Callide Oxyfuel Project: Combustion and Environmental Performance

Chris Spero (CS Energy), Toshihiko Yamada (IHI), Peter Nelson (Macquarie University), Tony Morrison (Macquarie University), Claire Bourhy-Weber (Air Liquide)

OCC3

10 – 12 September 2013

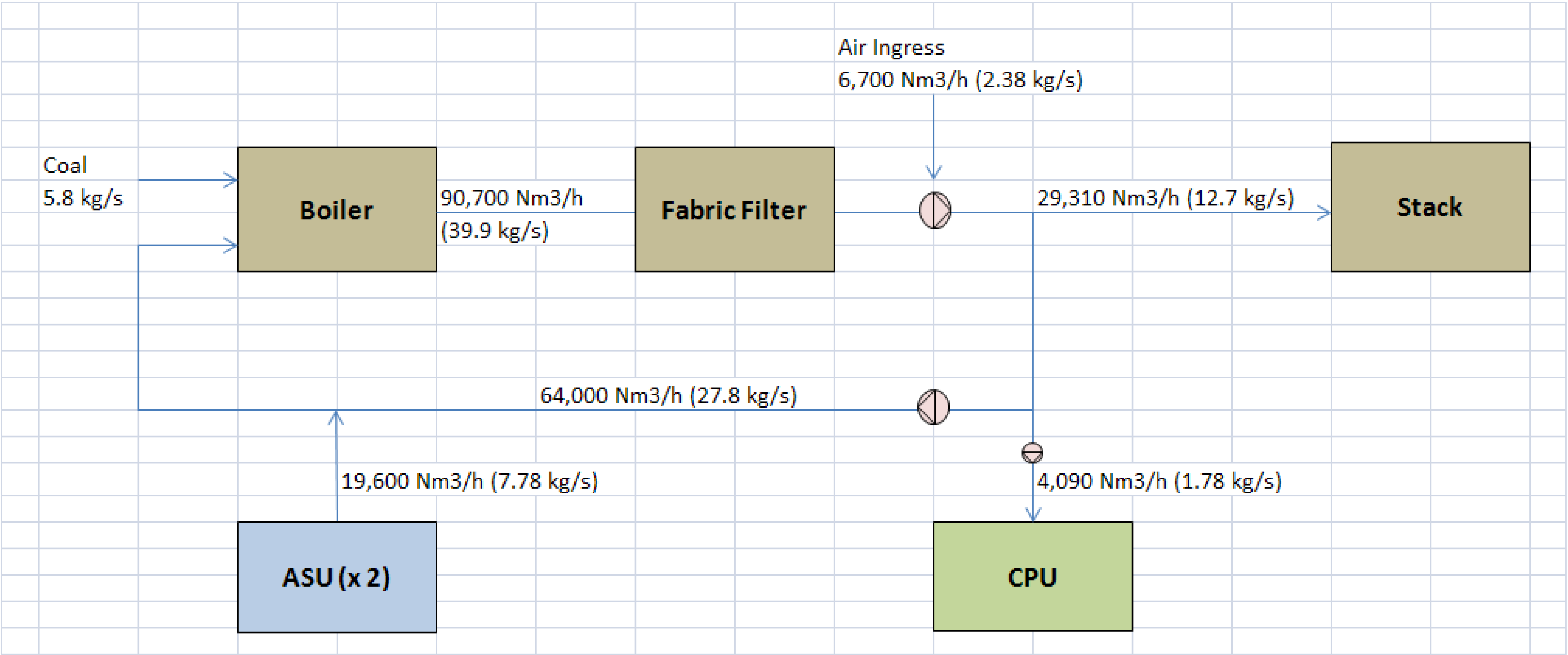
Callide Oxyfuel Project

Presentation Overview

- Purpose of the presentation is to provide an overview of the combustion and environmental performance of the Callide Oxyfuel boiler and CO2 capture plant (CPU) outcomes to date.
- Testing results are drawn from Feb 2012, May 2012 and December 2012 trials.
- Data and results are presented on the following specific items:
  - Basic characteristics of the test coals and test methodologies.
  - Combustion parameters considered are Mill performance, Carbon in Ash, slagging behavior, and heat recovery.
  - Environmental parameters considered are Particulate, NOX, SOX and Mercury behavior in the boiler and CO2 capture plant for the oxy-fuel boiler.
- Concluding comments

Boiler/Stack/CO2CPU - Flue gas mass balance

Data at 30 MWe (100% Load Factor)



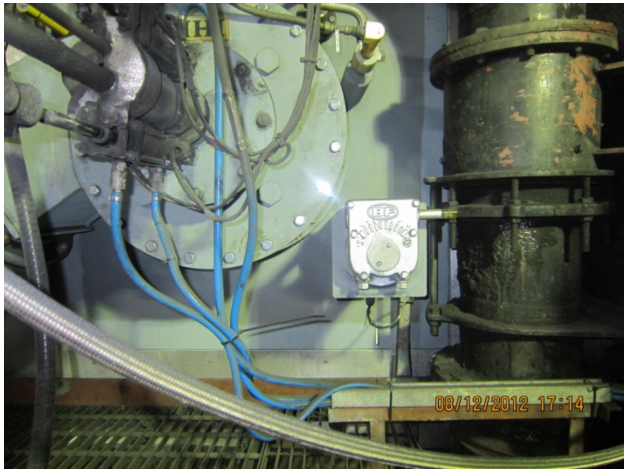
Callide OxyFuel Project

Test Coals

Coal		CL	CL + BL Blend 1	CL + MN Blend 2	MN
Description		Callide	Callide (75%) + Semi Anthracite (25%)	Callide (75%) + Med Vol. Bituminous (25%)	Medium Vol. Bit.
Total Moisture	%, as-received	12.2 - 14.1	11.5 - 12.7	11.8 - 12.5	5.8
Ash	%, as-received	22.2 - 25.6	18.9 - 20.8	24.8 - 23.7	23.9
Volatile Matter (VM)	%, as-received	20.4 - 21.9	17.2 - 18.6	21.6 - 21.9	27.9
Fixed Carbon (FC)	%, as-received	38.9 - 43.1	49.3 - 51.0	41.8 - 41.9	42.4
Fuel Ratio (FC/VM)		1.84 - 1.99	2.74 - 2.86	1.91 - 1.93	1.52
Total Sulfur	%, as-received	0.20 - 0.24	0.27 - 0.28	0.26	0.43
Chlorine	%, as-received	0.01 - 0.02	0.04	0.02	0.02
Gross Calorific Value	MJ/kg, as-received	17.28 - 19.12	20.59 - 21.91	19.04	23.43
HGI		76 - 86	80 - 85	73 - 77	50
Carbon	%, dry ash-free	73.5 - 76.7	80.6 - 81.0	76.6 - 77.9	86.1
Hydrogen	%, dry ash-free	3.52 - 3.85	3.76 - 3.84	4.12 - 4.30	5.56
Ntrogen	%, dry ash-free	0.95 - 1.07	1.31 - 1.33	1.38 - 1.44	2.69
Sulfur	%, dry ash-free	0.31 - 0.41	0.38 - 0.42	0.41 - 0.42	0.65
Oxygen	%, dry ash-free	18.1 - 23.3	13.4 - 14.0	15.9 - 17.5	5.04

Test methodology

- Trials were conducted over 2 days for each coal; min 24 hours air-firing and 24 hours oxy-firing.
- Coal blended on the stockpile using a front-end loader.
- Coal sampled from the test stockpile as it was loaded into the dump hopper feeding the boiler bunkers.
- Coal quality was reconfirmed by sampling pulverised coal at the mill outlets.
- Testing:
  - Unit data
  - Stack - CO2, CO, NO, NO2, SOx, H2O, O2, & Particulates – continuous monitoring.
  - Stack and CPU flue gas process streams – Halides, Trace elements, SO2 and SO3.
  - Condensates – from H2O remover, Low- and High-pressure scrubbers, compressor coolers.
  - Furnace hopper, boiler convection and airheater hoppers, Fabric filter hoppers - ash samples.
- Coal burn rates were determined by carefully managing coal bunker levels and weighing during coaling , plus cross-checking with PF sampling results
- Photos of flames, general observations.



IHI - Low NOx Burner (Callide a)

Callide OxyFuel Project

BOILER RESULTS

Callide
Oxyfuel Project

Mill performance

Coal	HGI (Average)	Ash (%, ar) average	Air-Firing - Mass % PF < 75 µm			Oxy-Firing - Mass % PF < 75 µm		
			A Mill	B Mill	C Mill	A Mill	B Mill	C Mill
CL	80	23.9	56.9 - 64.7	70.5 - 72.3		65.0 - 76.7		65.5 - 72.2
CL+ BL	83	19.8	69.9		66	75.9		
CL + MN	75	24.2	62.7		59.6			62.8
MN	50	23.9			55.6	51.3	49.3	

- No significant difference is observed in mill performance between Air-firing and Oxy-firing, despite higher mill temperatures in the later case.
- PF fineness increases with an increase in HGI of the coal as expected.

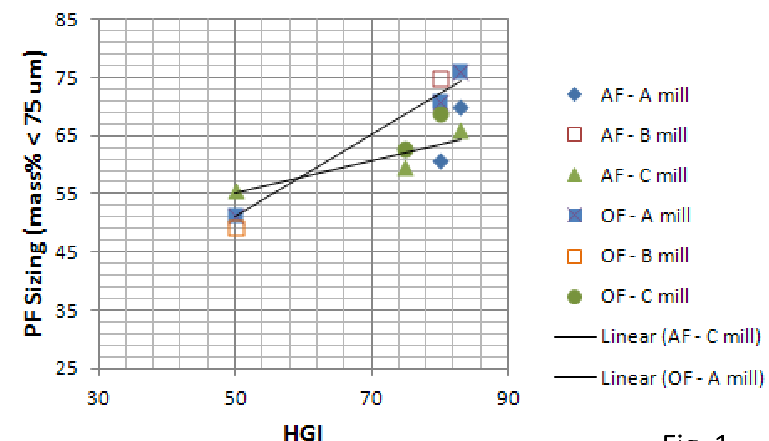


Fig. 1

Callide OxyFuel Project

Combustion efficiency

- Data is presented for three test coals:
  - ➢ CL - Callide coal (100%)
  - ➢ CL+ BL – Callide (75%) + Semi Anthracite (25%)
  - ➢ CL + MN – Callide (75%) + Med Vol. Bituminous coal (25%)
- Typical proportioning of ash from the boiler is 10 – 25% furnace (or bottom ash) and 75 to 90 % fly ash.
- Oxy-firing conditions yield significantly lower carbon in ash levels overall compared to air-firing.
- In Oxy-firing mode, the unburned carbon in the furnace ash is about the same as for the fly ash; usually it is much higher than in the fly ash.
- CO levels are slightly lower under oxy-firing conditions compared to air-firing conditions; consistent with improved combustion efficiency in oxy-mode.

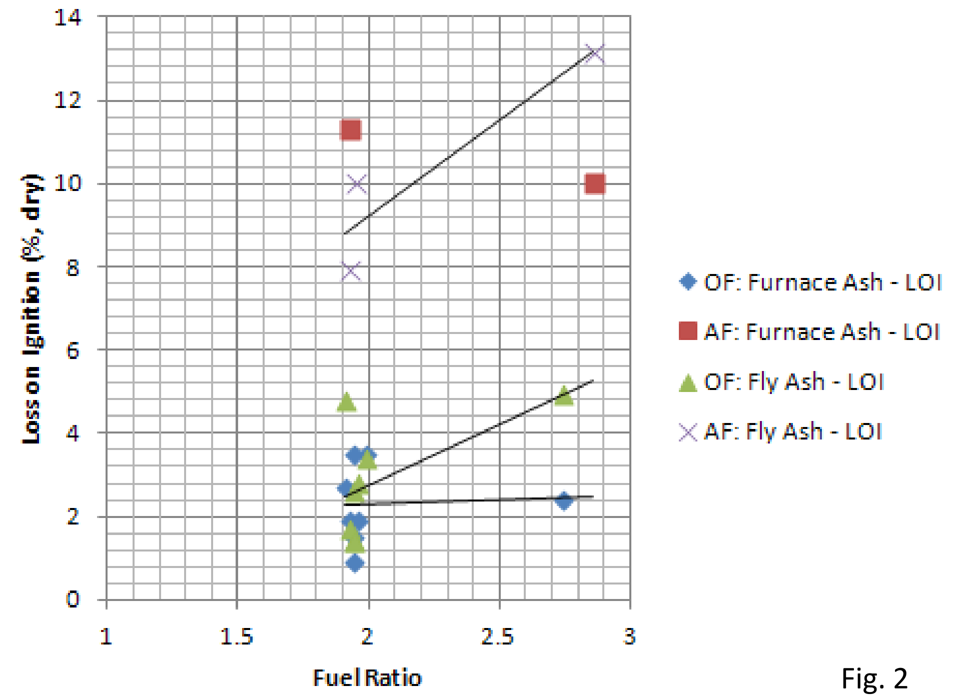


Fig. 2

Callide OxyFuel Project

Furnace - Ash deposition observations

Coal	IDT (Red) °C	Tcv (°C)	SI	S (%, ar)	Fe2O3 (% in Ash)	UBC (%)		Slagging Observations
						Air-Fir.	Oxy-Fir.	
CL	1550 - 1600	1470 - 1600	0.1 - 0.13	0.2 - 0.24	7 - 9	5 - 7	1.4 - 2.5	No ash deposits observed
CL + BL	1390	1470 - 1500	0.14 - 0.16	0.27 - 0.28	9	12	4 - 6	Some eyebrowing in Air mode
CL + MN	1550	1450	0.12	0.26	8	8	4 - 6	Some wall deposits in Air-mode
MN	1440	1600	0.1	0.43	5	> 12%	ND	Significant wall deposits in air mode but burner spreader had failed (Burner malfunction)

$$Tcv(^{\circ}C) = 2990 - 1470\left(\frac{SiO_2}{Al_2O_3}\right) + 360\left(\frac{SiO_2}{Al_2O_3}\right)^2 - 14.7(Fe_2O_3 + CaO + MgO) + 0.15(Fe_2O_3 + CaO + MgO)^2$$

$$SI = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$$

- Reduced ash deposition under Oxy-firing conditions
- High carbon in ash and high sulfur associated with increase in furnace wall ash deposits and increased ratio of furnace ash to fly ash

Callide OxyFuel Project

NOx emissions

- Data is presented for 24 – 30 MWe (80 – 100%) Load Factor.
- NOx mass emission rate (in kg NOx/s) is significantly reduced under oxy-firing conditions as expected; less than 50% of air-firing NOx emission rates (Fig. 3).
- NOx mass emission rates with increased fuel N input (Fig. 3 & Fig. 4).
- Ratio of NO2 to NO is much higher under oxy-firing conditions compared to air-firing conditions (Fig. 5).

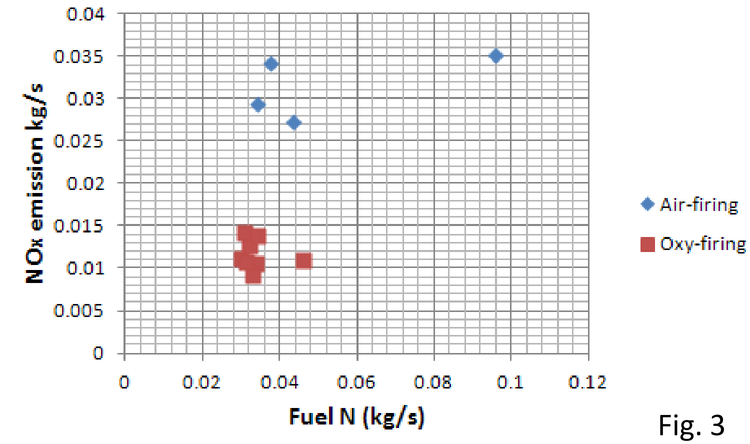


Fig. 3

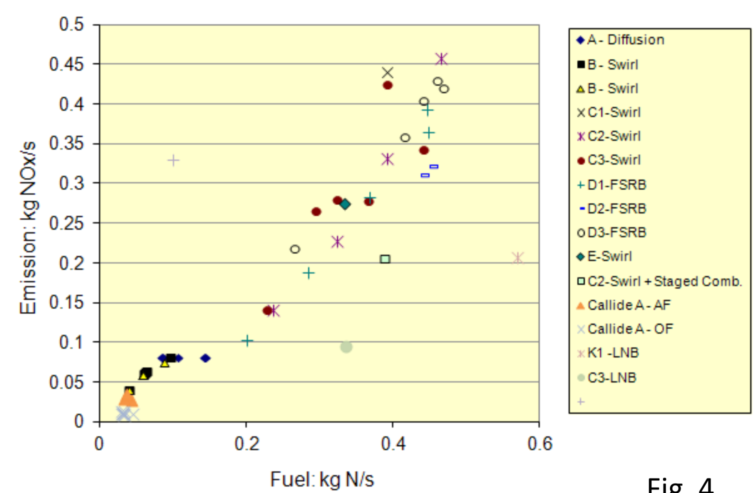


Fig. 4

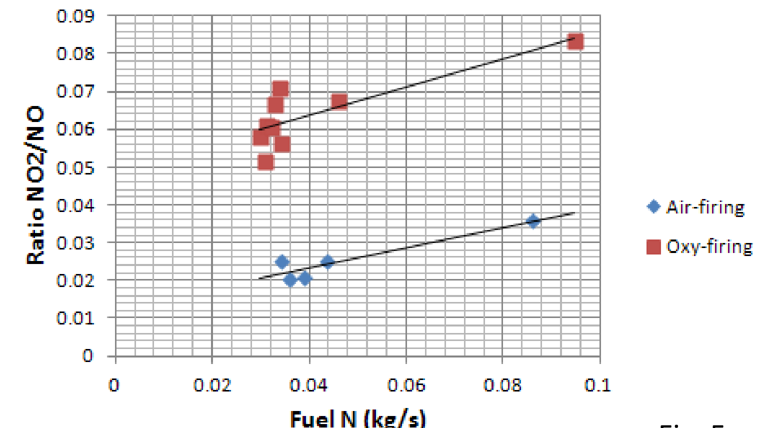


Fig. 5

Callide OxyFuel Project

SOx emissions

- Data corresponds to tests conducted at 24 – 25 MWe (80 - 85% Load Factor).
- SOx emission can be represented as a power function of total sulfur (Fig.6)
- SOx levels under oxy-firing conditions are 4 – 5 times higher than under air-firing conditions (as expected).
- There is slightly higher absorption of SOx by the fly ash under oxy-firing conditions (Fig 7)
- SO3 levels (limited data set):
  - Air-firing < 1 mg/Nm3 (< 1% of total SOx)
  - Oxy-firing 30 – 60 mg/Nm3 (1 – 2% of total SOx)
- Sulfate and Sulfuric acid deposits are evident throughout the ductwork.

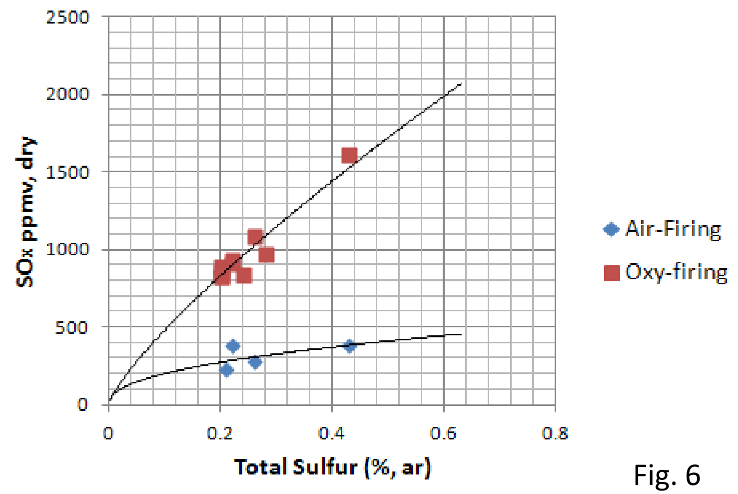


Fig. 6

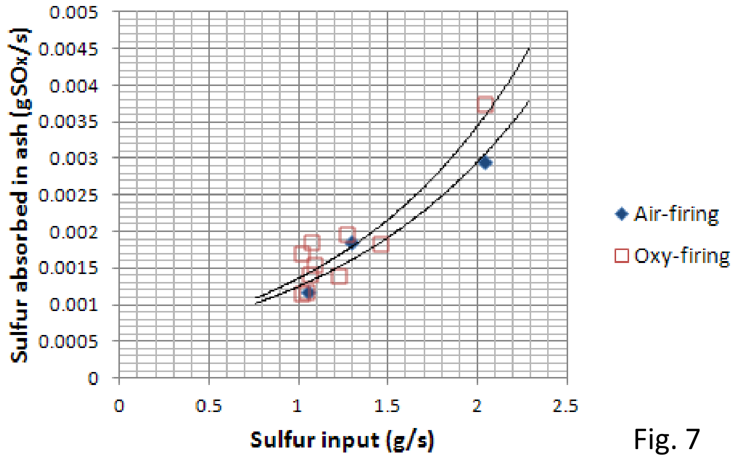


Fig. 7

Callide OxyFuel Project

Particulate emissions

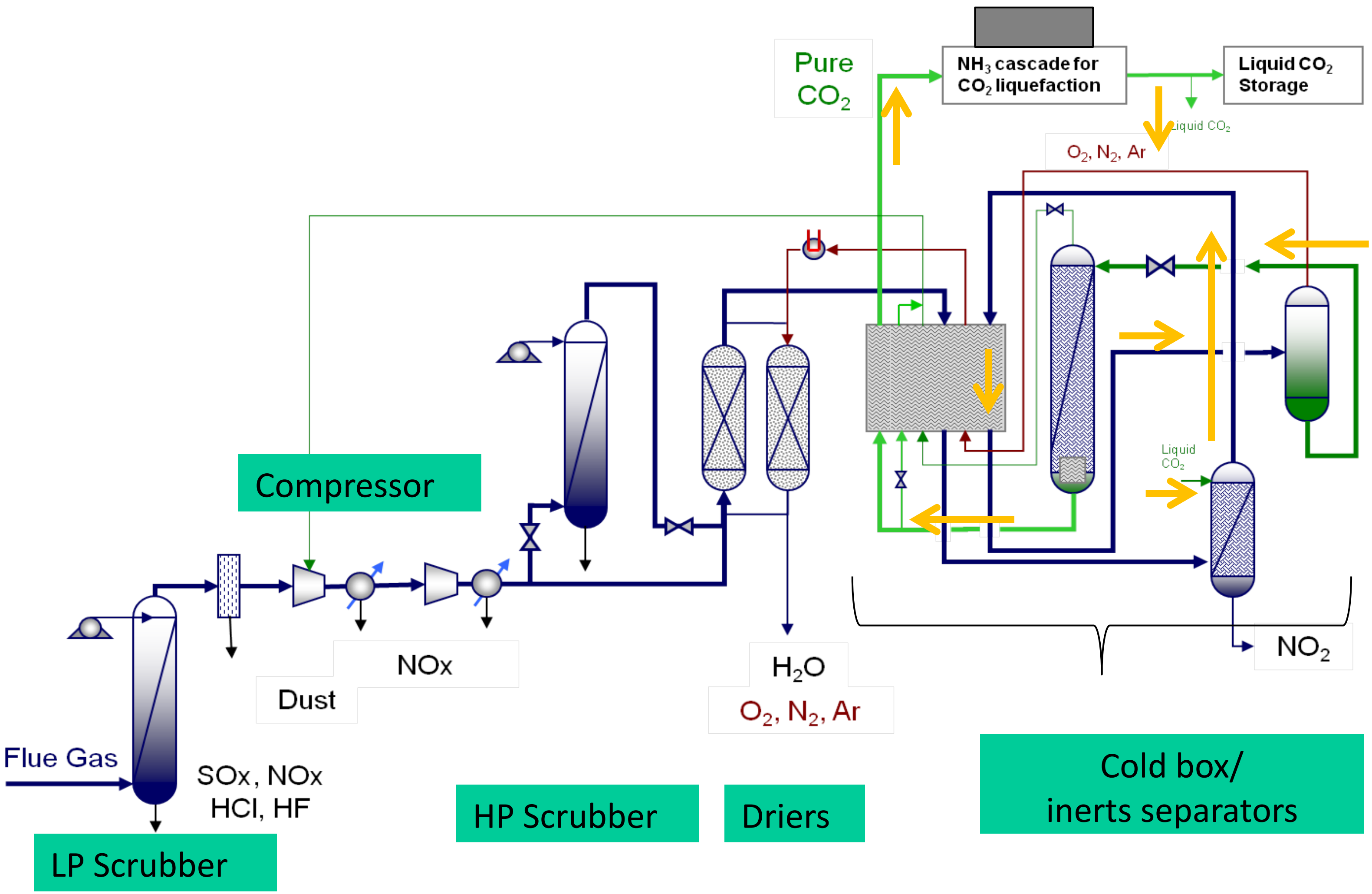
Load: 28 - 30 MWe			
Stack particulate parameters		**Air-mode**	**Oxy-mode**
Concentration	mg/Nm3 @ 12% CO2	60 - 80	30 - 40
CO2 concentartion	mol %, dry	12 - 15	67 - 72
Gas flow rate	m3/s @ 0 °C, 101.3 kPa(a), wet	~ 35	~ 10
Stack efflux velocity	m/s	6 - 7	2 - 2.5
Mass emission rate	g/s	2 - 2.5	1.6 - 2.3

- Particulate mass emission rates are slightly less in oxy-mode (assuming no flue gas to CPU) because of H2O remover on primary gas recirculation line.
- Additional particulate will be removed if flue gas is sent to the CPU.
- Stack efflux velocity in oxy-mode is significantly less than in air mode – which will have some impact on dispersion.
- At Callide A, because efflux velocity is so low in oxy-mode that it is difficult to measure gas flow and sample particulates iso-kinetically.

Callide OxyFuel Project

CPU RESULTS

Carbon dioxide capture plant



Courtesy of Air Liquide

Callide
OxyFuel Project

CPU – Process gas quality (actual)

Gas Composition	Unit of Measure	CPU - LP Inlet	CPU - LP Outlet	Product CO_2
		From Boiler	To compressor	
Boiler Load Factor	%	80 - 100		
H_2O	mol. %	19 - 22	5 - 7	< 20 ppm
O_2	mol. %	3 - 5	3.5 - 6	30 ppm
CO_2	mol. %	50 - 57	58 - 67	> 99.95
CO	ppmv	20 - > 200	25 - > 200	< 10
NO	ppmv	500 - 700	580 - 820	< 2.5
NO_2	ppmv	20 - 40	Nil	14
SO_2	ppmv	800 - 1000	< 10	< 0.1 ppm
SO_3	ppmv	10 - 15	< 0.1	< 0.1 ppm
N_2 (+ Ar)	mol. %	Balance	Balance	trace
Hg	ppbv	0.3 - 0.5	0.04 - 0.1	< 0.0002
	µg/Nm^3	2.7 - 4.9	0.4 - 0.9	< 0.002
Particulates	mg/Nm^3 (at 60 - 70% CO_2)	150 - 250	< 0.02	nil
	mg/Nm^3 (at 12% CO_2)	20 - 50	< 0.01	nil

CPU – Environmental performance

- Low pressure scrubbers utilise a caustic soda wash to remove SO_2 from the gas stream (< 10 ppm in gas phase). The scrubber condensate streams are pumped into the waste ash sluicing system and are stored in the ash dam.
- Further work is required to optimise the low pressure scrubbing process and to understand the competition between SO_2 and CO_2 in this process.
- Nitrous Oxide (NO) passes through the LP scrubbers but is effectively converted to NO_2 during flue gas compression.
- Further work is required to characterise and understand the behaviour on NOx in the CPU especially in regard to adsorption and desorption of NO_2 in the drier vessels. Near field dispersion modelling is planned to more fully understand the Health & Safety aspects of this part of the process.
- Trace elements in the gas phase are also effectively extracted from the gas phase in the CPU.
- The principal gaseous emissions from the CPU are CO_2 and NO_2. Further work is planned to characterise the behaviour of NOx in the CPU.

Gas Composition	Unit of Measure	CPU - LP Inlet	CPU - LP Outlet	Product CO2
		From Boiler	To compressor	
Boiler Load Factor	%	80 - 100		
H2O	mol. %	19 - 22	5 - 7	< 20 ppm
O2	mol. %	3 - 5	3.5 - 6	< 30 ppm
CO2	mol. %	50 - 57	58 - 67	> 99.95
CO	ppmv	20 - > 200	25 - > 200	< 10
NO	ppmv	500 - 700	580 - 820	< 2.5
NO2	ppmv	20 - 40	Nil	< 20
SO2	ppmv	800 - 1000	< 10	< 0.1 ppm
SO3	ppmv	10 - 15	< 0.1	< 0.1 ppm
N2 (+ Ar)	mol. %	Balance	Balance	trace
Hg	ppbv	0.3 - 0.5	0.04 - 0.1	< 0.0002
	µg/Nm3	2.7 - 4.9	0.4 - 0.9	< 0.002
Particulates	mg/Nm3 (at 60 - 70% CO2)	150 - 250	< 0.02	nil
	mg/Nm3 (at 12% CO2)	20 - 50	< 0.01	nil

CPU – Process condensates

Parameter	Unit of Meas.	Raw Water	Quencher	LP Scrubber	Compressor		HP Scrubber
					1st Cooler	2nd Cooler	
pH		~ 7	~ 7	7.5 - 8	0.5 - 1	1 - 1.5	0.5 - 1
Total Dissolved Salts	mg/L	100 - 150	5,000 - 6,000	1,000 - 2,000	< 5	< 5	up to 1,000
Tot. Alkalinity	mg/L as CaCO3	< 10	1,500 - 2,000	1,000 - 1,500	< 1	< 1	< 1
Sulfate as SO4	mg/L	10 - 20	3,000 - 4,000	< 100 - 2,000	< 1	< 1	10 - 30
Chloride	mg/L	< 10	50 - 100	<50	< 1	< 1	10 - 50
Nitrate + Nitrite as N	mg/L	ND	< 5	< 5	5,000 - 15,000	1,000 - 2,000	1,500 - 15,000
Mercury (Hg)	µg/L	ND	up to 15	< 0.1	20 - 50	up to 10	< 2.5

Test data indicates:

- LP area (caustic wet scrubbers and filters) remove particulates, SOX, NO2 and a major portion of trace elements
- NO is converted to NO2 in the compressor and a significant portion is removed with the intercooler condensates as Nitric Acid.
- Almost all the Hg that has passed through the LP area is removed with the compressor condensates.

Callide Oxyfuel Project

Concluding comments

- The principal driver for oxy-firing technology development has been primarily CO2 capture, and secondarily reduction in other flue gas emissions.
- Testing at Callide A has demonstrated almost complete removal of all toxic gaseous emissions (such as SOx, NOx, particulates, and trace elements) from the flue gas stream into the waste ash/condensate streams of the process.
- In the case of NOx, significant reduction in stack mass emission rates are observed due the oxy0firing re-burning effect in the furnace.
- Other improvements noted are improved combustion efficiency measured as reduced Carbon-in-Ash, and a reduction in the tendency to produce furnace ash deposits.

- Further work is planned to more fully characterize the combustion and environmental performance of oxy-firing.
- It might be interesting to explore the commercial value of oxy-firing in addition to CO2 capture.

Callide Oxyfuel Project

Callide Oxyfuel Project – Participants

Oxyfuel Project Partners

CS energy

xstrata coal

IHI

AUSTRALIAN COAL ASSOCIATION LOW EMISSION TECHNOLOGIES

Schlumberger

J-POWER EPDC

MITSUI & CO., LTD.

Australian Government

Queensland Government

METI Ministry of Economy, Trade and Industry

Supporting Collaborator

JCOAL Japan Coal Energy Center

Thank you

for more information: www.callideoxyfuel.com