved during the 3 year demonstration phase
- In addition, overall reliability of the boiler in oxyfuel mode improved significantly with experience.
- CO_2 capture plant reliability was very high; the main issues were failure of Liquid CO_2 pumps and faults with valves and actuators of the CPU Drier skid.



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Key demonstration items achieved

- Excellent Safety and Environmental performance
- 14,800 Generation hours
- 10,200 hours of actual oxy-firing operation
- 5,600 hours of CO_2 capture plant operation
- Demonstrated boiler turn-down to 50% Load Factor
- Demonstrated > 95% capture of SOx, NOx, particulates and trace metals
- Demonstrated high purity of CO_2 product (> 99.9%)
- Over 4,000 visitors to site, including some 280 international visitors to date

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Callide Oxyfuel Project (COP)/CO2CRC – CO2 Injection Test

- Injection test conducted to assess the geochemical effect of CO_2 in the reservoir.
- Collaboration between COP and the CO2CRC.
- Test location: Nirranda South (Otway Basin) Victoria
- Injection ~ 1400 m into Paaratte Sandstone formation
- New scientific knowledge obtained

Callide Oxyfuel CO_2 Product	Injection Date	Injection quantity (t)	CO_2 (%)	O_2 (ppm)	N_2 (ppm)	NOx as NO_2 (ppm)	SO_2 (ppm)	Comment
Pure CO_2	14 - 15 Oct. 2014	5.2	>99.99	5	0	16	< 0.1	Geochemical testing
CO_2 + Impurities	8 - 9 Nov. 2014	4.5	99.3	6150	1100	9	67	
Pure CO_2	10 - 11 Dec., and 15 - 16 Dec. 2014	21.1	>99.99	4	0	29	< 0.1	Residual Saturation Test (how much CO_2 does the rock hold)

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Special learnings – what would we do next time

1. The Callide Oxyfuel demonstration was predicated on selecting a demonstration plant configuration within an available budget; and compromises had to be made.
2. A clearer vision of the 'value proposition' for the Project; and more buy in from Project stakeholders.
3. Additional level of detail in the Front End Engineering Design should give a better overall outcome on future projects; with special consideration to Feed Gas CO_2 concentration and deNOx at the boiler end.
4. There are a number of opportunities to integrate the oxyfuel boiler with the CPU front end.
5. A first-of-a-kind is very difficult; especially in developing logic for oxyfuel boiler and CPU control, and new types of equipment that have not been trialled with Recycled flue gas.
6. However, there were no show stoppers; everything worked more or less as it should have. The attention now is making use of the knowledge to do things bigger and better next time.

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Video presentation

Oxyfuel Legacy - External (1).mp4

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Commercialization Activity

COP commercialization activity has four parts:

1. Proactive engagement with Government to facilitate policy development around clean coal technology (manufacture and application)
2. Public dissemination to promote the merits and the commercial uptake of the technology
   - Industry presentations, scientific publications, cooperation with other projects wherever possible
3. Internal use of Intellectual Property (IP) to support the business interests of the Project participants
4. External business development:
   - Feasibility studies to be conducted in the Asia Pacific and elsewhere
   - Through International partnerships and consulting business

Concluding comments

1. The Callide Oxyfuel Project was inspired by the technical collaboration already existing between Japan and Australia.
2. The Project was implemented and completed within the agreed time frames and budget.
3. The project goals have also been largely achieved including assessment of CO_2 storage capacity in Queensland (Australia) and CO_2 injection trials to understand more fully the effect underground on rock and water.
4. COP is recognised as the largest demonstration of oxy-firing in the world and has received a very large number of visitors.
5. The Project has demonstrated that the technology works at 30 MWe scale and is ready for scale-up.
6. The final activity is focussed on IP capture and commercialization, and plant decommissioning.

Collaboration between Japan and Australia, at Government and Industry level, has been very strong and one of the hallmarks of this project.

The support of the project partners and the inputs of our research partners such as the University of Newcastle through ANLEC R&D, and our participation in the IEAGHG Oxy-combustion Conferences and Research Network meetings, has substantially contributed to the success of this project.

Finally one must acknowledge the dedication and shear hard work of the Project Team!

Selected Bibliography

The following is a listing of some key, peer-reviewed publications from the Callide Oxyfuel Project for reference:

Uchida, T., Goto, T., Yamada, T., Kiga, T. and Spero, C. Oxyfuel combustion as CO2 capture technology advancing for practical use – Callide Oxyfuel Project. *Energy Procedia* 37 (2013) 1471 – 1479.

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Stanger, R., Ting, T., Belo, L., Spero, C. and Wall, T. Field measurements of NOx and mercury from oxy-fuel compression condensates at the Callide Oxyfuel Project. *International Journal of Greenhouse Gas Control* 42 (2015) 485 – 493.

Callide Oxyfuel Project

Callide Oxyfuel Project – Participants

Oxyfuel Project Partners

CS energy

IHI

COAL21 FUND

GLENCORE

Schlumberger Carbon Services

J-POWER EPDC

MITSUI & CO.

Australian Government

Queensland Government

METI Ministry of Economy, Trade and Industry

Supporting Collaborator

JCOAL Japan Coal Energy Center

www.callideoxyfuel.com