CLEAN COAL TECHNOLOGIES SCENARIO AND EVALUATION OF PRESENT CO_2 DWINDLING INITIATIVES TO APPROACH ZERO EMISSION POWER STATIONS BY COAL COMBUSTION. DEPLOYMENT SITUATION AND EVALUATION STUDY

Francisco Guerrero, Carmen Clemente-Jul

Department of Chemical Engineering and Fuels. ETS Ingenieros de Minas. Universidad Politécnica de Madrid (UPM), Alenza 4. 28003 Madrid (Spain).

Abstract

In the present uncertain global context of reaching an equal social stability and steady thriving economy, power demand expected to grow and global electricity generation could nearly double from 2005 to 2030. Fossil fuels will remain a significant contribution on this energy mix up to 2050, with an expected part of around 70% of global and ca. 60% of European electricity generation. Coal will remain a key player. Hence, a direct effect on the considered CO_2 emissions business-as-usual scenario is expected, forecasting three times the present CO_2 concentration values up to 1,200ppm by the end of this century.

Kyoto protocol was the first approach to take global responsibility onto CO_2 emissions monitoring and cap targets by 2012 with reference to 1990. Some of principal CO_2 emitters did not ratify the reduction targets. Although USA and China spur are taking its own actions and parallel reduction measures.

More efficient combustion processes comprising less fuel consuming, a significant contribution from the electricity generation sector to a CO_2 dwindling concentration levels, might not be sufficient. Carbon Capture and Storage (CCS) technologies have started to gain more importance from the beginning of the decade, with research and funds coming out to drive its come in useful. After first researching projects and initial scale testing, three principal capture processes came out available today with first figures showing up to 90% CO_2 removal by its standard applications in coal fired power stations. Regarding last part of CO_2 reduction chain, two options could be considered worthy, reusing (EOR & EGR) and storage.

The study evaluates the state of the CO_2 capture technology development, availability and investment cost of the different technologies, with few operation cost analysis possible at the time. Main findings and the abatement potential for coal applications are presented. DOE, NETL, MIT, European universities and research institutions, key technology enterprises and utilities, and key technology suppliers are the main sources of this study. A vision of the technology deployment is presented.

A review and evaluation of the global initiatives carry out trough demonstration projects to aim CCS commercially available by 2020 – 2030. State and improvements of the different programs on going, the UK program, the European program EEPR and the like are part of the scenario analysis.

Keywords: Carbon Capture & Storage (CCS), CO2, Clean Coal Technologies, demonstration projects.

1. Introduction

A few main certainties currently well known have to be mentioned as starting point for further discussion: CO_2 minimum concentration in the atmosphere is necessary for life existence on Earth; [1] with reference before industrial revolution of the 18^{th} – 19^{th} centuries, CO_2 global emissions scaled up from around 280ppm to 450ppm values presented by 2005, with a forecast to 750ppm by 2050 and expecting to reach 1,200ppm by the end of this century; [2] Climate Change is taking place and human activity is directly related to it, with anthropogenic component of global warming and climate changes directly affecting species and natural biological systems. Current world population counts around 6.93 billion people [3] and is forecast to 50% increase by 2050. The world´s real income [4], valid approach concerning world GDP (Gross Domestic Product) and standard of living trend, apparently it has grown by 87% over the past 20 years, even the financial crisis faced in 2008.

At a global level more people with more income means that the consumption and production of energy will raise. The rise in standard of living indicators and world real income observed is driven by the Non-OECD countries, mainly China, [5] with developing economies pushing up production, demanding infrastructures, hospitals, more comfortable homes, commercial services and the like.

World energy consumption [5] is expected to move up more than 45% from 2007 to 2035, with electricity generation use accounting for 57% of the growth to 2030. According to the IEA global electricity will nearly double from 2005 to 2030, stating that fossil fuels will comprise about 70% of global and 60% of European electricity generation.

Coal will remain a key player accounting today for about 27% of the global energy consumption, and provides the largest share of world electricity generation accounting for 42% in 2007 [5], it is about 7 trillion kWh. Currently in Europe some 30% of European electricity is generated from coal, it is 3,358 TWh for the EU27 [6]. According to the IEA forecast, coal consumption increases by 1.6% per annum on average from 2007 to 2035, but most of the growth in demand will occur after 2020. Only between 2002 and 2007 worldwide coal consumption increased by 35%, largely because of the growth in China´s coal use. China alone accounts for 78% of the net increase in world coal consumption, whereas India and the rest of non-OECD Asia account for 17% of the world increase.

Strong growth on the use of coal, specially by the non-OECD countries, translates into continuous increase of CO_2 global emissions. Values between 0.9 and 0.6 tCO_2/MWh are released depending on the coal type and technology. Based on IEA tables, currently global emission figure is about 27 Gt CO_2, and WEO 2009 [7] forecasts in its reference scenario that world emissions will reach 40.2 Gt CO_2 by 2030.

2. Scenario and evaluation study of CCS deployment

Application of Carbon Capture and Storage Technologies stands out from three promising measures set to contain global CO_2 emissions under necessary and objective limits. To increase the use of renewable energy and to improve energy efficiency are the two other options for reducing greenhouse gas emissions. Carbon Capture and Storage (CCS) concept comprises different technologies for CO_2 capture, transport and storage, to attend the three stages of the whole chain of CO_2 removal from fossil fuel combustion, particularly applicable to coal fueled power stations.

Potential impact of CCS is estimated in 2030 between 2 and 4 Gt/y of CO_2 abatement globally [8]. For Europe it is forecast at 0.4 Gt/y, which is around 20% of the total European abatement potential.

Post-combustion, Pre-combustion and Oxy-combustion are three ways to remove CO_2 from coal fired power stations concerning capture stage, and they depend on where and when the capture process is located referred to CO_2 formation.

Post-combustion refers to the installation of capture units that process flue gas after coal is combusted. Pre-combustion capture is applicable to coal gasification power stations (normally termed IGCC or Integrated Gasification in Combined Cycle), in which coal is partially oxidised. The capture unit to process syngas can be installed after a shift reaction occurs to raise H_2 and CO_2 concentration, then CO_2 is removed and syngas comprising mostly H_2 will be burnt. Oxy-combustion implies the combustion of coal in oxygen as high-purity oxidant stream, hence in a nitrogen depleted atmosphere; flue gas is highly concentrated in CO_2 which is then removed by dehydration and compression cycles.

Considering post-combustion processes, chemical absorption stands like the most promising technology to be implemented, with large experience through many years deploying in refineries and fertilizer processing facilities. Its application to a 400 MW_e coal fired power station tackles with relatively low CO_2 concentration levels of about 12 – 14%, and with very high flue gas stream of about 1.3 million Nm^3/h at atmospheric pressure. In the short term chilled ammonia and amine base solvents will result the most promising solvents to be implemented in a regeneration process comprising absorption and regeneration phases. Capture efficiency rates over 90% would be achieved. An influence on the overall efficiency (efficiency loss) of the coal fired power station is expected, mainly due to regeneration phase of the capture process and chemical composition of the solvent. Alternative adsorption processes are under research but CO_2 capture efficiencies achieved at the time, by testing different adsorbents based on very porous materials under particular conditions, are still low compared to chemical solvents.

Regarding pre-combustion, there is extensive experience in natural gas and synthesis gas treating industry, with available technology to process similar flows to coal gasification power stations or IGCC, it is about 200,000 Nm^3/h. Main features of the application of this technology to IGCC are syngas entering unit capture process at an inlet pressure between 12 – 30 bar, with CO_2 concentration levels between 30 – 40 % after shift reaction and variable presence of sulphur compounds. Capture efficiency rates over 90% would be achieved, by using available licensed processes based on chemical and physical absorption. Moreover, implementation of non-selective processes removing CO_2 and sulphur compounds (H_2S and COS) simultaneously would be possible. Regeneration phase of the chemical or physical solvent is also energy consuming and influences on the overall efficiency of IGCC coal power station. Alternative capture processes comprising physical adsorption and membranes are being researched, but still are not ready to compete with chemical processes in the short term.

Technology associated with Oxy-combustion processes has grown and improved rapidly during the last five years. Oxy-coal combustion power station will require, but it will not be limited to, the following units: Coal Storage, ASU (Air Separation Unit), O_2 Storage, Oxy-combustion boiler, Flue gas recirculation system, Flue gas cleaning unit (SO_2 removal and ESP principally) and CPU (Compression and Purification Unit). These required units will have impact on the overall efficiency of the power station, depending on scale of integration of the different units that will be achieved. For instance oxygen produced [9] by ASU implies a specific energy consumption of 180 kWh/tO_2 and about 160 kWh/tO_2 would be achievable with heat integration of the unit. Separation energy values [10] around 140 kWh/tO_2 are expected with heat integration by 2015. Additional efficiency penalty of the oxy-coal power station will come from energy consumed by the CO_2 compression process; its integration would be study. Oxy-combustion processes will draw oxygen concentration levels in stream varying from 27 to 75%. The application of oxy-combustion in coal fired power stations implies recirculation of flue gas to oxy-boiler to reach CO_2 concentration levels of ca.90%.

Then the flue gas is compressed into the CPU, where basically water condenses and CO_2 is compressed up to 90 bar at 25°C (variable, depending on integration strategy), making it ready to put on to transport step.

The next **Table 1** shows possible application of CO_2 capture processes and technologies to different coal fired power station configurations according to the systems of CO_2 capture presented before.

Table 1. Possible CO2 Capture Technologies Applicable

PRE-COMBUSTION	POST-COMBUSTION	OXY-COMBUSTION
ABQ – ABF – ABFQ – ADF	ABQ – ADF	ASU + CPU
WGS + (Selexol, Rectisol, Purisol) / WGS + Sulfinol / Amines	Amines / Chilled Amonia / Carbonation+Calcination Cycle	Oxy-mode / Carbonation+Calcination Cycle
IGCC	PC / SC PC / USC PC / CFB	

Abbreviations:

i) Processes: ABQ: Spanish term for Chemical Absorption; ABF: Spanish term for Physical Absorption; ABFQ: Spanish term for Chemical-Physical Absorption; ADF: Spanish term for Physical Adsorption

ii) Technologies: WGS: Water Gas Sift Reaction

iii) Coal fired power station configuration: PC: Pulverised Coal; SC: Supercritical (250-300 bar & 600°C); USC: Ultra Supercritical (350-375 & >700°C); CFB: Circulating Fluidised Bed

It is important to evaluate the impact of implementing CO_2 capture processes on the overall energy efficiency of coal fired power stations. Next **Table 2** presents a comparison of expected energy efficiency % for different power station configuration with (w) and without (w/o) CO_2 capture implementation, made by data evaluation of several reports [9, 10, 11, 12, 13].

Table 2. Evaluation of %Efficiency for Coal Fired Power Stations

PC (w/o)	PC (w)	CFB (w/o)	CFB (w)	IGCC (w/o)	IGCC (w)	SC PC (w/o)	SC PC (w)	USC PC (w/o)	USC PC (w)	Oxy PC	Oxy CFB	Oxy SC PC	Oxy USC PC
36–38	26–28	36–40	25–28	42 – 44	32–34	38 – 40	28 – 29	43 - 45	33 - 34	26-28	25 - 29	30-34	32-38

Notes: Number range in %; for abbreviations meaning please referred to Table 1

CO_2 Transport might not represent a big issue within the CCS deployment, apart from infrastructure investment costs, adequate monitoring during transport and availability of clear and efficient regulation. Transportation of carbon dioxide can be by tanks, onto ships or trains, and by pipe lines depending on the CCS strategy, integrated project definition and cost analysis. [11] Pipelines for transporting nearly 30 million tCO_2/y for EOR are available in some regions of the United States.

Storage of carbon dioxide is a crucial link of the chain to make CCS feasible. Many official studies have been carried out in order to evaluate necessary removal capacity of the total CO_2 amount, which results from the potential application of CO_2 capture technologies [14].

Due to the large amount of CO_2 expected to be necessarily removed, only little portion would be used by industrial sector (food / beverage industry and fertiliser production). Storage appears the only option short term to reduce the huge amount of CO_2 emitted.

Three ways of CO_2 storage are considered: geological storage, ocean storage and mineral carbonation [11]. Only geological storage would be applicable in the short term. The options for geological storage are sequestering into deep saline aquifers and EOR (Enhance Oil Recovery) or EGR (Enhance Gas Recovery), which consists in pumping CO_2 at particular conditions into depleted oil or gas fields to improve fossil fuel extraction.

World storage required in 2050 will be about 144.7 $GtCO_2$ [14]. Potential viable capacity of 1,680 $GtCO_2$. Only for OECD Europe this potential is 94 $GtCO_2$.

3. Results and Discussion

According to the vision provided by the IEA CCS Technology Roadmap 2009, some 100 commercial-scale CCS projects must be operational worldwide by 2020 and 3,400 by 2050 if global warming is to stay below 2°C [15]. The principal metric used to define commercial scale integrated projects are those with a storage capacity rate of 1 million tCO2/y or greater [16].

Achieving 0.4 $GtCO_2$ abatement per year from CCS in Europe by 2030, would require the installation of between 80 and 120 commercial scale CCS projects [8]. It is likely to develop as a series of capture clusters, all connected into a common transport and storage network. To reach this range of power stations in operation would be necessary to evaluate and prove the technical and economical feasibility of integration projects comprising capture, transport and storage of carbon dioxide, hence in a previous demonstrations scale.

For European market, studies shows that first demonstration projects will have a CO_2 reduction cost between 60 – 90 €/tCO_2, considering capture, transport and storage and assuming similar costs for capture process selected [8]. First commercial scale projects would have around 35 – 50 €/tCO_2, forecast 30 – 45 €/tCO_2 achievable by 2030. Distribution of the total will be 64 – 72% for capture, 11 – 12% in transport and 11 – 24% in storage.

Construction of new built coal fired power stations implementing CO_2 capture technologies will bring better results than retrofit existing ones [8], mainly because of high efficiencies reached by the implementation of new technology and units.

In the year 2010 there are globally 238 active or planed CCS projects [16], with 151 projects integrated. From the total, up to 80 are large-scale integrated projects, presenting the following relation by technology implementing: 33 Pre-combustion, 22 Post-combustion, 13 Gas processing, 2 Oxyfuel combustion, 3 Pre-combustion and Post-combustion, 1 Pre-combustion and Gas processing, 1 Oxyfuel combustion and 5 not specified.

On 9 December 2009, the European Commission announced details of the 6 CCS demonstration scale projects (around 300 MW_e) which receive funding of 1 billion € under the EEPR [17]. The origin of EEPR (European Energy Program for Recovery) is the global 200 billion € European Economic Recovery Plan presented by the Commission at the end of 2008. The six projects selected are Belchatow (Post-combustion, Poland), Compostilla (Oxyfuel, Spain), Hatfield (Pre-combustion, UK, location/project to be confirmed), Jänschwalde (Oxy + Post-combustion, Germany), Porto Tolle (Post-combustion, Italy) and Rotterdam (Post-combustion, The Netherlands). Final Investment Decision for the construction of these projects is scheduled by middle 2012, bearing further funding under the NER300 (New Entrant Reserve), in principal only for selected ones. NER makes funding available for commercial-scale CCS projects, with the funds generated through the sale of 300 million EU ETS allowances for the New Entrant Reserve of Phase 3 of the EU ETS. The European Commission estimates that the sale of these allowances will raise between 15 – 30 €/tCO_2, dependent on the carbon price.

The UK Demonstration Programme, managed by the OCCS (Office Of Carbon Capture and Storage), part of the UK Government´s DECC (Department of Energy and Climate Change), will fund 4 CCS commercial-scale projects, involving coal and gas fuel, with up to £1b to support the capital cost of the first one ongoing [18]. Main features of the UK Demonstration Programme are: alignment with NER300 schedule and compatibility with other funding programme; projects will receive a fixed strike price per tCO_2 abated, and therefore the fund received will be strike price minus EAUs (EU ETS);

requirements and specification of CO_2 transport will be proposed by the Project Proposer; no onshore storage projects will be funded; only will be funded offshore UK storage in compliance with storage terms of the Energy Act 2008, Storage Carbon Dioxide Regulation 2010 and the EU Directive 2009/31/CE.

US Power generation sector produced more than 40% of total US anthropogenic CO_2 emissions in 2008, and the majority result from the combustion of coal, about 1.9 billion tCO_2 [11]. EPRI and other recent studies result that wide-scale deployment of CCS provides the largest share of potential CO_2 reduction. The CCPI (Clean Coal Power Initiative) will begin to demonstrate, by 2015, commercial-scale capture and storage or beneficial reuse technologies that target to achieve 90% capture efficiency for CO_2 to enable subsequent commercial deployment in the coal fired utility industry.

Under the CPPI Programme [11], 7 CO_2 capture demonstration projects in USA are planed and ongoing. 3 of them Pre-combustion technology related, another 3 of them Post-combustion related and only 1 will demonstrate Oxy-combustion deployment.

Within the USA framework, the Recovery Act funding is being used for the following CCS related activities [11]: CCPI with a total of $800 million; Industrial Carbon Capture & Storage with a total of $1.5 billion; around $20 million for scale-up a current project; a total of $100 million is being used to characterize about 10 geological formations; a total of $20 million is being used in education related to CCS sector; FutreGen 2.0 with a total of $1 billion for the construction of Oxy-combustion power station to capture 1 million tCO_2/y since 2015; Carbon Capture and Storage Simulation Initiative with a total of $40 million is being used to accelerate CCS technology development using advanced simulation and modeling techniques; and the National Risk Assessment Partnership to develop the tools and science base for ensuring long-term storage.

In China, the GreenGen Project ongoing will demonstrate the feasibility of 250 MW IGCC in 2009, scale up to 400 MW and 25% CO_2 captured by 2015.

According to OECD/IEA currently exist more than 20.000 km of CO_2 pipeline globally, and forecasts the total CO_2 pipeline needs over 200.000 km for the period 2030 – 2050 contingent on the level of optimisation in building common carriage networks able to link multiple sources and storage sites.

Currently, a pan-European project called GeoCapacity is underway in order to provide a comprehensive database of European CO_2 storage availability.

4. Conclusions

Coal reserves are widespread and the international coal market ensures that demand is largely met from the most economic suppliers. Coal will represent, at least, a steady share of the World Primary Energy demand over the next 20 years and the future contribution to power generation relies mostly on how coal's carbon intensity can be coupled with sustainable emission levels. CCS and clean coal technologies are paving the way to meet the most demanding greenhouse-gas emission targets and the design of the future coal power stations will be more capital intensive and more sustainable.

Acknowledgment

Special thanks to Javier Pisa for his outstanding support.

References

[1] IPCC – CO2 equivalent - IPCC data base

[2] IPCC 4Assessment Report 2007

[3] U.S. Census Bureau

[4] BP 2011, Energy Outlook 2030

[5] International Energy Outlook 2010

[6] The Role of Coal Power Generation 2008, EURACOAL statistics, official website

[7] World Energy Outlook 2009

[8] McKinsey&Company 2008 – Carbon Capture & Storage: Assessing the Economics

[9] Air Liquide Technical Papers 2010 – Air Separation Unit for Oxy-coal Combustion

[10] Air Liquide / B&W Technical Presentations 2010 – Oxy-coal Combustion for Demonstration Plants

[11] DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap – December 2010

[12] International Energy Agency, Clean Coal Technologies, 2008

[13] MIT, The Future of Coal, 2007

[14] OECD/IEA, Carbon Capture & Storage Roadmap, 2010

[15] CO2 Capture Project, Annual Report 2010, April 2011

[16] Global CCS Institute, The Status of CCS Projects, Interim Report 2010

[17] CCS European Energy Program for Recovery (EEPR), Energy European Commission website 2010

[18] UK Department of Energy and Climate Change, UK CCS Commercial Scale Demonstration Programme, Delivering Projects 2-4, December 2010