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A novel approach for the economic evaluation of new CO_2 capture technologies for power plants

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Abstract

This paper presents a novel approach for assessing the economic performance of novel CO_2 capture technologies for power plants. The method consists in three main steps: (i) definition of the carbon and energy balances with a simplified approach using few fundamental data on the novel capture technique, (ii) calculation of the CAPEX and OPEX of the conventional unit operations of the power plant integrating the novel technology and (iii) calculation of the minimum theoretical cost of CO_2 avoided (CCA) and of the breakeven CAPEX and OPEX of the novel capture technology making it competitive with the benchmark capture technology. The proposed methodology has been applied to selected technologies showing that: (i) a clear relationship exists between the breakeven cost and the efficiency penalty which mainly affects the specific cost (in $\$/kW_e$) of the conventional components of the power plant; (ii) ideal minimum CCA is closely related to the efficiency penalty and range between ~20 $\$/t_{CO2}$ for efficiency penalties of 2.7% pts. and ~60 $\$/t_{CO2}$ for efficiency penalties of 11% pts. Significant reductions in the ideal minimum CCA may only be obtained through technologies allowing consistent economic savings by the removal of major components of the conventional power plant.

Keywords: CCS; solvents; oxyfuel; sorbents; membrane; CLC

1. Introduction

All CO_2 capture technologies are targeting at some point in their complete process scheme at least one major gas separation step, that can be based on a wide range of phenomena (including absorption of gases in solvents, adsorption in solids, cryogenic phase change of gases, gas-solid looping reactions at high temperatures, selective transport of gases through membranes). However, when planning a full CO_2 capture system (including the required gas separation devices, reactors, unit operations and other enabling components), it becomes evident that all capture technologies share at least some conventional elements in their process scheme. Indeed, some “novel capture technologies” may be only “truly novel” in one particular part of the full capture system, while sharing the rest of the sub-systems with other “more mature” capture technologies.

The first objective of this paper is to exploit this fact in order to propose a methodology to estimate full CO_2

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capture system cost by accounting first for the contribution to overall cost of the most mature elements required in the full novel capture system, so that the maximum cost reduction potential can be established for the novel capture system respect to a well-known benchmark. The second objective of the paper is to show how this methodology can be used to provide indicative values for the breakeven CAPEX and OPEX cost of some selected novel technologies to make them competitive with benchmark CO_2 capture technologies. Such costs may be seen as target costs for technology developers.

2. Methodology

In this work, the technical and economic data from DOE-NETL reports [1–3] are used to define a model, which is based on the following three sequential steps:

1. Definition of a general simplified method to estimate the mass and energy balances of coal-fired power plants with CO_2 capture, based on a limited number of inputs characterizing the capture process. The method allows defining a general energy balance of the power plant which can be represented as shown in the Sankey diagram of Figure 1.

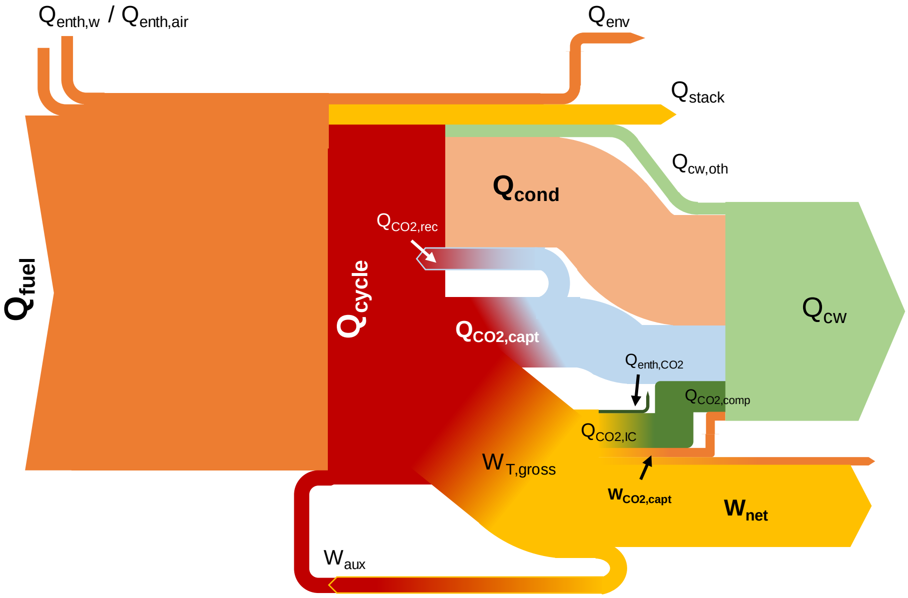

Figure 1. Sankey diagram for the USC power plant with CO_2 capture system

2. Estimation of the CAPEX and OPEX of the industrially mature components of the power plants (i.e. all the units except the novel CO_2 or O_2 separation process), sized according to the simplified mass and energy balance determined at point 1. CAPEX are estimated with exponential cost functions.

3. Calculation of the breakeven CAPEX and OPEX of the novel separation processes (i.e. costs making the novel CO_2 capture technology competitive with the benchmark MEA process) and calculation of the minimum theoretical cost of CO_2 avoided (i.e. assuming that the novel technology has zero CAPEX and OPEX). As a result, a chart like the one shown in Figure 2 can be generated, where a breakeven line shows combinations of the maximum CAPEX (in \$ per kg/s of CO_2 separated) and maximum OPEX (in \$ per ton of CO_2 separated) that the novel technology can have to be competitive with the benchmark. Therefore, if the novel technology has CAPEX and OPEX below the breakeven line, it lies in the economically competitive region, i.e. the final cost of the CO_2 avoided is lower than the cost of the benchmark technology.

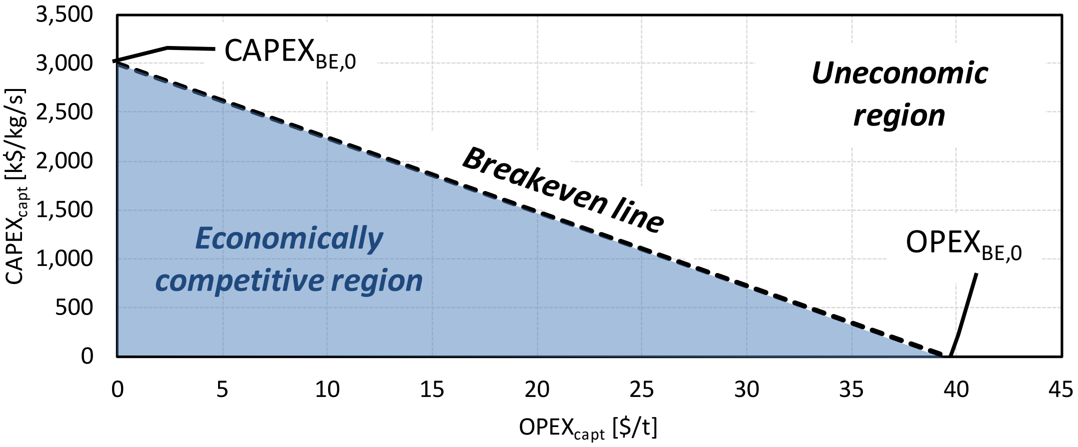

Figure 2. Break-even line showing regions of economic competitiveness of a CO_2 capture technology in comparison with a benchmark technology.

3. Discussion

The model has been applied to selected CO_2 capture technologies assessed in the literature, namely: alternative MEA processes, oxycombustion, piperazine (PZ), chilled ammonia process (CAP), CO_2 membranes, pressure swing adsorption (PSA), Calcium looping (CaL), chemical looping combustion (CLC). The breakeven lines have been calculated with respect to the benchmark USC-MEA, as depicted in Figure 3.

Minimum cost of CO_2 avoided for the different technologies, calculated assuming CAPEX and OPEX of the capture technology equal to zero, have also been calculated, as shown in Figure 4.

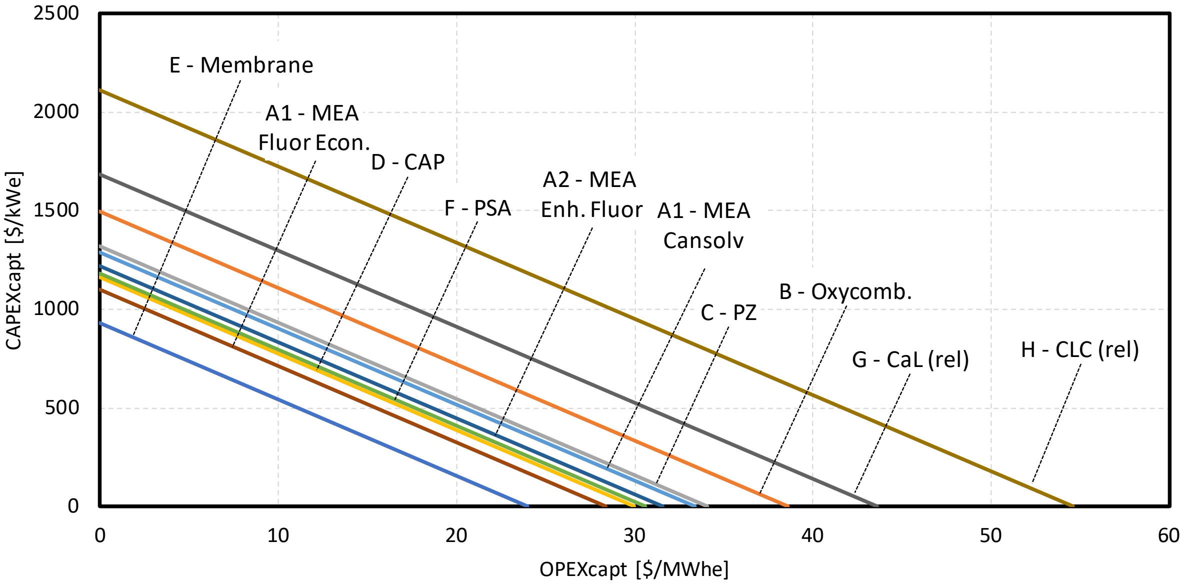

Figure 3. Breakeven cost lines for the assessed case studies.

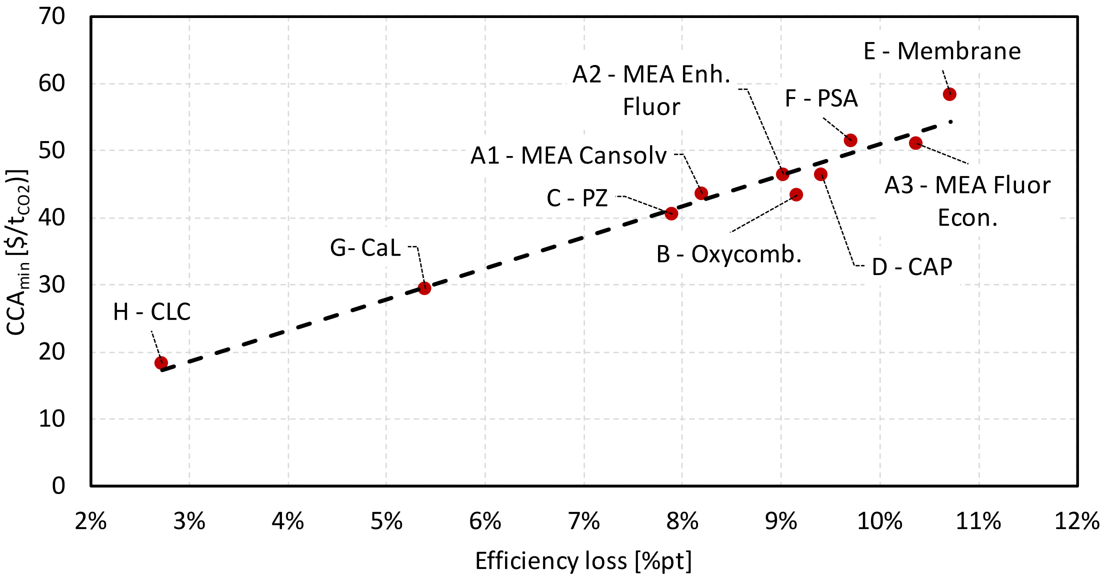

Figure 4. Minimum cost of CO_2 avoided for the different technologies.

The methodology proposed in this work, which is not intended to substitute for rigorous process simulation studies or more detailed economic analyses or to rank different CO_2 capture technologies, led to the following general conclusions:

- A clear relationship between the breakeven cost and the efficiency penalty caused by the CO_2 capture process has been shown. Efficiency penalty reflects not only the higher cost for the higher fuel consumption per unit of electricity generated, but mainly reflects the higher specific cost (in $/kW$_e$) of the conventional components of the power plant.
- The minimum cost of CO_2 avoided has been calculated assuming zero CAPEX and OPEX of the CO_2 capture technology. The resulting ideal minimum CCA is again closely related to the efficiency penalty and range between ~20 $/t$_{CO2}$ for efficiency penalties of 2.7% pts and ~60 $/t$_{CO2}$ for efficiency penalties of 11% pts. Significant reductions in the ideal minimum CCA may only be obtained through technologies allowing consistent economic savings by the removal of major components of the conventional power plant.
- For a given efficiency penalty, breakeven CAPEX and OPEX of greenfield plants also depend on whether the efficiency loss is mainly associated to steam extraction from the turbine to provide heat to the capture process (e.g. with solvent systems) or to direct electricity consumption (e.g. compressors in ASU, PSA and membrane systems). Capture systems requiring mainly heat are favored from this perspective because of the smaller and cheaper steam turbine, electric generator, condenser and accessory electric plant needed.

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