TECHNOLOGY FACTSHEET

DIRECT AIR CAPTURE (DAC) OF CARBON DIOXIDE

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Sector	Atmospheric CO2 capture
ETS / Non-ETS	Non-ETS
Type of Technology	Atmospheric CO2 capture
Description	This factsheet describes the use of technology to capture and concentrate CO2 from the atmosphere. Several types of DAC systems are being developed, based on e.g. aqueous scrubbing solutions (water with amines or hydroxides) or solid adsorbents (amine resins). No large scale commercial plants exist today and pilot plants vary significantly in their process design. We here describe the plant very basicly, without a strict technology design, and use average values for costs and energy use. We here assume that the produced CO2 is 100% pure, although in reality the product may contain traces of other gasses and H2O. From website Climeworks: "Our plants capture atmospheric carbon with a filter. Air is drawn into the plant and the CO2 within the air is chemically bound to the filter.Once the filter is saturated with CO2 it is heated (using mainly low-grade heat as an energy source) to around 100 °C (212 °F). The CO2 is then released from the filter and collected as concentrated CO2 gas to supply to customers or for negative emissions technologies. CO2-free air is released back into the atmosphere. This continuous cycle is then ready to start again. The filter is reused many times and lasts for several thousand cycles." From website Carbon Engineering (CE): "Our DAC technology has four major pieces of equipment. The process starts with an air contactor, which is a large structure modelled off industrial cooling towers. A giant fan pulls air into this structure, where it passes over thin plastic surfaces that have potassium hydroxide solution flowing over them. This non-toxic solution chemically binds with the CO2 molecules, removing them from the air and trapping them in the liquid solution as a carbonate salt. The CO2 contained in this carbonate solution is then put through a series of chemical processes to increase its concentration, purify and compress it, so it can be delivered in gas form ready for use or storage. This involves separating the salt out from solution into small pellets in a structure called a pellet reactor. These pellets are then heated in our third step, a calciner, in order to release the CO2 in pure gas form. This step also leaves behind processed pellets that are hydrated in a slaker and recycled back within the system to reproduce the original capture chemical."
TRL level 2020	TRL 7
	Currently two pilot plants exist, besides several small scale applications. The first is from Carbon Engineering in Canada (2015, around 500 ton/yr), and the second from Climeworks (2017, 900 ton/yr). Climeworks sells modular systems up to 1.8 kton CO2/yr and Carbon Engineering is in a process to construct a commercial plant of 1000 kton/yr.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	Mton		1.00								
			0.00			-			1.00		
			Current			2030			2050		
Potential			unlimited			-			-		
			-	–	-	*Min*	–	*Max*	*Min*	–	*Max*
Market share		%	0.01 Mton CO2/yr			10 Mton CO2/yr			1000 Mton CO2/yr		
			-	–	-	0.10	–	16.68	10.00	–	3,170.01
Capacity utlization factor	1.00										
Full-load running hours per year	8,322.00										
Unit of Activity	Mton/year										
Technical lifetime (years)	25.00										
Progress ratio	0.80										
Hourly profile	no										
Explanation	We assume that the process runs 95% of the time. The technology is novel and no learning rate has been reported. We estimate a progress ratio of 0.8, which seems to be an reasonable assumption for mass produced modular units (a relatively high learning rate 20%). The potential is very high but also very uncertain and the deployment rate would have a significant impact on the future costs. Future costs are based on literature and no projection based on the estimated learning rate is provided.										

COSTS

	Euro per Functional Unit	Current			2030			2050		
Year of Euro	2015									
Investment costs	mln. € / Mton	1,200.00			600.00			300.00		
		519.00	–	2,003.28	250.11	–	1,119.08	87.92	–	794.85
Other costs per year	mln. € / Mton	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / Mton	48.00			24.00			12.00		
		10.38	–	86.14	12.00	–	40.00	6.00	–	20.00
Variable costs per year	mln. € /	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Costs explanation	Costs to produce CO2 from air vary significantly among studies. To date, no commercial plant exists and estimates are uncertain. We selected a value for 2020 that is the high end of that reported by companies (although based on detailed techno-economic analysis (Keith 2018)) and the low end of general estimates by others. We assume that costs may decrease significantly if the technology is developed to large scale. We take 4% of initial investments costs as O&M costs and assume this includes all maintenance and replacement costs (no variable costs). Costs for energy use are excluded from the O&M costs.									

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Heat	PJ	6.00			5.00			3.00		
			-	–	7.05	5.00	–	5.00	3.00	–	3.00
	Electricity	PJ	1.00			0.90			0.80		
			0.80	–	1.78	0.90	–	0.90	0.80	–	0.80
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Energy in- and Outputs explanation	The type of DAC technology determines the energy demand. For liquid sorbent systems (described in Keith 2018, Socolow 2011), the precipitated CaCO3 is calcined to produce CO2 and CaO. This process requires high temperature heat (900 °C) and uses a kiln typically running on natural gas. Solid sorbent technology requires low temperature heat to warm the sorbent to approximately 100 °C to desorb the CO2. Electricity is used to drive the ventilators and compressors. The final CO2 pressure largely determines how much electricity is needed for the compressors: high pressure (150 bar) requires around 1 GJ/ton more than low pressure CO2 (1 bar), based on Keith 2018. Thermodynamicly only around 0.5 GJ/ton CO2 is needed to concentrate 400 ppm to a pure CO2 stream (Socolow 2011). It is likely that energy usage of future systems will become closer to this limit. Such developments are uncertain and it might well be possible that more electricity will be used in the future and less heat or that only electricity is used (also generating required heat). This is why we assumed the heat usage declines to 3 GJ/ton CO2 in 2050. We select on average use of 1 PJ electricity to produce 1 Mt of CO2 at any desired pressure. Electricity use declines to 0.8 PJ/MtCO2 in 2050. Especially for the solid sorbent technology, low grade waste heat is an attractive energy source as only 100 C heat is required.										

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	Air	Mton	1,829.00			1,829.00			1,829.00		
			1,829.00	–	1,829.00	1,829.00	–	1,829.00	1,829.00	–	1,829.00
	CO2	Mton product	-1.00			-1.00			-1.00		
			-1.00	–	-1.00	-1.00	–	-1.00	-1.00	–	-1.00
Material flows explanation	The technology extracts CO2 from air and thus requires large amounts of air. With a capture rate of 90%, more than 1.8 Gton of air is needed to produce 1 Mt of CO2 (400 ppm). If natural gas is used to produce heat, its CO2 emissions can be used as additional CO2 source (considered as such in Keith 2018). In their analysis 0.98 Mt CO2 is captured from air, while 0.48 Mt is captured from natural gas. In our estimate we only capture from air and use only heat (irrespective of its source) and electricity as energy inputs.										

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)											
	Substance	**Unit**	**Current**			**2030**			**2050**		
Emissions				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Emissions explanation											

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

Carbon Engineering. website: https://carbonengineering.com, and https://carbonengineering.com/worlds-largest-direct-air-capture-and-sequestration-plant/

Climeworks. website: https://www.climeworks.com

Keith et al. 2018. A Process for Capturing CO2 from the Atmosphere, Joule, https://doi.org/10.1016/j.joule.2018.05.006

Socolow et al. 2011. Direct Air Capture of CO2 with Chemicals, https://www.aps.org/policy/reports/assessments/upload/dac2011.pdf

Siegemund et al. 2017. The potential of electricity-based fuels for low-emission transport in the EU, https://www.dena.de/fileadmin/dena/Dokumente/Pdf/9219_E-FUELS-STUDY_The_potential_of_electricity_based_fuels_for_low_emission_transport_in_the_EU.pdf

Agora Energiewende 2018 (Study by Frontier Economics), The Future Cost of Electricity-Based Synthetic Fuels, https://www.agora-energiewende.de/fileadmin2/Projekte/2017/SynKost_2050/Agora_SynKost_Study_EN_WEB.pdf

Schmidt et al. 2018. Power-to-Liquids as Renewable Fuel Option for Aviation: A Review, https://doi.org/10.1002/cite.201700129

Van der Giesen et al. 2014. Energy and Climate Impacts of Producing Synthetic Hydrocarbon Fuels from CO2, https://doi.org/10.1021/es500191g