TECHNOLOGY FACTSHEET

TNO

POST-COMBUSTION CO2 CAPTURE ADD-ON FOR POWER PLANTS - SOLID FUELS

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Sector	CCS
ETS / Non-ETS	ETS
Type of Technology	CCS
Description	In this factsheet a generic end-of-pipe solution to capture CO2 from flue gases after the combustion of solid fuels such as coal, solid biomass and municipal solid waste (MSW) in power plants is considered. Similar technology can be used for large boilers, but these are not the focus of the factsheet. Reference plants are solid fuel power plants without CCS ((ultra)supercritical coal/lignite, solid biomass, MSW, etc.). There are different requirements for flue gas cleaning and preparation for CO2 capture (dust filters, NOx removal, sulphur scrubbers, etc.) which will influence performance and costs. The performance and cost ranges are considered to be sufficiently close for the variety of solid fuels to group them together in a single factsheet. Post-combustion capture can be attached to an existing power plant or incorporated in the design of a new plant, the latter with potential for increased efficiency and lower total costs. The focus of this factsheet is add-on capture for a stand-alone plant, regardless of age or type of solid fuel, and therefore does not take into account potential efficiency gains or cost reductions from integrated design of new plants. Post-combustion CCS generally entails capture from flue gases with low CO2 concentrations. In the case of solid fuels CO2 concentrations are generally below 15% (IPCC, 2005; IEAGHG 2013). There are a variety of techniques that can be used to separate CO2 from the flue gas, including using sorbents/solvents, membranes and distillation machinery. Chemical solvents, such as Mono-Ethanolamine (MEA), are the most commonplace technique for post-combustion capture for power plants (IPCC 2005), therefore they are considered the default for this factsheet. After CO2 capture, a regeneration step is required to release the CO2 and clean the solvent so it can be reused. By adopting amine technology, 85-95% of CO2 can be captured from the flue gas (IPCC, 2005). Energy requirements for capture and compression of CO2 lead to higher fuel consumption, hence net CO2 reductions achieved are lower than the capture rate. CO2 emission reduction rates for coal power plant retrofits range from 63%-94%, depending on whether emissions from auxilliary energy supply are captured or not (IPCC, 2005; Rubin et al., 2015a, Mantripragada, 2019).
TRL level 2020	TRL 9 Commercial post-combustion CO2 capture solutions have been available for several decades (IPCC 2005). As of 2019 there are two operational commercial coal power plants with post-combustion capture (Mantripragada et al 2019).

TECHNICAL DIMENSIONS

Capacity	Functional Unit		Value and Range								
	Mton CO2/year		2.00								
			1.00			-			5.60		
Potential	EU	Gton CO2	Current			2030			2050		
			300.00			-			-		
			300.00	–	300.00	Min	–	Max	Min	–	Max
Market share	0	%	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max

Capacity utlization factor	-	
Full-load running hours per year	7,500-8,000	
Unit of Activity	Mton/year	
Technical lifetime (years)	30-40 (IPCC 2005)	
Progress ratio	0.9-0.99 (Rubin et al 2015b)	
Hourly profile	No	
Explanation	Annual capture capacity depends on many factors such as the size of power plant, capture rate, etc. Value and range are given here solely to give an impression of typical scale, for power plants of a common size (500-1000 MW). Capture potential is dependent on the number of deployed power plants and the CO2 capture rates - and therefore difficult to assess. A potential limiting factor can be the available storage capacity, which is estimated at (at least) 300 Gton CO2 in the EU and 10,000 Gton CO2 globally (IOGP 2019). Full-load running hours per year are determined by the power plant running hours, typically between 7,500 and 8,000 hours per year. Progress ratio is based on Rubin et al (2015b) projections for learning rates for pulverised coal with CCS (1-10%). No estimates are given in the study for solid biomass or MSW with CCS.	

COSTS

Year of Euro	2015								
	Euro per Functional Unit	Current			2030			2050		
Investment costs	€ / kWe	1,200.00			950.00			950.00		
		700.00	–	1,700.00	660.00	–	1,150.00	660.00	–	1,150.00
Other costs per year	€ / kWe	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max
Fixed operational costs per year (excl. fuel costs)	€ / kWe	28.00			24.00			24.00		
		28.00	–	28.00	24.00	–	24.00	24.00	–	24.00
Variable costs per year	€ / MWh	2.00			2.00			2.00		
		2.00	–	2.00	2.00	–	2.00	2.00	–	2.00

Costs explanation	Costs are given in terms of additional costs per kWe of power production capacity, such as additional costs for flue gas preparation and the amine CO2 capture plant. The investment and operational costs of the existing plant are not included. Data is mostly based on coal-fired power plants, as there is more data on CCS costs available for these than for biomass or MSW plants. Costs for biomass and MSW are expected to be higher than average costs for coal plants due to additional requirements for flue gas cleaning (e.g. SOx and NOx removal) to prevent rapid solvent degradation. Additional investment costs include costs for CO2 capture, CO2 compression and utility units (IEAGHG, 2014a). Additional fixed O&M costs include additional costs for maintenance, labour, administration insurance and taxes (IEAGHG, 2014a). Variable O&M costs include additional chemicals, cooling water charges and waste disposal costs (ZEP, 2011). In particular, costs for solvents still contain high levels of uncertainty (ZEP, 2011). Costs per ton of CO2 captured range from 24-62 €/ton (IPCC, 2005; Rubin et al, 2015a, Mantripragada, 2019). Costs per avoided ton CO2 range from 25-100 €/ton CO2 (IPCC, 2005; Rubin et al. 2015a, Mantripragada, 2019; IEA, 2013; ZEP 2011). Note that all these sources report costs for new coal-fired power plants with CCS. The cost of add-on CCS is expected to be higher due to project specific costs, such as construction challenges due to limited space, integration of existing plant with new capture plant and lower economies of scale at smaller existing plants (Rubin et al. 2015a).

ENERGY IN- AND OUTPUTS

Energy carriers (per unit of main output)	Energy carrier	Unit	Current			2030			2050		
	Main output: Electricity	PJ	-1.00			-			-		
			-1.00	–	-1.00	Min	–	Max	Min	–	Max
	Electricity	PJ	1.12			-			-		
			1.08	–	1.18	Min	–	Max	Min	–	Max
	Heat	PJ	0.18			-			-		
			0.12	–	0.27	Min	–	Max	Min	–	Max
		PJ	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max

Energy in- and Outputs explanation	The energy penalty for CO2 capture is estimated at 20-45% (% more input/MWh) (Rubin et al., 2015a; IPCC, 2005; IEA, 2013). Additional energy is required as electricity for pumps and compression and as heat, mostly for the regeneration of the solvent used for CO2 capture. The ratio of additional electricity and heat required depends on the plant design. It is here assumed that 40% of additional energy requirement is electricity and 60% heat (based on IEAGHG, 2013). The reported heat required for the regeneration of the solvent varies from 0.23-1 MWhth/ton CO2 captured (IEAGHG, 2013; Mantripragada, 2019). Additional electricity consumption is approximately 0.17 MWh/ton CO2 captured (IEAGHG, 2013).

MATERIAL FLOWS (OPTIONAL)											
Material flows	Material	Unit	Current			2030			2050		
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Material flows explanation											

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)											
Emissions	Substance	Unit	Current			2030			2050		
	CO_2	ton/MWhe		-1.00			-			-	
			-1.57	–	-0.50	*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 inclusion of CCS reduces CO_2 emissions from a plant. Reference is a supercritical pulverised coal power plant. CO_2 reductions per MWh are assumed to be 75%-90% (IPCC, 2005; Rubin et al., 2015a; JRC, 2014). CO_2 emissions from flue gas before capture (including CO_2 from additional fuel consumed for CO_2 capture) ranges from 0.9-1.5 ton CO_2/MWh (Rubin et al., 2015a; IEAGHG, 2013). Emissions to the atmosphere after capture are 0.09-0.22 ton CO_2/MWh (Rubin et al., 2015a; JRC, 2014; IEAGHG, 2013). Emissions for a similar plant without CCS are in the range of 0.75-0.9 ton CO_2/MWh (Rubin et al. 2015a; JRC, 2014; Manrtipragada, 2019).										

OTHER										
Parameter	Unit	Current			2030			2050		
Capture rate	% CO_2 captured		0.90			-			-	
		0.85	–	0.95	*Min*	–	*Max*	*Min*	–	*Max*
Solvent consumption	kg/ton CO_2		0.90			-			-	
		0.20	–	1.60	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Explanation	According to Rubin et al. (2015) there have not been significant developments in CO_2 capture rates since the IPCC Special Report on CCS from 2005, who reported a range of 85-95% at the time. Some reports indicate higher capture rates are technically and economically feasible in some specific applications (IEAGHG, 2014b). The performance of solvents declines over time and therefore requires replacement and recovery. This leads to consumption of solvent of 0.2-1.6 kg/ton CO_2 captured (IPCC, 2005).									

REFERENCES AND SOURCES

IPCC (20015); Kelly, Thambimuthu, Soltanieh, Abanades et al - Special Report on Carbon dioxide Capture and Storage

IEAGHG (2013) - Post-combustion CO2 capture scale up study

Rubin, Davison and Herzog (2015a) - The cost of CO2 capture and storage

Mantripragada, Zhai and Rubin (2019) - Boundary dam or Petra Nova - Which is a better model for CCS energy supply?

MIT CCS - Boundary Dam Fact Sheet, link: https://sequestration.mit.edu/tools/projects/boundary_dam.html, Accessed on January 16 2020

IOGP (2019) - The Potential for CCS and CCU in Europe

Rubin, Azevedo, Jaramillo and Yeh (2015b) - A review of learning rates for electricity supply technologies

JRC (2014) - Energy Technology Reference Indicators

ZEP (2011) - The costs of CO2 capture

IEA (2013) - Technology Roadmap: Carbon Capture and Storage

IEAGHG (2014a) - CO2 capture at coal based power and hydrogen plants

IEAGHG (2014b) - Assessment of Emerging CO2 Capture Technologies and their Potential to Reduce Costs