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A Review on: CO_2 Capture Technology on Fossil Fuel Power Plant

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Abstract

World energy consumption has been increasing steadily since industrialization, and especially within the last 30 years, this recent increase is also the major cause for the increase in CO_2 concentration in the atmosphere, climate change is a key issue in power industry. Fossil fuels play a central role in our energy consumption. To make progress in low carbon development, more efforts should be made, in order to set up ways to reduce GHG emissions under current social, economic, technological and resource conditions. This task will undergo pressures and face challenges, but will also provide incentives and opportunities. This paper discusses the perspectives for development at the Progress on Carbon Capture Use and Storage (CCUS/CCS) in fossil fuels Power Plants, which is a vital component to reduce future carbon emissions, in the global fight against climate change.

This year, power companies began invitations for tenders of the new thermal power facilities. The increase of them, however, brings up another serious issue: how to cope with combating global warming. That is why CCUS/CCS is receiving more attention nowadays together with the discussion on carbon dioxide emission reduction. Electric machinery companies, putting focus on CO_2 capture technologies have successfully developed the capture technologies for coal and gas fired power stations with their own funds and/or in collaboration with power companies. To do this, they undertook a process to investigate various methods such as adsorption, absorption, membranes and cryogenic, through which they obtained abundant data on pros and cons of the technologies.

This paper analyzed the growth of CO_2 emissions by fossil fuels. We show the CCS projects status; Challenges, SWOT analysis, and the currently Global CCS Technology Activity. For this, we consider the Large Scale Integrated Projects (LSIP). Besides, we make a review of the methods of separation of CO_2, their status, advantages, challenges, etc.

Keywords: Power fossil fuel plant; CO_2 emissions; CCUS CCS technologies; Large scale integrated CCS projects; Separation methods

Introduction

Actually at least 3.6 billion people lack adequate access to electricity and 1.6 billion have no access to electricity in their homes and consequently are without means for electric lighting, mechanical power, and telecommunications. Besides, it is estimated that worldwide there are 2.4 billion people–more than one third of humanity–who rely on wood, charcoal, and dung as their principal source of energy for cooking and heating [1]. It is estimated that four out of five people in a developing world, live in rural areas without electricity, mainly in South Asia and Sub Saharan Africa. According to the International Energy Agency (IEA) these figures will remain largely unchanged in 2015 unless new policies are adopted to expand investment in rural energy infrastructure. In fact, the IEA estimates that a total of US$200 billion worth of investment in electricity will be needed to help half the proportion of people living on less than US$1 a day by 2015. This amount is in addition to the US$5.8 trillion needed just to meet existing projections in electricity demand [2].

Energy is strongly linked to human development; there is no country in modern times that have substantially reduced poverty without a massive increase in its use of energy and/or a shift to efficient energy sources. The provision of electric power is one of the prerequisites of prosperity. Across the world economies indicators signal that there will be continued growth and increased electricity demand.

Coal has played a major role in electrical production since the first power plants that were built in the USA in the 1880's. Presently, coal power is still based on the same methods started over 100 years ago, but improvements in all areas have brought coal power to be the inexpensive power source used so widely today, also the cost of coal fired power is low compared to the alternatives in the near term. Since planning of new coal fired power plants occurs as much as a decade in advance, there is not likely to be a major change in the forecast through 2020. There is also a strongly growing demand for natural gas, a clean capable of being used in power generation with high efficiency.

CO_2 is the primary anthropogenic greenhouse gas, accounting for 77% of the human contribution to the greenhouse effect in recent decade (26 to 30 percent of all CO_2 emissions). Main anthropogenic emissions of that come from the combustion of fossil fuels. CO_2 concentration in flue gases depends on the fuel such as coal (12–15 mol % CO_2) and natural gas (34 mol % CO_2) [3].

Carbon Capture Use and Storage (CCUS) is the most indicated technology to decrease CO_2 emission from fossil fuels sources to atmosphere. Also, CO_2 separated from flue gases can be used in enhanced oil recovery (EOR) operations where CO_2 is injected into oil reservoirs to increase mobility of oil and reservoir recovery [4,5]. Pure CO_2 has many applications in food/beverage and different chemical industries such as urea and fertilizer production, foam blowing, carbonation of beverages and dry ice production, or even in

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the supercritical state as supercritical solvent [6-8]. With eight major CCS projects anticipated to be implemented in a range of industries worldwide by 2016, this low carbon technology is reaching the critical mass necessary for widespread deployment. Brad Page, CEO of the Global CCS Institute, said, "CCS in the power sector is now a reality with the world's first large scale CCS project operating at Boundary Dam, Canada. " There are now 22 projects in construction or operation worldwide, a 50% increase since 2011. The report details progress on CCS over the past year, provide a raft of recommendations for decision makers [9].

Energy Overview to 2008 2035

According to the IEO2011 Reference case [10] the projections are as follows in the Figure 1. According to these studies:

The World net electricity generation increases by 84%, from 19.1 trillion kilowatt hours in 2008 to 25.5 trillion kilowatt hours in 2020 and 35.2 trillion kilowatt hours in 2035.

Total net electricity generation in non OECD countries increases by an average of 3.3% per year, led by non OECD Asia (including China and India), where annual increases average 4% from 2008 to 2035. In contrast, net generation among OECD nations grows by an average of 1.2% per year in the same.

In many parts of the world, concerns about security of energy supplies and the environmental consequences of GHG emissions have spurred government policies that support a projected increase in renewable energy sources. As a result, renewable energy sources are the fastest growing sources of electricity generation at 3.1% per year from 2008 to 2035.

Natural gas is the second fastest growing generation source, increasing by 2.6% per year. An increase in unconventional natural gas resources, particularly in North America but elsewhere as well, helps keep global markets well supplied and prices competitive. More than 82% of the increase in renewable generation is in the form of hydroelectric power and wind power.

Electricity generation from nuclear power worldwide increases from 2.6 trillion kilowatt hours in 2008 to 4.9 trillion kilowatt hours in 2035, as concerns about energy security and GHG emissions support the development of new nuclear generating capacity. 75% of the world expansion in installed nuclear power capacity occurs in non OECD countries. China, Russia, and India account for the largest increment in world net installed nuclear power from 2008 to 2035: China adds 106 GW of nuclear capacity over the period, Russia 28 GW, and India 24 GW.

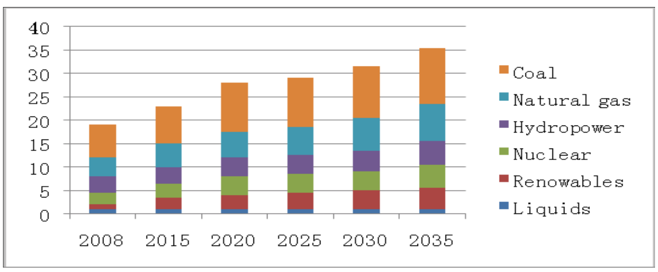


Figure 1: World net electricity generation by fuel type, 2008-2035 (trillion kilowatt-hours) [10].

Future generation from renewable, natural gas, and to a lesser extent nuclear power largely displaces coal fired generation, although coal remains the largest source of world electricity through 2035.

Until September 2013 according to the data from EIA [11], the main production of energy of the world comes from Coal and Natural Gas such as fuels, as showing in the Figure 2. In this paper we focus on these fuels.

Electric Generation - Natural Gas Vs. Coal

In the natural gas versus coal discussion, there are some issues in consideration.

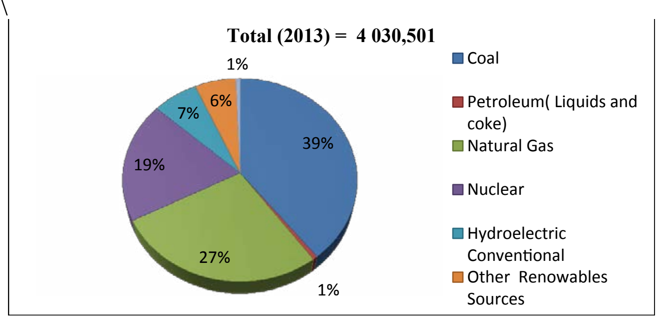
The coal supply is safer in respect to the other fuels for the following reasons:

Coal reserves are abundant and distributed in more than 100 countries, while oil and gas reserves are concentrated within few countries and many of these countries are politically instable;

Unlike natural gas, coal is not suitable for dispersed on-site use. Coal can be used most effectively where it permits the user to enjoy the economics of scale of large units and coal delivery by ship, barge, unit train or conveyor (for a mine mouth plant). Coal has high availability of coal extraction, transportation, storage and handling systems on worldwide basis.

Natural gas also allows for smaller 'distributed generation' as opposed to large centralized plants, providing autonomy and electricity security at a more localized level. The US Department of Energy, EIA, estimates world proved NG reserves to be around 5,210.8 Tcf , most of these reserves are located in the Middle East with 34% of the world total, and Europe and the Russia with 42% of total world reserves.

Price differentials between coal and natural gas are projected to grow larger in the next future. While coal prices are expected to remain stable (depending also upon region and coal quality) natural gas prices are expected to increase as higher cost natural gas reserves need to be developed to meet growing demand and offset losses from depleting gas wells. Another factor increasing the cost of the natural gas is its high transportation cost both through pipeline line and through the liquefied natural gas chain. Coal-based technologies offer a significant fuel price advantage over its natural gas based competitors to virtually any power plant location. On the other hand, NG based technologies have a capital cost advantage over coal technologies.



Period	Coal	Petroleum Liquids	Petroleum Coke	Natural Gas	Nuclear	Hydroelectric Conventional	Other Renewables Sources	Other	Total
2013	1,586,375	13,268	12,323	1,109,920	774,595	270,836	244,266	24,537	4,030,501

Figure 2: Net Generation by Energy Source (Thousand Megawatt hours) 11].

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The CO_2 emissions from NGCC plants are reduced relative to those produced by burning coal given the same power output because of the higher heat content of natural gas, the lower carbon intensity of gas relative to coal, and the higher overall efficiency of the NGCC plant relative to a coal-fired plant. Compared to the average air emissions from coal-fired generation, NG produces half as much CO_2, less than a third as much NOX, and 1% as much Sulphur oxides at the power plant.

The Technology Choices and Their Costs (excluding CCS) Plant capital costs are significantly different between the coal and the natural gas fired power generation options. Natural gas based technologies have lower capital costs than coal based technologies and this difference is also depending from the technology selected for coal generation option. This capital cost advantage of the NG plants is ranging between \$500 to \$1000/kW depending upon the assumptions used that is fuel source, required by authorities environmental limitations, selected technology for the coal fired plant, major equipment redundancy, plant site location and labor cost on the plant site.

Carbon Dioxide Emissions Intensity

CO_2 emissions from fossil fuel burning and cement production increased by 2.3% in 2013, with a total of 9.9 ± 0.5 GtC (36 $GtCO_2$) emitted to the atmosphere. These emissions were the highest in human history and 61% higher than in 1990 (the Kyoto Protocol reference year). In 2013, coal burning was responsible for 43% of the total emissions, oil 33%, gas 18%, cement 5.5%, and gas flaring 0.5% as seen in Figure 3. Emissions are projected to increase by 2.5% in 2014, to a record high of 10.1 ± 0.5 GtC (37 ± 1.9 $GtCO_2$), 65% above emissions in 1990. Total cumulative emissions (the sum of the total CO_2 emitted) from 1870 to 2013 were 390 ± 20 GtC from fossil fuels and cement, and 145 ± 50 from land use change. This total of 535 ± 55GtC was partitioned among the atmosphere (225 ± 5 GtC), ocean (150 ± 20 GtC), and the land (155 ± 60 GtC) [12].

At the 2011 year the CO_2 emissions by sector as following in Figure 4.

- The electricity and heating sector are the largest sources, producing over 13Gt in 2011, being equivalent to more than 40% in 2000. The power generation sector plays an important direct role by reducing substantially its carbon intensity, but electricity now plays an indirect role by substituting for fossil fuels in all final demand sectors (Figure 5).

- Transport emissions, including international aviation and ships, these are the main sources of emissions in end-use, constituting just under 7Gt in 2011. The oil dominates land transport, which comes with an average increase of 1.7% annually since 2000.

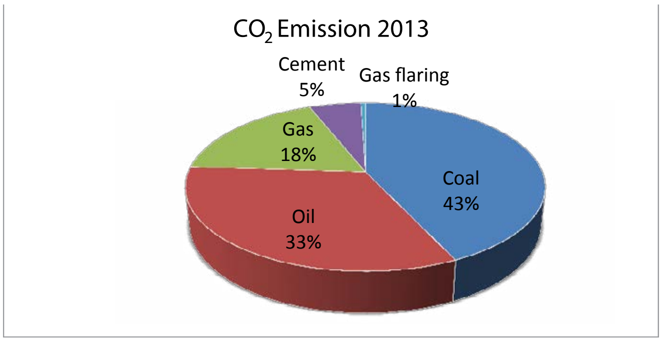

Figure 3: Total CO_2 Emission at 2013.

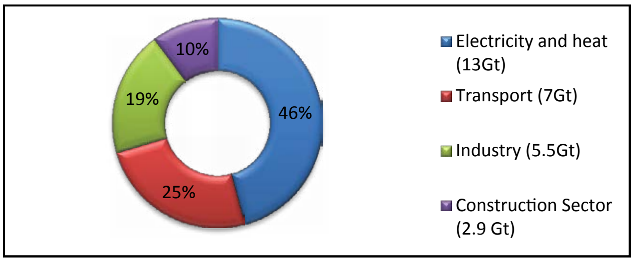

Figure 4: CO_2 Emissions by Sector in 2011 [13].

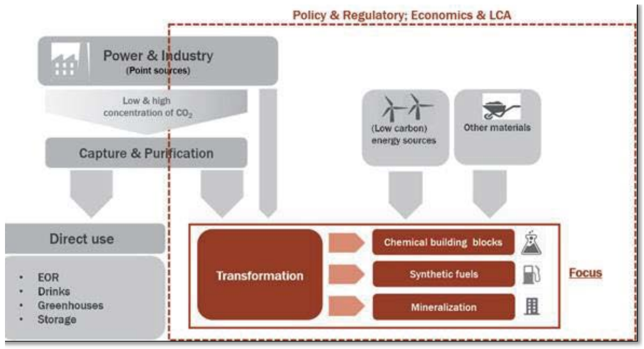

Figure 5: Scheme of Carbon Dioxide Capture, transportation use and orage [17].

- Emissions from industry have increased 38% since the 2000s, reaching 5.5 Gt.

- The total CO_2 emissions related to the construction sector (including residential and services) reached 2.9 Gt by 2011. Natural gas is the largest source with about 50% of the total, mainly in the U. S. and Europe.

Without additional abatement measures, the WEO 2012 [14] projections by 2035 are as follows:

- Emissions from coal will grow to 15.3 $GtCO_2$ in 2035. However, through use of more efficient plants and end-use technologies as well as increased use of renewable, nuclear and CCS technologies could see coal consumption drop and CO_2 emissions from coal reduced to 5.6 Gt.

- Emissions from oil will grow to 12.6 $GtCO_2$, mainly due to increased transportation demand.

- Emissions from gas will continue to grow, rising to 9.2 $GtCO_2$.

Carbon Capture and Use-Storage (CCUS) as a Potential GHG Reduction Alternative

According to the Working Group III on the "Mitigation of Climate Change" of the Intergovernmental Panel on Climate Change (IPCC) at the Assessment Report, dealing with the economic, technological and political measures to mitigate climate change; the scientists unequivocally demand that action has to be taken now if the 2 degree goal is to be achieved. "If we wait until 2030, as the window of opportunity closes faster and faster, everything will become considerably more difficult, risky and expensive," warned Ottmar Edenhofer, Co-Chair of the working group [15].

Potentially, there is a wide range of ways to reduce emissions of GHG, most of the efforts to mitigate global warming have concentrated on reducing CO_2 emissions, different technology option have been proposed and explored in order to achieve a sustainable low carbon energy society. "CCUS will be a key technology to reduce CO_2 emissions, not only from coal, but also gas and industrial sources. The International Energy Agency has estimated that CCUS could deliver 14% of cumulative GHG emissions cuts through to 2050 and that climate change action will cost an additional US$4.7 trillion without CCUS. However, in comparison to other low carbon technologies, CCUS is underfunded. Nuclear and renewable energy projects (excluding hydroelectricity) receive US$45 billion and US$27 billion in public funds respectively every year. In comparison, in the decade since 2005, only US$12. 2 billion has been available to fund CCUS demonstration…in total," continued Mr Sporton. "It is vital that negotiators in Lima support all low emission technologies if we are to have an effective and sustainable climate response, which integrates environmental imperatives with the legitimate aims of energy security and economic development, including poverty alleviation" [16].

CCUS is a technology that can reduce the amount of CO_2 released into the atmosphere from the use of fossil fuel in power plants and other industries such as from steel, cement and ammonia manufacture; also it enables the reduction of other pollutants like SO_X, NO_X, and particulate matters.

In addition, recycling CO_2 emissions into products could become key in achieving these goals unlocking innovative business models and increasing the competitiveness of the European industry. The SCOT project (Smart CO_2 Transformation) is a collaborative European project (supported by the Seventh Framework programmers) aims to coordinate research and policy efforts across Europe to achieve this high level goal. Through a stronger coordination of the efforts of the Consortium partners, the SCOT project will lead:

- To the definition of a Strategic European Research and Innovation Agenda (SERIA) aimed at improving the techno-economic performance of emerging CO_2 transformation technologies and at developing new breakthrough solutions and market applications;

- To the creation of a network of actors willing to contribute to the implementation of the SERIA

- To the proposition of structural policy measures to favor the transition to a new European society based on the positive paradigm of "CO_2-as-a-resource" [17].

The project focuses on the recycling of CO_2 through its transformation into valuable products via chemical or biological technologies. The work is structured along three different valorization routes for CO_2 re-use: CO_2 chemistry to make chemical building blocks, CO_2 used to create synthetic fuels and mineralization of CO_2 into building materials.

For now, SCOT has established a fairly comprehensive inventory of the business models that lead to CO_2 transformation into value added products. In terms of technical and economical bottlenecks, enabling policies and process optimization to achieve cost-efficiency are clearly standing out as common needs for the development of all three valorization routes. In terms of drivers, funding availability to set-up pilot plants to ease the transition to commercial entities will be essential [17].

Technology CO_2 Capture

Capturing the CO_2 is the first stage; this can be done in several ways. Broadly, three different types of technologies exist: Post-combustion, Pre-combustion, and Oxy-fuel combustion. We focus on the Post – Combustion Technology.

Post combustion capture and separation methods: This system capture CO_2 from the flue gases produced after fossil fuels or other carbonaceous materials are burned. Combustion – based power plants provide most of the world's electricity today. Existing post-combustion capture methods rely primary on the chemical absorption of the CO_2 in a solvent (amines are most commonly used).

Post combustion capture is a well-established technology which can be delivered commercially but needs scaled-up engineering and optimization to be able to be applied to large scale power plants. Therefore, the challenge for post-combustion capture systems is to develop new designs for commercial-scale applications in large industrial facilities.

Post-combustion capture system (Figure 6) includes the power plant island and a large scale new device to separate the CO_2 from flue gas after combustion at low pressure (atmospheric) and low CO_2 content (3-20%). The capture unit is an end-of-pipe unit, even if the power and capture plant are partly integrated as steam is extracted from the power plant for CO_2 regeneration.

On the Post-Combustion CCS system, after the combustion; CO_2 is captured from a gas mixture with predominantly H_2 gas at low pressure (101,3 kPa) and low CO_2 concentration about 14-20% in case of the coal and 4-5% in case of natural gas. The separation task is to remove CO_2 from a mixture of mainly nitrogen (N_2) and oxygen (O_2),but the impact of flue gas impurities (SO_X, NO_X, particulates) also needs to be taken into account.

The separation of CO_2 from gas streams can be achieved by several physical and chemical separation methods, which can be seen as the technological platforms, these methods are as follows:

- Membranes, using selective barrier materials with different gas permeability to separate gases in a continuous process.

- Absorption, using liquids with strong affinity to one or more of the components to separate gases in a cyclic operation.

- Adsorbents, using solids with a strong affinity to one or more of the components to separate gases in a cyclic operation.

- Cryogenic, using different in points of condensation or solidification to separate gases.

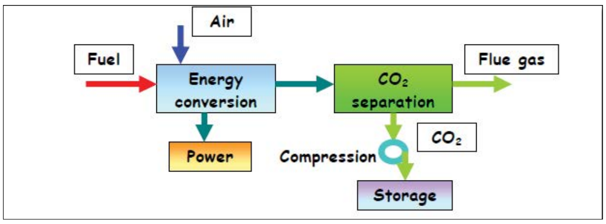

Figure 6: Post Combustion Scheme [18].

CO_2 Separation Technologies	Absorption Amine	Ammonia	Adsorption	Membranes	Cryogenic
Description	Using liquids with strong affinity to one or more of the components to separate gases in a cyclic operation.		Physical adsorption, involves relatively weak intermolecular forces, include dispersion, dipolar or Van der Waal interactions between the absorbent surface and the adsorbate CO_2 molecules.	Using selective barrier materials with different gas permeability to separate gases in a continuous process.	-Using different in points of condensation or solidification to separate gases. -Use a distillation column.
Advantages	- Good stability of absorbent. - Enhancement role used as additive - Can be retrofitted to existing coal-fired power plants.	-Ammonia is inexpensive. - Low energy requirement for absorbent regeneration. - Large absorption capability and high loading capacity - Utilization of products as fertilizer. - Wide distribution of absorbent	-Sorbent materials have lower heat capacity than solvents and thus require less regeneration energy to change their temperature. -They also have the potential for significant energy savings over liquid solvents.	-Not require a separating agent, no regeneration is required, not contain any chemical reactions or moving parts, making it simple to operate and maintain. - The membrane material has a high tolerance of wet acid gases and is inert to O_2. -Modular design allows optimization of process arrangement by using multi-stage operation. - Low energy cost. -The system is compact and light weight, so low maintenance requirements because there are no moving parts in the membrane unit. -Membranes tend to be more suitable for high-pressure process such as IGCC.	-The substantial energy savings of this process directly lead to significant cooling water decreases relative to other carbon capture processes - Reduces water demand by between 25-30%
Challenges	- Energy penalty, high energy demand for regenerating the solvent - Some amines and amines degradation products can have negative effects on human health (irritation, sensitization, carcinogenicity, genotoxicity), also be toxic to animals and aquatic organisms, and eutrophication and acidification in marine environments. -Developing new solvents that reduce the energy required to release the CO_2 from the solvent. -Easy degradation by SO_2 and O_2 in flue gas -Plot space requirements are significant.	-Ammonia is a toxic gas; prevention of ammonia “slip” to the atmosphere is a necessity. - Easy to volatilize and leak. -Thermal instability of products. -Corrosion to equipment.	-Developing new materials such as carbon-based sorbents, metal organic frameworks (MOFs), zeolites, immobilized amine sorbents, and regenerable solid sorbents. -Heat required reversing chemical reaction. -Heat management in solid system is difficult. -Pressure drop can be large in flue gas applications. -Sorbent attrition may be high.	-Requires high selectivity (due to CO_2 concentration and low pressure ratio). -Multiple stages and recycle streams may be required. -Requires a large membrane surface area to achieve separation due to the low partial pressure of CO_2 in flue gas. -The countercurrent sweep module design could result in several potential inefficiencies. -Particulate matter needs to be controlled to reduce its potential impact on the membrane lifetime. -Feed and permeate side pressure drops may lead to excessive energy losses. - Cost reductions for the membrane materials will be needed if the technology is to become economically viable.	The liquefaction process is energy intensive and is therefore only suitable for application with high CO_2 concentrations.
Process Design	- The Kerr-McGee/ABB Lummus Crest process, (15-20 wt% aqueous MEA solution) (Coal-fired power) [19] - The Fluor Daniel Econamine process (30 wt% MEA) (Coal-fired power) [20] - The KEPCO/MHI process, (Coal-fired power) - High Pressure Acid Gas Capture Tech. (NG power plant)	-The Alstom Chilled Ammonia Process (CAP), they can be applied to both coal-fired and NGCC power plants [21]. -The Powerspan ECO2 process can be installed following a conventional SO_2 scrubbing technology, or can be installed downstream of Powerspan’s ECO or ECO-SO2 multi-pollutant control technologies [22].	-Post-combustion fluidized bed system for CO_2 capture (Lime Carbonation/ calcinations) [18].	- MTR’s CO2 capture membrane process (Membrane technology and Research process) [23].	The cryogenic CO_2 capture (CCC) process [24].
Currently status	Commercially available for post-combustion carbon capture on coal-fired power stations.	Large pilot testing. WorleyParsons Group Inc. assessment of the ECO2 pilot unit for new and retrofitted coal-fired power plants (200 MW and larger units) [22].	Under research	Small-scale pilot testing for Power Plants. Commercially available for other applications.	Commercially available, commonly used to liquefied and purify CO_2 from relatively high purity (>90%) sources

Table 1: Summarize of CO_2 separation post combustion technologies.

In the Table 1, we show their Advantages, challenges, Process Design and the currently status of them.

Pulverized coal plants with post combustion CCS (PCC): amine-based capture processes: Amine scrubbing technology was established over 60 years ago in the oil and chemical industries, for removal of hydrogen sulphide and CO_2 from gas streams. Commercially, it is the most well established of the techniques available for CO_2 capture although practical experience is mainly in gas streams which are chemically reducing, the opposite of the oxidizing environment of a flue gas stream [25].

Post-combustion CO_2 removal processes have to deal with low gas pressure, low partial pressure of CO_2 and trace elements like SO_2 and NO_x that need to be removed prior to entering the absorber, as their removal to low concentrations is essential, since these components form heat stable, corrosive salts that cause operational problems and solvent losses. Flue gas conditioning steps are also costly and energy intensive. Parasitic losses for thermal power plants that use amine scrubbing ranges between 10 and 30% of the total power generated if CO_2 capture were not included [26].

Mono-ethanolamine (MEA) is a widely used type of amine for CO_2 capture. CO_2 recovery rates of 98% and product purity in excess of 99% can be achieved [25]. Many other amines and, especially in recent years, amine blends such as MEA plus ethyl-di-ethanolamine (MDEA), have also been utilized. Amines are relatively nonvolatile and inexpensive. However, they are corrosive and so require more expensive materials of construction. In addition, they do gradually volatilize (which can be especially problematic in the case of MEA) and they degrade, especially in the presence of O-14 and/or SO_2, both of which phenomena necessitate the timely injection of fresh solution. The considerable amounts of thermal energy required to strip CO_2 from loaded MEA solutions are an acceptable expense when the CO_2-purged gas is valuable. However, when MEA is applied to flue gas purification in conventional absorber/stripper systems, the parasitic energy consumption is considerable; the energy savings relative to MEA are partially offset by capital cost increases for the larger scrubbing equipment that is necessitated by lower absorption rates. Alternatively, MEA has been blended either with amines that are less corrosive and require less steam to regenerate, or with the additive piperazine (PZ) that is of limited solubility in water and more volatile than MEA but markedly accelerates CO_2 absorption and allows use of lower MEA concentrations [27].

Process description: As showing in the Figure 7, the process consists of two major sections, an absorption section where CO_2 in the flue gas is absorbed into the liquid solvent and a regeneration section where the absorbed CO_2 is stripped out by means of heat.

Prior to CO_2 removal, flue gases (usually at near atmospheric pressure and temperatures above 100°C) from power plant are cooled down to the temperature levels required for absorption, and treated for contaminants. After cooling, the flue gas is passed through an absorption vessel where it comes into contact with the chemical solvent, which absorbs much of the CO_2 by chemically reacting with it to form a loosely bound compound.

The key parameters determining the technical and economic operation of a CO_2 absorption system are:

- Flue gas flow rate

The flue gas rate will determine the size of the absorber and the absorber represents a sizeable contribution to the overall cost.

- CO_2 content in flue gas

Since flue gas is usually at atmospheric pressure, the partial pressure of CO_2 will be as low as 3-15 kPa. Under these low CO_2 partial pressure conditions, aqueous amines (chemical solvents) are the most suitable absorption solvents (Kohl and Nielsen, 1997).

- CO_2 removal

In practice, typical CO_2 recoveries are between 80% and 95%. The exact recovery choice is an economic trade-off; a higher recovery will lead to a taller absorption column, higher energy penalties and hence increased costs.

- Solvent flow rate

The solvent flow rate will determine the size of most equipment apart from the absorber. For a given solvent, the flow rate will be fixed by the previous parameters and also the chosen CO_2 concentrations within the lean and the rich solutions.

- Energy requirement

The energy consumption of the process is the sum of the thermal energy needed to regenerate the solvents and the electrical energy required to operate liquid pumps and the flue gas blower or fan. Energy is also required to compress the CO_2. Recovered to the final pressure required for transport and storage.

- Cooling requirement

Cooling is needed to bring the flue gas and solvent temperatures down to temperature levels required for efficient absorption of CO_2. Also, the product from the stripper will require cooling to recover steam from the stripping process.

The purity and pressure of CO_2 typically recovered from an amine-based chemical absorption process are as follows (Sander and Mariz):

- CO_2 purity: 99.9% by volume or more (water saturated conditions)
- CO_2 pressure: 50 kPa (gauge)

A further CO_2 purification step makes it possible to bring the CO_2 -quality up to food-grade standard. This is required for use in beverages and packaging [28].

Natural gas combined cycle with post combustion with CCS (NGCCC): For the NGCC plant that features CCS, CO_2 capture technology is an amine system post-combustion one which accomplishes the capture via adding the MEA scrubber to the system.

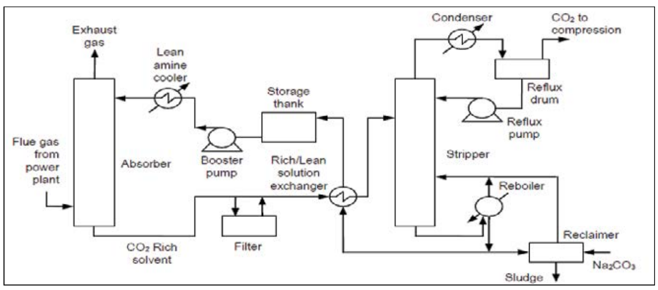

Figure 7: Process flow diagram of an amine-based system [28].

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The CCS design parameters for the NGCC capture plant are identical to the ones for PC post-combustion plants. Post Combustion Offers flexibility, in case the capture plant shuts down, the power plant can still operate. The other capture options are highly integrated with the power plant: so if capture fails, the entire plant must shut down. Furthermore, it offers utilities the option to allow for increased capacity by temporarily curtailing the capture process during periods of peak power demand. However, there has been very slow progress in the commercialization of IGCC for power generation applications. Several utilities are currently considering building IGCC plants; all have considerable obstacles to overcome.

Comparative power plant performances

The database of NETL [29] has been used. They compare the performance of natural gas, four kind of coal on Power Plants with different systems.

Net plant efficiency, HHV (%): As obvious in the Table 2, the coal power plants have significantly lower efficiency than NGCC in both cases with/without CCS. With the usage of high rank coals such as Appalachian medium sulfur or Illinois #6, coal power plants can be a technology of choice for electricity production. With addition of post-combustion capture to PC plants, 10% reduction in efficiency relative to non-capture PC plants is observable. For NGCC capture plant, the efficiency decrease due to capture is about 8%.

Net electrical output (MW): As showing in the Table 3. The gross electrical output is set at 500 MW for PC plants. The net electricity output will be calculated by subtracting a sum accounting for boiler use, hot-side SCR use, cold-side ESP use, wet FGD use and amine scrubber use (for the capture plant) from the gross electrical output.

For NGCC plants, the gross electrical output is dependent on the number of turbines used. This value corresponds to the total generator output minus the energy requirement of the air compressor and turbine shaft losses. The energy usage of the air compressor accounts for one third the energy produced from the generator. The net electricity is then resulted from subtracting the energy losses due to miscellaneous power block use and CO_2 absorption use (in case of capture plant) from the gross electrical output.

CO_2 emissions and captured: The emission rates are attractive for comparing CO_2 emissions of each power generation technology relative

	Appalachian medium sulfur(Bituminous)	Illinois # 6 (Bituminous)	Wyoming powder river basin	North Dakota lignite
PC	39.34	38.60	38.27	36.25
PCC	29.72	28.90	27.66	26.15
Natural Gas				
NGCC	50.15			
NGCCC	42.80			

Table 2: IECM model net plant efficiency, HHV (%).

	Appalachian medium sulfur	Illinois # 6	Wyoming powder river basin	North Dakota lignite
PC	459	456.5	467.0	456.8
PCC	346.7	341.7	337.6	329.6
Natural Gas				
NGCC	506.5			
NGCCC	432.3			

Table 3: IECM model net electrical output (MW).

to its capture plant as showing in the Table 4. It can be concluded that NGCCC capture plant has the lowest emission per unit output.

Captured CO_2 to storage: The Table 5 expresses the captured CO_2 for the plants with CCS. NGCCC shows the highest capability in capturing CO_2. Among the coal capture plants, IGCCC shows a better potential in capturing CO_2 for bituminous coals relative to PC capture plants.

Global CCS Status – Large Integrated Scale Projects

According to the Global Status of CCS: 2013 [30], the Large Scale Integrated Projects (LSIPs) are defined as projects involving the capture, transport and storage of CO_2 at a scale of:

- At least 800,000 tones of CO_2 annually for a coal-based power plant; or
- At least 400,000 tones of CO_2 annually for other emission-intensive industrial facilities (including natural gas-based power generation).

At the 2013, there are 65 LSIPs, 30 occurring in the power generation sector and most of these are planned to occur in coal-fired applications, as seen in Figure 8. This level of activity in the power generation sector is commensurate with the need to reduce emissions from this sector through the application of CCS.

On average, power generation projects currently on the LSIP list plan to be in operation by 2017, compared to 2016 for natural gas processing and other industries. Figure 9 demonstrates this time differential. Excluding those in Execute stage, twelve power generation projects expect to be in operation by 2017. Power plants can take between three and four years to construct, depending on whether a new build or retrofit with capture, this is an ambitious time frame.

There is a mix of industries represented in the CCS project portfolios of most countries and regions (Figure 10). In Europe, most of the projects are in power generation representing 12 of the 15 planned projects, also in China, with a large expected energy demand, CCS

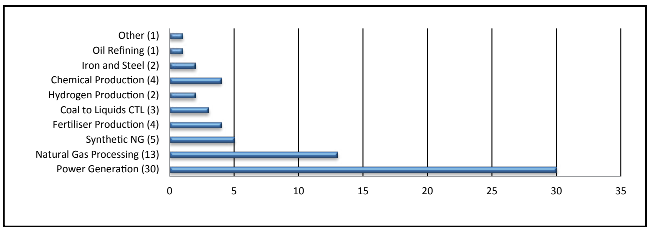

Figure 8: LISPs by industry sector in 2013Data [30].

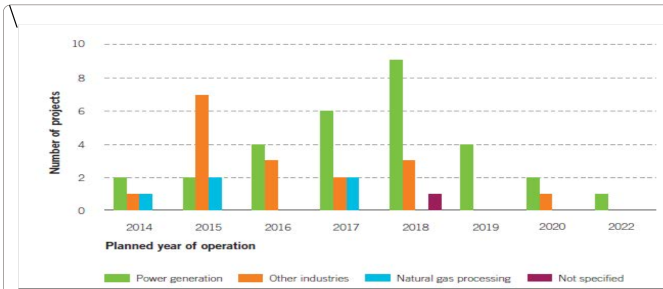

Figure 9: Planned years for operation by industry (not including operating projects) [30].

technology is growing in all sectors.

According to the Figure 11, the Post-Combustion with thirteen projects is still the most widely chosen capture technology, representing 43% of all power projects in the 2013 LSIP list, while the shares of pre-combustion capture (gasification) with eleven projects, and Oxy-fuel with five projects represent 37% and 17% respectively of all power generation LSIPs.

Large-scale CCS projects in the power sector 2014

- In October 2014, Sask Power launched the world's first operational large-scale power facility equipped with carbon capture technology – the Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project in Canada. The CO_2 captured will be used primarily for EOR at the Weyburn oil unit. Any CO_2 from the project that is not used in EOR will be injected into a nearby deep saline formation through the Aquistore project. Utility Sask power spent around $1.4 billion for a 110 megawatt retrofit of the Boundary Dam coal-fired power plant, equipping it with carbon-capture technology that will trap around 1 million tonnes of carbon dioxide yearly to reduce the carbon emission of the facility by 90 percent [31].

- Commissioning activities on a new-build 582 megawatt (MW) power plant beginning at the Kemper County Energy Facility in Mississippi (US, CO_2 capture capacity of 3 Mtpa) with CO_2 capture expected to commence in 2015, and [32]

- The Petra Nova Carbon Capture Project at the W. A. Parish power plant near Houston, Texas (US, CO_2 capture capacity of 1.4 Mtpa) entering construction in July 2014, with CO_2 capture anticipated by the end of 2016 [32].

CCS SWOT Analysis

CCS strengths

- CCS technologies are now widely recognized as the most promising and the only nearly commercially viable technology available to disassociate CO_2 emissions from fossil fuel usage at scale. CCS is included in all cost effective climate change mitigation strategies of the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change. The IEA [33] estimates that CCS can contribute 19% of the emission reduction needed to constrain a rise in global temperature to within the agreed limit of 2°C; and the cost of achieving the same emission reduction without CCS would be 70% higher.

- CCS was approved at the Climate Conference in Durban in 2011 as a project type under the Clean Development Mechanism (CDM), after a subsequent series of consultations and negotiations. The decision also provides a set of internationally accepted rules for CCS projects, dealing with key issues such as site selection, liability and environmental assurance. It also sets an important precedent for the inclusion of CCS into other financing and technology support mechanisms. Through the CDM, the carbon market could be one among several means of supporting the demonstration, diffusion and deployment of CCS in the first commitment period and providing useful insights for discussions on CCS deployment post-2012.

i. CCS has been used successfully in oil and gas industries for decades and aggressive international efforts are underway to demonstrate CCS in coal and NG power plants.

ii. CCS Technology provides the benefit of continued exploitation of fossil energy source while provides a solution towards containing carbon emissions.

iii. New economy growing opportunity.

iv. Technology innovation and advancement.

v. Optimization of de development mode.

vi. Cleaner environment and more sustainable ecology.

CCS weaknesses

vii. Advances in technology are notoriously unpredictable. It is not possible to predict the cost of natural gas from hydrates below the ocean floor in 50 years from now. It is equally difficult to predict whether coal seams 2000 m below the ground will remain unmineable. Neither the gas hydrates nor the deep seams are counted in today`s resources estimate.

viii. There is the potential for schedule delays associated with the development of a particular element of the CCS chain lagging behind. For example, if the development of a transport and storage network is delayed, this also imposes significant delays to the capture plant project [34].

CCS opportunities

ix. Fossil fuel resources are large enough and fossil fuel technology is sufficiently developed, playing a major role in providing for the world's growing energy demand.

x. Demonstrating CCS in developing countries dependent on fossil fuels is now viewed by all stakeholders as essential to making its deployment likely and to de-carbonizing their power sectors.

xi. Develop Capture and storage technologies will be a new business opportunities from a technological point of view. As for CO_2 capture processes, a whole new industry needs to be created for the market in both the industrialized and developing countries. We shall take the opportunity as the country is making efforts on energy

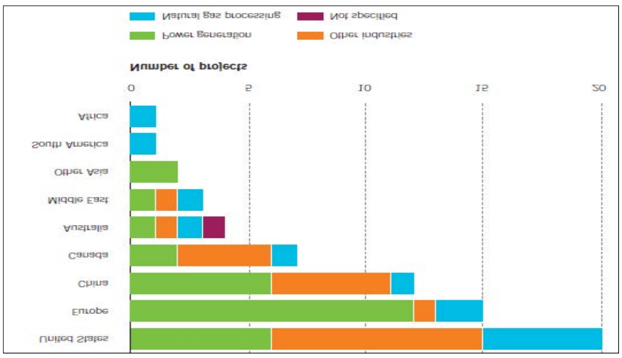

Figure 10: LSIPs by industry type and region [30].

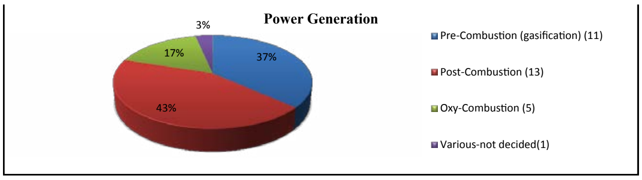

Figure 11: Distribution Power Generation LSIP by capture technology Data [30].

conservation and emission reduction and on the expansion of their applications in various sectors.

xii. The development of renewable energy resources will definitely increase the consumption of fossil energy because wind and solar energy resources are intermittent by nature. This means that electricity will be generated only when there is wind or sunlight, but production and utilities also need electricity and with even greater demands when the wind or sunlight is absent. To make the most use of wind power and solar photovoltaic, the installed capacity of thermal power must be increased to guarantee a steady and sufficient supply of energy, and this requires more coal power to be developed.

xiii. The transfer of large-scale project experience from successfully operating projects to new projects will help to reduce costs and risks, as well as build confidence about CCS among the general public, governments and the finance community. In particular, transferring experience from developed to developing economies will be vital given the future scale of the mitigation task and the role of CCS in helping to achieve mitigation goals in those countries at least cost.

xiv. The study also finds that the scale of the CO_2 storage industry will be large. Both in terms of material and human resources, storage operations will be on par with the current oil and gas industry. This could lead to a 'competition' for resources between 'carbon emitters' and 'carbon sequesters', which may delay growth of the storage industry. But it also affords Europe an opportunity to develop a huge new industrial sector that tackles climate change and provides thousands of jobs [34].

CCS threats

xv. CCS is not approved being included in emission reduction mechanism because of the high uncertainty of the technology itself. Climate change regulations do not include explicit definitions on CCS. Furthermore, different emission reduction mechanisms (CDM, JIT and ET) stated in the Kyoto Protocol did not include CCS either. So the definition of CCS technology will be an important question in future climate negotiations. The largest challenge for CCS in the future is the lack of consensus on long-term targets. Without such clear target, it will be difficult for countries to employ CCS technology at large scale.

xvi. There are many alternative technologies which can also contribute to emission reduction on a large scale. For example CCS has a lower competitiveness than wind power; the viable option depends mainly on its cost.

xvii. Rising fossil- fuel prices [33].

CCS challenges

CCS technology faces many challenges to successful, full scale demonstration and commercial deployment including issues such as: Financing large scale demonstration projects and Integration of CCS into GHG policies;

The higher cost and efficiency penalty of CCS technologies; development and financing of adequate CO_2 transport infrastructure; development of legal and regulatory frameworks to ensure safe, permanent CO_2 storage; adequate public consultation; and developing capacity and awareness in rapidly growing fossil based economies.

However, the critical next step is to verify the performance of CCS at scale, with capture from a variety of different industries and storage in a variety of geologic settings. To date, only a few large scale CCS projects are in operation.

There is also a need to ensure widespread CCS development in a variety of settings. Thus, the following guiding principles should help to shape the global portfolio of CCS projects:

- CCS projects need to be:

1. Demonstrated at scale in all major fossil based economies, including emerging economies.

2. Designed to maximize knowledge sharing via transparent and regular publication of results.

- CO_2 capture needs to be demonstrated:

3. Using a variety of CO_2 capture technologies.

4. At a variety of point sources, including coal and gas fired power plants, refineries, chemical plants; cement plants, iron and steel manufacturing facilities, and other industrial operations.

5. Through retrofitting at a coal fired power plant (this is an urgent need).

6. Using biomass input (this offers an important carbon reduction opportunity, and should be pursued urgently).

- CO_2 transport needs to be enhanced:

7. Through deployment of infrastructure.

8. By applying effective design and regulation of networks.

- CO_2 storage needs to be demonstrated:

9. In a wider set of projects with different geologic settings.

10. Enhanced oil and gas recovery offer cost effective opportunities for CCS demonstration, and should be pursued as an early opportunity.

- Climate change legislation must not be delayed.
- In order to achieve emission reductions in the most efficient and effective way CCS must not be disadvantaged.
- Funding for CCS demonstration projects should be accelerated.
- Expertise and learning must be shared.

Conclusion and Recommendations

▪ This paper attempts to analyse the role of the CCS projects at the Energy Sector. The promoting of low carbon technologies, as CCUS and CCS projects which contribute towards a portfolio options for climate change mitigation. From our assessment framework, it was shown that the practicality of CCS will depend on a few key criteria, namely the climate policies on the international and local front, the maturity of the technology, the economic competitiveness of the technology, the speed in which the technology can become available and also the availability of quality storage capacity.

Existing policy support alone over the past five years has not been enough to 'launch' the number of large-scale CCS projects anticipated at the start of the decade. In fact, more than 40% of respondents to the Perceptions Survey indicated that the incentives currently in place are inadequate for ensuring projects are not commercially stranded.

▪ CCS in either new build or retrofit application enables the continued deployment of the well-established Pulverized Coal (PC) technology familiar to power industries worldwide, allowing the

	Appalachian medium sulfur		Illinois # 6		Wyoming powder river basin		North Dakota lignite	
	tonne/MWhr	tonne/hr	tonne/MWhr	tonne/hr	tonne/MWhr	tonne/hr	tonne/MWhr	tonne/hr
PC	0.81024	371.9	0.840526	383.7	0.857173	400.3	0.918345	419.5
PCC	0.107326	37.2139	0.112087	38.3	0.1188	40.12	0.127367	41.98
Natural Gas								
	tonne/MWhr				tonne/hr			
NGCC	0.367423				186.1			
NGCCC	0.043049				18.61			

Table 4: IECM model power plant total CO_2 out.

	Appalachian medium sulfur		Illinois # 6		Wyoming powder river basin		North Dakota lignite	
	tonne/MWhr	tonne/hr	tonne/MWhr	tonne/hr	tonne/MWhr	tonne/hr	tonne/MWhr	tonne/hr
PC C	1.034617	335.1	0.988715	345.6	0.935439	360.9	0.871958	378
Natural Gas								
	tonne/MWhr				tonne/hr			
NGCCC	2.580896				167.5			

Table 5: IECM model captured CO_2 to storage.

continued operation of valuable resources. The widespread R&D on improved sorbents and capture equipment should reduce the energy penalty of PC with Carbon capture.

- According to the IEA, the emission rates with CCS systems are attractive when comparing with CO_2 emissions of each power generation technology relative to its capture plant as showed in the Table 4. The CO_2 emissions from NGCC plants are reduced relative to those produced by burning coal given the same power output because of the higher heat content of natural gas, the lower carbon intensity of gas as to coal, and the higher overall efficiency of the NGCC plant as to a coal-fired plant. Compared to the average air emissions from coal-fired generation, NG produces half as much CO_2, less than a third as much NO_X, and 1% as much sulphur oxides at the power plant. It can be concluded that NGCC capture plant has the lowest emission per unit output.

In Table 5, the NGCCC shows the highest capability in capturing CO_2; also among the coal capture plants, IGCCC shows a better potential in capturing CO_2 for bituminous coals as to PC capture plants.

- The SWOT analysis shows that despite of the weaknesses and threats, strengths and opportunities are greater, especially in terms of opportunities. Develop capture and storage technologies will be new business opportunities from a technological point of view. As for CO_2 capture processes, a whole new industry is in need to be created for the market in both the industrialized and developing countries. We should take the opportunity as the country is making efforts on energy conservation and emission reduction and on the expansion of their applications in various sectors.

- Separation of CO_2 from coal and NG fired flue gas presents a significant challenge to the utility and environmental industries. Four CO_2 separation technologies: absorption, adsorption, membrane and cryogenic processes, were critically reviewed. The results indicate, many of them are in the early stages of development and will require a great deal of R&D to overcome current technical limitations, produce innovations and further advancements needed to demonstrate the viability of each approach. Amine scrubbing technology are the most promising options for CO_2 capture from post-combustion flue gases at the present time, commercially, it is the most well established ; but this process requires energy in the form of electricity and steam both supplied by the power plant, consequently reducing the overall efficiency of the power plant, and also the higher number of components (absorber, re-boiler, compressor, circulation pumps, etc.), increases the maintenance cost and the complexity of operation. Another factor increasing the O&M cost is the consumption of the solvent.

Membranes Technology Research (MTR) is developing a commercial-scale membrane module with high CO_2permeance and high CO_2/N_2 selectivity for post combustion flue gas applications. Some of the main advantages of Membranes are: Not requiring a separating agent, no regeneration, not containing any chemical reactions or moving parts, making it simple to operate and maintain and required low energy cost. Therefore it is a promising alternative for application on fossil fuel fired Power Plant.

- Notwithstanding the steady progress in CCS projects entering operation and construction, momentum is too slow to support the widespread commercial deployment needed to underpin climate change risk mitigation scenarios. A very substantial increase in new projects entering construction is required. The IEA envisioned in its CCS Roadmap that there would be 100 CCS projects by 2020 and over 3,000 projects in 2050. Despite these predictions and the billions of dollars of public funding committed to CCS development, there are currently only eight demonstration projects in operation, showcasing different parts of the technology chain.

- The inclusion of the CCS in the CDM would generate carbon credits are a direct subsidy to oil industry conducting business-as-usual work. CCS projects which have no income source (from fossil fuel sales) can confirm an income stream through the sale of CERs. The CDM can help to attract debt/equity investors to finance the CCS project. Buyers include private companies, international institutions and governments in countries such as EU 15, Japan, etc.

- The transfer of large-scale project experience from successfully operating projects to new projects will help to reduce costs and risks, as well as build confidence about CCS among the general public, governments and the finance community. In particular, transferring experience from developed to developing economies will be vital given the future scale of the mitigation task and the role of CCS in helping to achieve mitigation goals in those countries at minimum cost.

- Finally, the urgency in developing realistic plans for the rapid deployment of the lowest-GHG-emission technologies such as CCS. We can and must change our current path, but this will take an energy revolution and low-carbon technologies will have a crucial role play. Every major country and sector of the economy must be involved. The task is also urgent if we are to make sure that investment decisions are taken now and do not saddle us with sub-optimal technologies in the long-term.

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