TECHNOLOGY FACTSHEET

Retrofit of post-combustion CO2 capture for steam crackers using MEA solvents

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Sector	CCS
	Industry: Petrochemicals
ETS / Non-ETS	ETS
Type of Technology	CCS
Description	There are a variety of techniques for post-combustion carbon capture that can be applied to flue gases; this factsheet considers chemical absorption with monoethanolamine (MEA) solvents. Post-combustion capture does not require any major modifications to the refining process; MEA amine stripping technology is an end-of-pipe technology added to the plant to capture CO2 from existing flue gas streams. The modifications required for CO2 capture are cleaner flue gas (additional desulphurisation equipment); a CO2 capture unit (absorber and stripper columns, heat exchangers, condensers, and a reboiler); and a CO2 compression and dehydration unit. As the capture process requires electricity (notably for compression) and steam (mainly for solvent recovery), additional investments are also required to expand the site's utilities. If there is excess heat and electricity capacity, this could reduce the cost, but the potential to use existing excess heat or existing utility capacity depends largely on site design and site-specific constraints, so has not been considered in this factsheet. This factsheet is based on literature looking both at theoretical steam cracker sites and at specific sites. The cleaned flue gas enters the absorber and is brought into contact with the MEA amine solution. About 90% of the CO2 is absorbed into the amine solution (now together referred to as a rich loading solution), and is then pumped to the stripper. In the stripper column, the rich loading solvent is heated with steam from the reboiler (which uses a heat exchanger to transfer heat from external steam to a heat transfer fluid), breaking the chemical bonds between the amine solvent and the CO2, and causing it to release its CO2, creating a relatively pure CO2 stream. The CO2 continues to the compressor, which compresses the gas to about 110 bar/11 MPa for transport and storage. The remaining solution (called a lean loading solution), now at a temperature of about 120 degrees C, is pumped back to the absorber to begin the cycle again, first passing through a heat exchanger to preheat the rich loading solution. While the MEA solvent capture technique is can also be applied to flue gases from power plants, there are two major differences when considering a steam cracker. First, the installations require combination of several flue gas streams (from furnaces and utilities), which leads to different equipment costs per unit of captured CO2. Second, the final concentration of CO2 in the flue gases is higher than those of a typical gas-fired power plant (cracking furnaces have concentrations above 10%vol, while a typical gas turbine has a concentration below 10%vol, and sometimes even below 5%vol). Post-combustion carbon capture can be either retrofitted or designed in a greenfield steam cracker; this factsheet considers a retrofit to an existing steam cracker. Integrated design could lead to lower costs or higher efficiency. This factsheet considers configurations with capture of CO2 from the cracker furnaces and/or the utilities on site. The flue gases of the cracker furnace is estimated to have a CO2 concentration of about 13-15%vol. The power plant flue gases have slightly lower concentrations but can account for a large point source of CO2 emissions, and therefore are often included in studies of CO2 capture. At lower concentrations, the cost per tonne of captured CO2 rises. (Zero Emissions Platform 2013).
TRL level 2020	TRL 6
	Post-combustion carbon capture has not yet been demonstrated at full scale in a steam cracker, but it already operates commercially using the same technology in power plants. The specific design and costs will vary, but the basic principle of chemical absorption carbon capture using MEA solvents remains the same. Geological storage of carbon dioxide has also been demonstrated and is commercially available, though there are currently no CCS projects operating in the Netherlands. The Porthos project, which will transport CO2 captured in the port of Rotterdam by pipeline, for storage in retired gas fields in the North Sea, has signed Joint Development Agreements with several industrial partners. The partners will apply for SDE++ funding for the project. Construction, according to the project timeline, will begin in 2022, and operation will begin in 2024. While the existing steam crackers in the Netherlands are not part of the initial plans for the project, the Porthos project would demonstrate the feasibility of geological CO2 storage in the Netherlands, and this project or another project could potentially expand to include additional CO2 sources (such as the 3 steam crackers located in Moerdijk, Geleen, and Terneuzen).

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	Mton CO2 captured		0,64								
			0,43			-			1,80		
Potential			Current			2030			2050		
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
Market share		%	-			-			-		
			-	–	-	Min	–	Max	Min	–	Max
Capacity utlization factor	1,00										
Full-load running hours per year											
Unit of Activity	Mton CO2 captured/year										
Technical lifetime (years)	25,00										
Progress ratio											
Hourly profile											
Explanation	Capacity varies depending on steam cracker size and utilities. Each of the steam crackers in the Netherlands has a different configuration, size and different processes on-site; thus this factsheet is not equally applicable to all steam crackers. The 3 sites considered are Sabic Geleen (1310 kt ethylene/year), Shell Moerdijk (910 kt ethylene/year) and Dow Terneuzen (3 units with a total capacity of 1825 kt ethylene/year). It is not possible to determine the potential or market share of this technology in the future, as it will be highly dependent on policy, subsidies, and CO2 prices, as well as the future of the Dutch petrochemicals sector. Utilization factor will likely be similar to the utilization factor of the steam cracker process equipment. No data was available on progress ratio or hourly profile, though CO2 capture processes are expected to run continuously, similar to the steam cracking process.										

COSTS

Year of Euro	2015								
	Euro per Functional Unit	Current			2030			2050	
Investment costs	mln. € / Mton CO2 captured	170,00			-			-	
		139,00	–	229,00	Min	–	Max	Min	–	Max
Other costs per year	mln. € / Mton CO2 captured	-			-			-	
		Min	–	Max	Min	–	Max	Min	–	Max
Fixed operational costs per year (excl. fuel costs)	mln. € / Mton CO2 captured	6,80			-			-	
		6,80	–	8,90	Min	–	Max	Min	–	Max
Variable costs per year	mln. € / MtCO2 captured	-			-			-	
		Min	–	Max	Min	–	Max	Min	–	Max

Costs explanation	Cost estimates in literature for carbon capture retrofits to steam crackers are limited. The wide range of investment costs reflects uncertainty in cost, as this is not yet commercialized. Sherif (2010) presents a study of the Borealis steam cracker in Stenungsund, Sweden. Ho et al. 2011 and Kuramochi et al 2012 both provide general estimates for the refining and petrochemicals sectors, and note considerable uncertainty in these cost estimates. Fixed O&M costs from Sherif 2010 are calculated on the basis of 4% of capital investment. In addition to the underlying uncertainty in cost estimates, the costs of capture can also vary depending on the size and configuration of the steam cracker considered, cost of capital, and other company and site-specific parameters. Cost estimates are often presented on an annualized basis, per tonne of CO2 captured or avoided, including fixed and variable O&M costs. These costs are not directly comparable to the investment costs presented above, which are overnight capital investments per unit of capacity. Note that cost per tonne of CO2 captured differs from the cost per tonne of CO2 avoided (which takes into account the energy penalty - CO2 emitted in generating the additional energy needed for capture and compression of CO2 - and is therefore higher). However, for a 625 kt/year ethylene capacity steam cracker, about €80/tCO2 captured is estimated (Sherif 2010). Sources cited for the petro-chemicals sector in Ho et al. 2011 give a range of about €35-75/tCO2 captured.

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Steam	PJ	3,30			-			-		
			2,40	–	4,40	*Min*	–	*Max*	*Min*	–	*Max*
	Electricity	PJ	0,48			-			-		
			0,45	–	0,62	*Min*	–	*Max*	*Min*	–	*Max*
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Energy in- and Outputs explanation	Many steam crackers have on-site utilities (boilers and/or CHP units) to meet their process steam demand. Steam is generated using both natural gas and excess process gases. The additional steam demand for CO2 capture can be met by on-site utilities or can be purchased from an off-site steam generator. Some sites may already have sufficient steam generation capacity on-site to meet the extra demand; in this case, additional fuel will be consumed. Steam demand is shown here, rather than fuel, to provide a generic case relevant to most steam cracker sites.

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	MEA solvent (make-up)	kt	2,09			-			-		
			2,09	–	2,09	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Material flows explanation	MEA solvent use and make-up input for steam cracking CO2 capture units is assumed to be similar to that of refineries.

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)

	Substance	Unit	Current			2030			2050		
Emissions	CO2 captured	Mton CO2-eq	-1,00			-			-		
			-1,00	–	-1,00	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Emissions explanation	The CO2 capture rate that is achievable using MEA solvents will depend on the configuration of the steam cracker site, and which streams are combined. This factsheet considers overall CO2 capture rates of about 71-85%. About 64-70% of CO2 emissions are avoided (considering the additional energy needed for the capture process).

OTHER

Parameter	Unit	Current			2030			2050		
		-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Explanation	

REFERENCES AND SOURCES

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