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CARBON SEQUESTRATION TECHNOLOGIES: a TECHNO-ECONOMIC REVIEW

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Abstract: CO_2 sequestration and storage is getting a remarkable attention due to potential Greenhouse Gas mitigation method for the fossil fuel power plant. Economic analysis of various available technologies is a very important tool in deciding the best carbon capture technology. Thus, particular studies often are limited values to analysts, researchers and industrial personnel who are in search of results for alternative cases. In this article we have discussed the current costs of fossil fuel power plants with carbon capture techniques. The major 3 plant types are considered here are pulverized Coal (PC), Natural Gas Combined Cycle plants (NGCC), and Integrated Gasification Combined Cycle (IGCC). Along with these three plants, comparison of the cost of electricity of NGCC + MCFC (Molten Carbonate Fuel Cell) plant with conventional NGCC + MEA (mono-ethanol ammine based CO2 capture system) is done.

Key words: CO_2 sequestration, Economic analysis, Molten Carbonate Fuel Cell, mono-ethanol ammine.

I. INTRODUCTION

Carbon Capture and Storage (CCS) is receiving considerable attention as a potential Greenhouse Gas mitigation measure that could allow a smoother and less costly transition to a sustainable, low carbon energy future over the next century . Although commercial technologies exists to separate and capture the CO_2 generated in large scale industrial processes, application to date are found mainly in the petroleum and petrochemical industries. Capture of CO_2 from combustion generated flue gases also has been demonstrated commercially at small scale for gas fired and coal fired boilers . However to date there have been no applications of CO_2 capture at an electric power plant at a large scale (eg. >100 MW). Geological sequestration of captured CO_2 also has been demonstrated at 3 large scale project in Norway, Canada and Algeria (each storing over 1 million tons $C0_2$/year), with other smaller scale project planned.

The cost of such technologies could be pose another barrier to its widespread use as a Greenhouse Gas control strategy. The total cost of carbon capture and storage (CCS) include the cost of carbon captured and compression; the cost of carbon transported (usually by pipelines); and cost of storage. The number of articles were published recently have estimated CCS costs based on technology that are either currently commercial or under development. Relatively few studies are published in peer reviewed journals. For the most part the focus is on coal based power plants which are major source of CO_2 emissions. A complete picture of environment and resource implications of CO_2 capture is largely lacking in the current literature.

II. REVIEW OF RECENT ECONOMIC STUDIES

Table I displays the costs testified for various power generation systems in recent studies. These costs are for new power plants using current commercial power generation and carbon capture technique. This comprise cost of CO_2 compression but not transport and storage. A study by shows the role of various factors to the overall cost of a PC plant with CCS. Table 1 reproduces even widervariety of viewpoints for each of the 3 systems.

III. MCFC TECHNOLOGY

MCFCs are a well-known candidate for clean power generation from a variety of fossil fuels, including natural gas and biogas . The operating principle of a MCFC involves that oxygen is taken from ambient air and is transported to the cell anode combined with CO_2 by carbonate ions (CO^-_3). At the anode oxygen is released and oxidizes the fuel, primarily joining with hydrogen to yield steam. Hydrogen can be produced by an internal reforming process, either taking place at the anode or in a thermally integrated reactor, in both cases exploiting heat released by the fuel cell to sustain the reforming endothermic reactions. The carbon monoxide generated by reforming is converted to CO2 by the concurrent water gas shift reaction which produces additional hydrogen, again oxidized in the process. In separate applications, usually a fraction of the anode effluent stream is burned in a catalytic combustor and recycled at the cathode inlet, in order to sustain the formation of carbonate ions. The MCFC converts natural gas into electricity and simultaneously moves CO2 from the cathode to the anode side, simplifying its separation. It is therefore possible to reduce the energy demand for CO2 capture with a superior efficiency compared to conventional competitive CCS techniques.

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TABLE I: SUMMARY OF REPORTED CO_2 EMISSIONS AND COSTS FOR A NEW ELECTRIC POWER PLANT WITH AND WITHOUT CO_2 CAPTURE BASED ON PRESENT TECHNOLOGIES (TRANSPORTATION AND STORAGE COST EXCLUDED)

Performance and cost measures	IGCC Plant		PC Plant		NGCC Plant	
	Range	Representative value	Range	Representative value	Range	Representative value
Total capital requirement without capture (□ /kW)	24838.45-34918.50	27394.50	55995-71669.80	62023.80	56380.80-75479.90	63953
Total capital requirement with capture (□ /kW)	43841-60818	48133.50	91347.60-124337	101090	68197-109482	88019.75
% increase in capital cost with capture (%)	64-100	76	44-74	63	19-66	37
COE without capture (□ /MWh)	1495.10-2411.50	1784.50	2073.90-2508	2218.58	1977.50-2942	2266.80
COE with capture (□ /MWh)	2073.80-3472.50	2604.40	2990-4147.80	3520	2604.40-3810	2990
Increase in COE with capture (□ /MWh)	578.76-1157.50	820	868.15-1639.80	1302.21	434-1061	771.60
% increase in COE with capture (%)	37-69	46	42-66	57	20-55	33
Cost of net CO_2 captured (□ /tCO_2)	1784.50-3569	2556	1399-2460	1977	627-1784	1109

All costs in constant Indian rupee

Notes: NGCC: Natural Gas Combined Cycle; PC: Pulverized Coal; IGCC: Integrated Gasification Combined Cycle; representative value is based on the average of values in the different studies reviewed; COE: Cost of Electricity production; Mwh: Megawatt hours; All PC and IGCC data are for bituminous coal only at costs of 48.23-72.34 □ /GJ (Lower Heating Value); NGCC data based on natural gas price 135-210 □ /GJ (LHV); Power plant size varies from 400-800 MW without capture and 300-700 MW with capture;

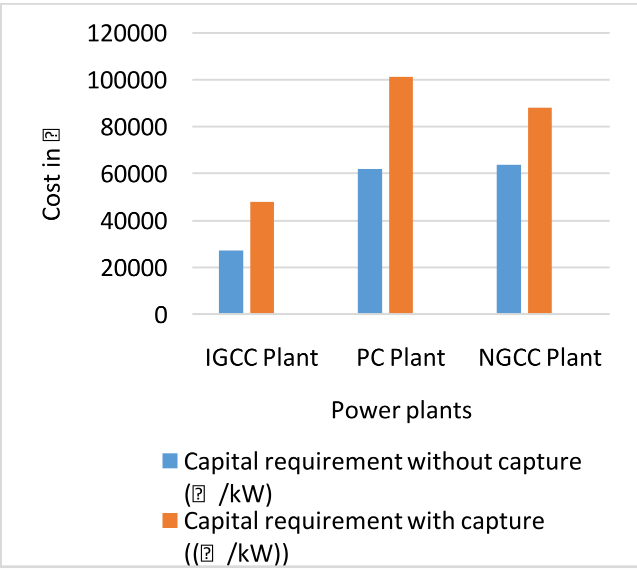

Fig. 1. Capital investment required with or without capture

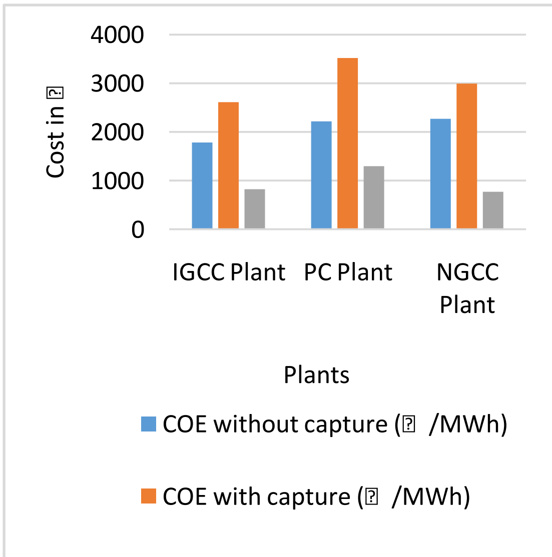

Fig. 2. Comparison of COE with and without CO_2 capture.

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IV. NGCC ALONG WITH MCFC

The power cycles are based on a natural gas combined cycle (NGCC), where a MCFC is placed downstream the gas turbine and ahead the heat recovery steam generator (HRSG). The gas turbine exhaust gases are used as cathode feed for the fuel cell, where CO_2 is transferred to the anode side, concentrating the CO_2 in the anode effluent. The MCFC works with internal reforming; natural gas feeding the MCFC must be desulfurized by a proper treatment since reformer catalysts and MCFCs do not tolerate the presence of sulfur compounds (including NG odorizing additives) above 0.5–1 ppmv (parts per million by volume). Several options including Zinc-oxide absorption beds or active carbon filters could be considered;here the economic outlook of the active carbon is considered, relying on active carbons with metal impregnation, which does not require sulfur hydrogenation and can be regenerated with steam below 400ºC .

After the fuel cell, the anode effluent requires additional purification processes to recover the unconverted fuel species and achieve the stipulated CO_2 purity (i.e., >96%). In this article NGCC–MCFC plant configurations, based on two different CO_2 separation processes compared,

1) Cryogenic option
2) Oxy-combustion option

TABLE II GIVES THE ECONOMIC COMPARISON RESULTS OF NGCC WITH MEA, CRYOGENIC AND OXY.

Plant component	NGCC	MEA	Cryogenic	Oxy
TEC: Total Equipment Cost in (10^6 □)	18400	23835	32608	30357
TPC: total plant cost in (10^6 □)	40605	53416	75000	69720
COE capita (□/MWh)	741.46	1211	2523	2316
Total cost of CO_2 avoided, (□ /tonCO_2)	-	3765	9316	8307

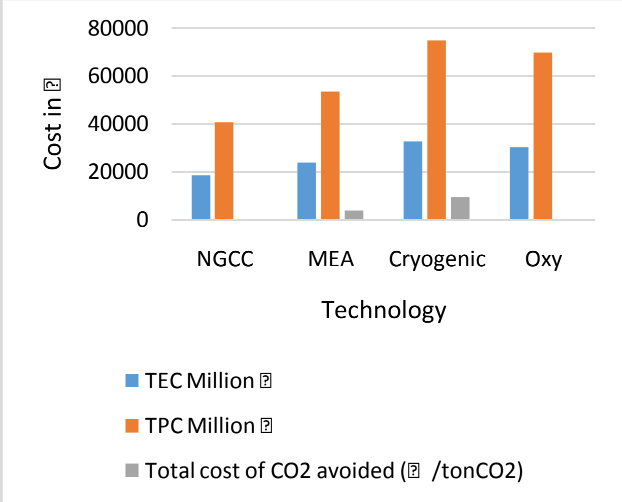

Fig. 3. Economic comparison of NGCC+MCFC with MEA

V. CONCLUSION

From these data the general conclusion can be made as the COE (Cost of electricity) to be lowest for NGCC plants with or without CO_2 capture for coal based plants, PC units tends to have lowest capital cost and lower COE without capture while IGCC plants tends to be less expensive when current CO_2 capture system added. However the costs depends on many other factors, generalisation may not apply in all the cases. In particular it can be elaborated as, the most recent studies of NGCC are based on fuel price and other factors or assumptions which are made are appear to be highly questionable today.

A successful race with conservative technologies could be attained for a lower MCFC specific cost, falling in the range 77639–116460 □/$kW_{electricity}$ (depending on natural gas cost), and agoal which could be reached by future development of the MCFC technology. In these forward-looking cases the greaterproductivity of the Cryogenic configuration leads to an improved economic result than the Oxy solution. In these cases, the NGCC + MCFC idea would become anattractiveresult also by the point of view of economics. In the present condition the cost of natural gas, as well as many raw materials has intensifiedsignificantly leading to cost increase that are not reflected in this current literature.

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