Techno-economic feasibility and practical implications of implementing CO_2 capture at industrial plant level

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Introduction

Industrial energy use contributes roughly 36% to the total CO_2 emissions worldwide (about 12 $GtCO_2$ in 2007) [1]. A recent report of the International Energy Agency [2] indicated a significant role for CO_2 capture and storage (CCS) in the industrial sector in order to reach CO_2 concentration stabilization targets of around 450 ppm or lower. To date, the techno-economic potential of CCS in the industrial sector has been assessed mostly at the aggregate or sector level (e.g. [2]). These types of studies are mainly exploratory and tend to take average industrial conditions. This study aims to provide in-depth insights into the operational implications and techno-economic feasibility of CCS deployment at plant level for the Dutch industry.

Methodology

This study uses a bottom-up approach to conduct a detailed analysis at industrial plant level. Five industrial facilities in the Netherlands were used as case studies (two crude oil refineries, an aromatic plant, an oxo-alcohol plant and a Steam Methane Reformer (SMR) hydrogen plant). Industrial plant data on energy flows, fuel consumption, CO_2 emissions as well as characteristics, capacities and load factors of process units, were taken from monitoring plans, which are compounded by the companies in commission of the Dutch Emission Authority. Data on CO_2 capture processes and equipment, such as additional energy use and costs were gathered from literature. Finally, a literature review and interviews with experts were conducted to identify and assess possible practical implications of CO_2 capture at industrial plant level (e.g. spatial constraints). Three CO_2 capture scenarios were devised for each case study: a post-combustion, pre-combustion, and oxyfuel combustion scenario. For each scenario we examined CO_2 capture potential, costs, and practical implications related to CO_2 capture. Scenarios were compared with a base case scenario, i.e., the situation when CCS is not implemented. The post-combustion scenario assumes centralized capture of almost all CO_2 from the flue gases by using monoethanolamine (MEA) for the short term and a more efficient future solvent (35% less heat consumption) for the long term. For the oxyfuel combustion scenario we examined the capture of nearly pure CO_2, which is formed during the combustion of the fuels with pure oxygen (instead of air) in the boilers, furnaces and catalytic cracker. Oxygen is produced by means of cryogenic air separation (short term) or via Ion Transport Membranes (ITM) (long term). The pre-combustion scenario involves fuelling of the process units with hydrogen, which is produced in a steam reforming unit combined with a water gas shift reactor (WGS). The CO_2 is partly captured from the high pressure syngas between the WGS reactor and a pressure swing adsorption (PSA) unit by using activated methyldiethanolamine (aMDEA), and partly from the atmospheric pressure SMR furnace flue gas by using MEA. For the hydrogen plant, a SMR-WGS scenario is devised in which the CO_2 is captured in a similar way as for the pre-combustion scenario. Additional heat required for the capture of CO_2 is provided by installing an additional on-site boiler (of which the CO_2 is also captured) and purchasing electricity from the grid.

Results

Table 1 gives an overview of the CO_2 reductions and avoidance costs for each case study. The results show significant reductions in CO_2 emissions (50-89%) for different industrial facilities with varying amounts of annual CO_2 emissions. For the refineries, the pre-combustion scenario results in the highest CO_2 reductions, whereas for the aromatic and oxo-alcohol plant, the oxyfuel scenarios display the highest CO_2 reductions. The oxyfuel scenarios show lower CO_2 avoidance costs than the post- and pre-combustion scenarios. For the refineries, the pre-combustion scenario shows lower avoidance costs than the post-combustion scenarios, whereas for the aromatic and oxo-alcohol plant, it is the other way around. For the hydrogen plant, the WGS-PSA scenario displays lower CO_2 avoidance costs than the post-combustion scenarios.

Table 1: Overview of CO_2 emission reductions and CO_2 capture costs (excluding CO_2 transport and storage)

	Unit	Post-combustion		Oxyfuel combustion		Pre-combustion
		Short term	**Long term**	**Short term**	**Long term**	
Refinery I (5.7 Mt CO_2/yr)						
CO_2 reduction	%	74	77	50	53	81
Avoidance costs	€/t CO_2	90	88	41	16	49
Refinery II (2.1 Mt CO_2/yr)						
CO_2 reduction	%	76	77	63	67	78
Avoidance costs	€/t CO_2	91	90	58	36	72
Aromatic plant (449 kt CO_2/yr)						
CO_2 reduction	%	72	75	82	87	83
Avoidance costs	€/t CO_2	105	101	58	47	144
Oxy-alcohol plant (64 kt CO_2/yr)						
CO_2 reduction	%	77	79	80	89	78
Avoidance costs	€/t CO_2	99	94	79	55	179

	Unit	Post-combustion		Capture WGS-PSA
		Short term	**Long term**	
Hydrogen plant (800 kt CO_2/yr)				
CO_2 reduction	%	73	76	94
Avoidance costs	€/t CO_2	108	100	44

The research findings indicate that retrofitting of process units – which is often preferred over replacement – is possible for all three capture technologies, although retrofitting of pre- and oxyfuel capture technologies might be more difficult for natural draft (instead of forced draft) furnaces and because of spatial constraints. For the post-combustion scenarios, no significant impact on the reliability of process units – i.e. an increased chance of an operational failure of process units – is expected as a consequence of CO_2 capture technologies, whereas for the pre-combustion and oxyfuel technologies, a slightly higher impact on the reliability is expected. Limited space availability for CO_2 capture equipment and ducting are not a problem for the specific plants analysed, although existing installations may have to be replaced or removed. All experts stated that practical difficulties regarding space availability and retrofitting can be solved, but that high costs hamper the implementation of CO_2 capture technologies. No consensus among experts was found on whether the retrofitting and installation of the capture units can be done during maintenance or whether a total operational stop would be required.

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References

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