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Oxyfuel combustion as CO_2 capture technology advancing for practical use - Callide Oxyfuel Project -

Terutoshi UCHIDA[a]*, Takahiro GOTO[a], Toshihiko YAMADA[a], Takashi KIGA[a], Chris SPERO[b]

a IHI Corporation, 1-1, Toyosu 3-chome, Koto-ku, Tokyo 135-8710 Japan
b CS Energy LTD, Level2, HQ North Tower, 540 Wickham Street Fortitude Valley, Brisbane, QLD 4001 Australia

Abstract

CCS, CO_2 capture and storage, is one of the ways to keep CO_2 concentration in atmosphere to be under certain value in order to mitigate the global warming and expectation for its practical use soars all over the world. IHI have developed the oxyfuel combustion technology as CO_2 capture technology since 1989 and we have been going forward the Callide oxyfuel Project in Australia since 2008. In this paper, we introduce the progress of the Callide oxyfuel Project and the action toward the practical use of the oxyfuel combustion technology.

"Keywords: Oxyfuel; Boiler; Coal; CCS; Oxy; CO2; Capture"

1. Introduction

As mitigation measure of climate change, emission reduction of CO_2 which is major factor of the global warming has long been clamored. Fig.1 shows CO_2 emission rate in each industrial sector in 2009 and 2050. 6 degC scenario is a scenario where current CO_2 emission trend continues, 2 degC scenario is a scenario to keep global warming within 2 degC which is allowable for sustainable world and 4 degC scenario is the intermediate one of both scenarios. The bottom part of the graph (green part) indicates power sector and we find from the graph that a contribution of power sector is very large compared to other sector. Fig.2 shows the trend of CO_2 emission of each scenario in power sector from 2009 to 2050. It is expected that CCS will contribute 20% of the reduction of CO_2 emission in reducing to 2 degC scenario from 4 degC scenario and this indicates high expectation of practical use of CCS.

We have progressed research and development of the oxyfuel combustion technology which is one of CO_2 capture technology since 1989. And we have worked on the Callide oxyfuel Project at Callide A power plant in Queensland State in Australia in partnership with private companies and organizations in

* Corresponding author. Tel.: +81-3-6204-7506; fax: +81-3-6204-8791.
E-mail address: terutoshi_uchida@ihi.co.jp

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Australia and Japan with financial support of Japanese government, Australian federal government and Queensland state government. This project is a demonstration one that the existing out-of-service coal fired power plant is modified using the oxyfuel combustion technology, CO_2 in boiler flue gas is captured effectively and the CO_2 is stored in the underground. Conducting oxyfuel combustion in power plant actually generating power to commercial grid is the world first challenge and therefore attention is paid to this project by the world.

In this paper, we introduce the general of this Callide oxyfuel Project, achievement of initial operation of oxyfuel combustion and our future plan.

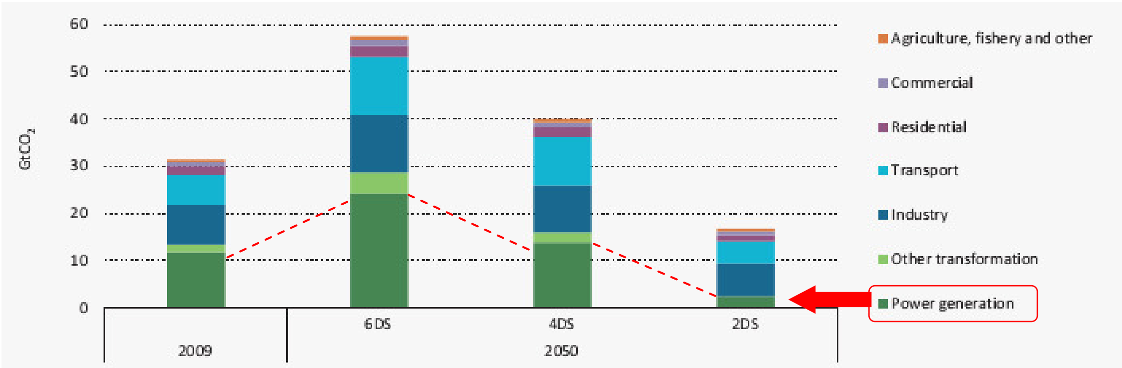

Fig. 1. Global CO_2 emissions by sector and scenario [1]

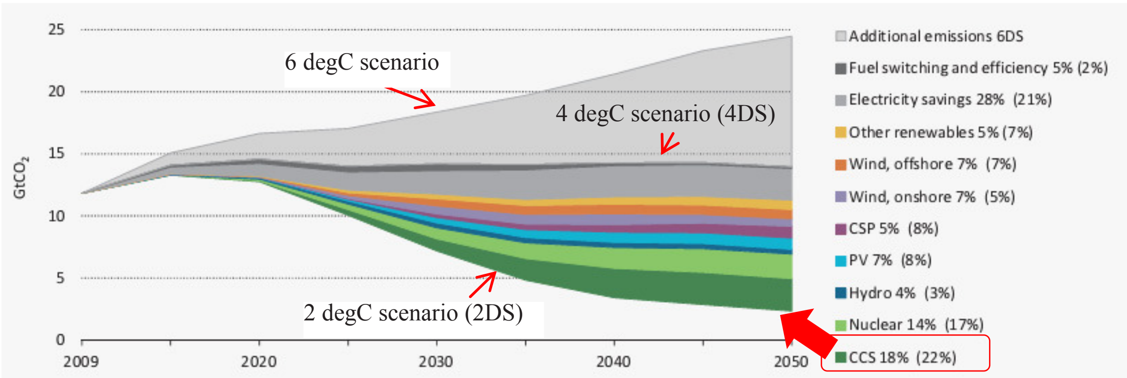

Fig. 2. Key technologies to reduce CO_2 emissions in the power sector in the 2DS, relative to the 4DS [1]

2. Feature of the oxyfuel combustion technology

2.1. CO_2 capture technology

Though three major technologies are known as CO_2 capture technology from power plant using coal, each technology does not reach the commercial level and technological development is advanced now. Table 1 shows their features.

Table 1. Major CO_2 capture methods for power plant using coal

Method	Feature
oxyfuel combustion	A method to get flue gas containing high concentration of CO_2 by burning fuel with high purity of O_2
Post combustion	A method to separate and capture CO_2 from air combustion flue gas by passing flue gas through alkali sorbent
Pre combustion	A method to separate and capture CO_2 from coal gasification gas by adsorbing or absorbing physically.

2.2. Difference between oxyfuel combustion and Air combustion

Air combustion uses air to burn the fuel literary. Since air consists of N_2 of 79% and O_2 of 21% on a volume base, flue gas of air combustion contains N_2 of approximately 79%. Meanwhile, the oxyfuel combustion uses pure O_2 instead of air to burn the fuel. Since N_2 contained in air is not supplied into boiler system, main components of oxyfuel flue gas are CO_2 and H_2O. We can capture CO_2 of approximately 90% after H_2O is removed from the oxyfuel flue gas. Also, the amount of flue gas is reduced to one fifth. This concept is shown in Fig.3.

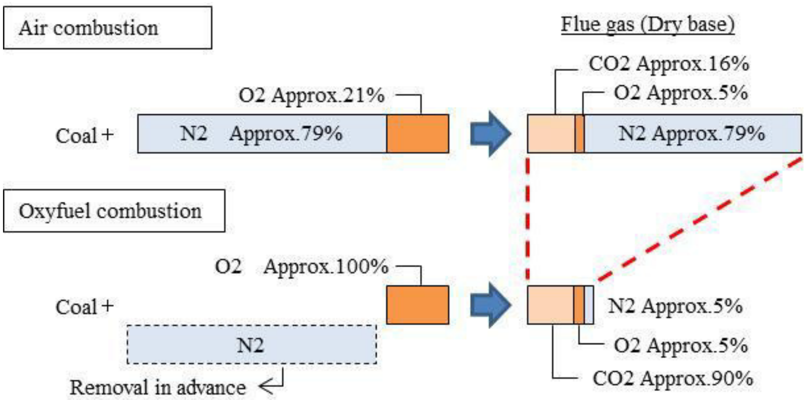

Fig. 3. Concept of oxyfuel combustion

In actual oxyfuel operation, flame temperature of oxyfuel combustion is controlled to almost same degree as that of air combustion by supplying recirculated flue gas into boiler in order to avoid the significant rise of the flame temperature in cases where coal is burnt by only pure O_2. By recirculating flue gas, we can design oxyfuel boiler without modifying existing air firing boiler substantially. .

2.3. Merit of oxyfuel combustion

oxyfuel combustion method has the following merits due to the feature shown in the previous section.

- We do not need to separate CO_2 from flue gas and we can store the captured CO_2 directly. (Purification of CO_2 may be needed depending on the way of transportation or storage.)
- We expect improvement of combustion efficiency due to oxygen enrichment.
- Boiler efficiency in oxyfuel combustion is higher than that in air combustion in the same operating condition since the amount of flue gas decreases.
- NOx emission decreases since NOx in flue gas is reduced by recirculating flue gas into boiler. Therefore there is a possibility that De-NOx plant becomes unnecessary.
- We can downsize FGD because the amount of flue gas decreases. In addition, when we install CO_2 purification plant, we do not need FGD since desulfurization can be done in CPU.
- We can apply the oxyfuel combustion technology to the modification of the existing power plant as well as newly installed power plant.

3. Approach of development of the oxyfuel combustion technology

Our company has obtained much knowledge and experience of oxyfuel combustion toward practical use through elemental study, pilot test with our oxyfuel combustion test facility, study of burner and furnace by numerical analysis, feasibility study aiming at 1000 MW class coal fired power plant. These footprints are shown in table. 2.

Table 2. Footprint of development of the oxyfuel combustion technology

Year	Action
1989	Start of research and development of the oxyfuel combustion technology
1992	Feasibility study aiming at newly installed 1000 MW class oxyfuel power plant
1993	Start of basic combustion characteristics confirmation test
1994	Start of combustion test in our Aioi test facility
1996	Start of oxyfuel combustion simulation
1998	Start of dynamic simulation of oxyfuel plant
2004	Start of feasibility study of Callide oxyfuel Project
2008	Start of Callide oxyfuel Project

4. Callide oxyfuel Project

4.1. The general of the project

This project continues for about ten years since we started feasibility study in 2004 and is progressed by private companies and organizations with financial support of Japanese government, Australian federal government and Queensland state government. History of the project is shown in Table 3.

Table 3. History of the Callide oxyfuel Project

Month/Year	History
2004	Feasibility study of the Callide oxyfuel Project was started
Mar 2006	MoU signed with Japanese participants
Oct 2006	Australian Government's Low-emissions Technology Demonstration Fund funding announcement
Mar 2008	Callide Oxyfuel Project Joint Venture agreements finalized
Aug 2008	Refurbishment of Unit A4 at Callide A Power Station Commenced
Oct 2008	Official launch of the Callide Oxyfuel Project
Jan 2009	Refurbishment of Unit A4 at Callide A Power Station completed
Mar 2011	Boiler modifications completed for oxyfuel combustion at Callide A Power Station and commissioning commenced
Apr 2011	First coal firing in air mode after boiler oxyfuel combustion modifications
Mar 2012	First boiler operation in full oxyfuel combustion

This project composes three stages. In stage 1, the existing boiler is modified to oxyfuel boiler, Air separation unit (ASU) and CO_2 purification unit (CPU) are newly installed and their operations are conducted. In stage 2, the CO_2 captured by oxyfuel operation is transported by truck and stored in the underground. In stage 3, we summarize the data acquired through the operation as a project overview. Currently we are in stage 1. The objectives of stage 1 are to comprehend design data and cost data toward practical use and to accumulate know-how of operation in addition to the demonstration of the oxyfuel boiler system and the CPU.

And the features of the project are the following three items;

- All components which are essential for the oxyfuel boiler and CO_2 capture system are equipped
- The existing coal fired power plant which is not CCS-ready-plant is modified to oxyfuel boiler and actually operated.
- Oxyfuel boiler power plant is connected to commercial grid.

4.2. The general of the plant

Callide power station is located at 550km North West from Brisbane, provincial capital of Queensland State. Coal is supplied from adjacent Callide mine. Callide power station composes Callide A, B and C power station and their total power output is 1720 MW. Callide A power station is used for the project. Callide A power station composes four units and Callide A No.4 unit is modified to oxyfuel boiler system. The location of power station is shown in Fig. 4, Side view of Callide A power station is shown in Fig. 5, Flow sheet of oxyfuel boiler system is shown in Fig. 6 and the major specification of the Callide oxyfuel plant is shown in Table 4.

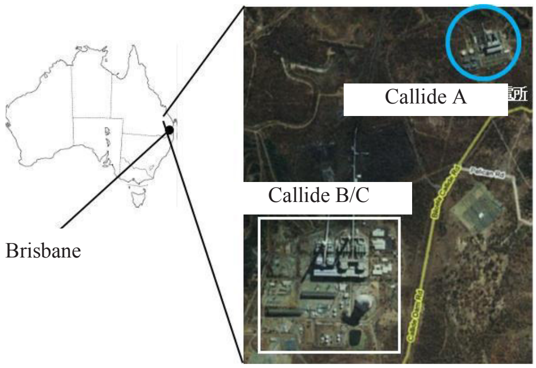

Fig. 4. Location of power station

Fig. 5. Side view of Callide A power station

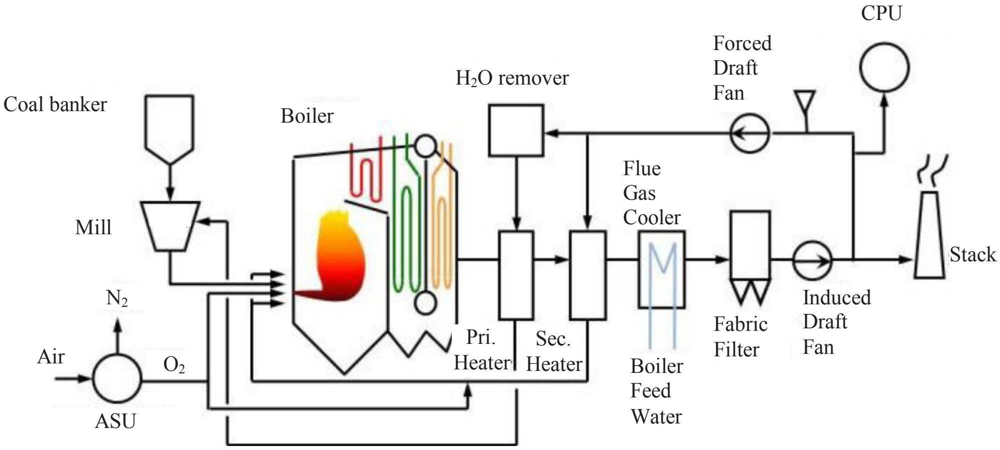

Fig. 6. Flow sheet of Callide oxyfuel boiler system

Table 4. Major specification of the Callide oxyfuel plant

Item	Description
Name	Callide A power station No.4 unit
Rated power	30MWe
Coal	Callide coal
Main Steam condition	Flow rate: 136 ton/h, Pressure: 4.1 MPa, Temperature: 460 degC
Boiler type	2 drum type without Reheater
Burner arrangement	Wall (front) firing (2 burners * 3 row)
Draft system	Balance draft with 1 Forced draft fan and 1 Induced draft fan
Type of dust remover	Fabric filter
ASU	Type: Cryogenic distillation method, Capacity: 2 * 330 ton/day, O_2 Purity: above 98%
CPU	Type: Cryogenic distillation method, Capacity: 70 ton/day, CO_2 capture condition: 1.6 MPa, -30 degC

4.3. Result of initial oxyfuel operation

The boiler was retrofitted so that we could operate it at 100% load (30MW) in air combustion as well as 100% load in oxyfuel combustion and commissioned in air combustion following the completion of retrofit work. In the commissioning in air combustion after retrofit, we confirmed that the operational condition after retrofit was almost same as the condition before retrofit and that we could operate it at 100% load in air combustion. Fig.7 shows flame condition at initial oil firing and Fig.8 shows flame condition in coal-air combustion.

Fig.7. Flame condition at initial oil firing

Fig.8. Flame condition in coal-air combustion

Commissioning in Air combustion was completed on July 2011. After ASU was ready to operate on March 2012, initial O_2 injection was conducted into boiler. Since we had much time since completion of commissioning in air combustion until start of commissioning in oxyfuel combustion, we were able to prepare sufficiently to the commissioning of oxyfuel combustion as commercial power plant by studying the detail. In addition, power station staffs had much experience of air firing boiler, but it was first experience for them to operate oxyfuel boiler or ASU. We were able to secure sufficient time for training for staffs and developing new internal rule to deal with high concentration of O_2 or CO_2. These were also fruitful experience for us as advance preparation to conduct safety operation in oxyfuel combustion since it is also first time for us to conduct oxyfuel combustion operation in power plant.

We have tuned the following items since oxyfuel combustion operation was started on March 2012.

- Switch operation from air combustion to oxyfuel combustion and vice versa
- Control of boiler inlet O_2 concentration and boiler outlet O_2 concentration.
- Safety stop from main fuel trip in various situation
- Combustion condition in oxyfuel operation

As a result of those tuning, we have secured safety operation of oxyfuel combustion and switch between air combustion and oxyfuel combustion. Fig. 9 shows the concept of switch operation. Switch operation is separated into each step and each step connects in sequence. Currently switch operation can run automatically with one push button.

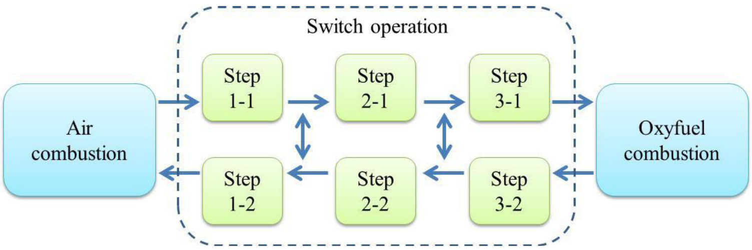

Fig. 9. Concept of switch operation between Air combustion and oxyfuel combustion

Fig. 10 shows operating condition before and after switch operation including air combustion and oxyfuel combustion. The period when Air intake damper position is 100% is Air combustion, the period when Air intake damper position is 0% is oxyfuel combustion and its transition period is switch operation. We can find from Fig.10 that Boiler inlet O_2 increases in oxyfuel operation and at the same time flue gas CO_2 is highly concentrated.

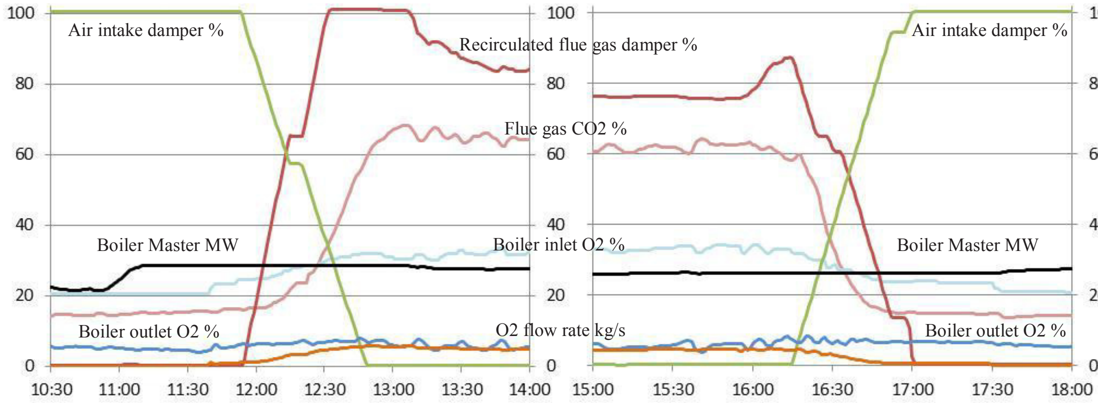

Fig. 10. Operating condition before and after switch operation including air combustion and oxyfuel combustion

Flame condition in oxyfuel combustion is shown in Fig. 11. We confirmed that good combustion condition was maintained in oxyfuel operation as well as in Air combustion operation.

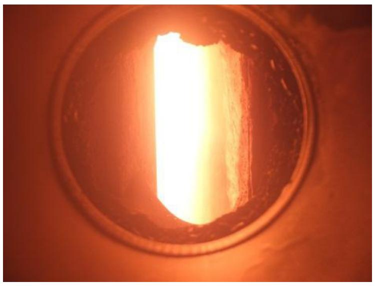

Fig. 11. Flame condition in oxyfuel combustion

In addition, power plant with the oxyfuel combustion is operated with connecting to commercial power grid and this is the world's first commercial power generation by the steam generated by coal fired oxyfuel boiler.

Currently, we are conducting the oxyfuel boiler basic characteristics confirmation test in the beginning of the demonstration stage and commissioning CPU.

4.4. Demonstration items

We will test the oxyfuel power plant in various conditions and evaluate or validate the plant performance by means of obtained data. Table 5 shows major demonstration items.

Table 5. Major demonstration items

Item		Description
Total system	Cooperation control among Boiler / ASU / CPU	Operability such as minimum load, load ramp rate
		Switch operation between air combustion and oxyfuel combustion
		Safety emergency stop, interlock action
	Performance	Gross output and efficiency, Net output and efficiency, Power consumption
	Safety	Handling of high concentration of O_2 and CO_2
Boiler	Performance	Boiler efficiency, CO_2 concentration in flue gas
	Combustion stability	Heat duty, Flame temperature, Flame detection performance, Ash behavior, Influence of coal
	Durability	Corrosion
	Control	Boiler inlet O_2 control, Boiler outlet O_2 control
CPU	Performance	CO_2 capture rate, CO_2 purity, Reduction performance of impurity such as SOx, NOx, Hg
	Durability	Corrosion

5. Conclusion

We would like to continue to contribute to increase of electricity demand and mitigation of global warming simultaneously. We intend to obtain the data toward practical use in the Callide oxyfuel Project steadily and advance R&D so that we can supply oxyfuel power generation system that is suitable for the demand of society and the needs of customers as soon as we can.

Acknowledgements

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[1] Energy Technology Perspectives 2012 (IEA)