Report on value chain components and their techno-economic performance based on literature data

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Lead Author:	Till Strunge (HWU)
Contributing Author(s):	Mijndert van der Spek (HWU), Evrim Ursavas (RUG), Alban Kryeziu (RUG), Niels Wouda (RUG)
Reviewed by:	Mijndert van der Spek
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Version Control Sheet

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1 Introduction

To achieve climate neutral industrial production, many industries will have to rely on CO_2 capture and utilisation and/or storage (CCUS), where otherwise emitted CO_2 is captured and either reused as feedstock for other products (e.g., in building materials) or stored underground (e.g., in depleted natural gas fields)[1]. Investment decisions on, and policy design for CCUS technologies need to be based on scientific evidence and must be underpinned by estimated costs[2], among other considerations. This is no mean feat and increases in complexity when considering complete industrial production clusters or regions, instead of individual production plants.

Work package 8 of the ConsenCUS project aims to develop cost optimal CCUS clusters in northwest and southeast Europe. To that end, network optimization models are developed that link CO_2 sources (industries, electricity production, among others) and sinks (storage, utilization) and design networks that reach full decarbonisation at minimum cost. The emitters in the industrial clusters can have several decarbonisation options each (hereafter called interventions), each with a specific materials, energy, and cost effect. These interventions can be fed into a network model so the model can design/determine the cost optimal intervention for each plant, as well as the corresponding network (here, CO_2 network) design. This deliverable presents component models for common emitter types (cement, iron & steel, power production) and relevant interventions that can be used in the network models developed in task 8.4. It also presents component models for CO_2 transport and storage. All are sourced from the open literature. Parts of the materials presented here are produced by and also used in the UK industrial decarbonisation research and innovation centre (MIP2.1).

2 Description of technologies

2.1 Cement

Cement is produced by calcining limestone ($CaCO_3$) and mixing this with other minerals to produce clinker, the active ingredient in cement. Here, not only high temperatures of up to

1500°C are needed, but also CO_2 is released from the limestone calcination itself. Hence, the cement industry is limited in its options to make significant emission reductions because its emissions stem from both its energy consumption rate (i.e., energy-related emissions) and the calcination reaction itself (i.e., process-inherent emissions). To reduce the energy-related emissions, they must use efficiency and substitution measures like the use of alternative fuels[3-8] and process electrification[9]. As these measures will only reduce the energy-related emissions down to zero at best, further measures must be implemented to tackle the process-inherent emissions (which account for around 60% of total emissions[10]). The cement industry usually relies on the use of clinker substitutes known as supplementary cementitious materials (SCMs) such as industrial wastes and virgin minerals to reduce emissions, but there are problems with strength and workability with this approach[3,6,8,11,12]. As such, we here consider interventions with high emission reduction potential such as carbon capture and storage, biofuels, carbon capture and CO_2 mineralisation, and calcined clay cement, as well as combinations of these approaches, to address this problem. Traditional SCMs such as fly ash and blast furnace slag were not included, in addition to other options such as carbon-based productions, as they do not store CO_2 permanently. An overview of the emission reduction approaches with high emission reduction potentials included in this publication are the following:

- Carbon capture and storage
- Biofuels
- Carbon capture and CO_2 mineralisation to produce an SCM
- Calcined clay cement

The cost data shown in section 4 represent combinations of these interventions if they can be implemented in combination. We excluded the use of traditional SCMs from waste streams (fly ash and blast furnace slag) as they have been used extensively to reduce emissions and are unlikely to be able to significantly reduce the emissions further[3]. Additionally, we excluded other means of carbon capture and utilisation, where CO_2 is not stored in minerals (e.g., production of carbon-based fuels) since it does not lead to permanent storage of CO_2.

2.2 Steel

Steel production is one of the biggest contributors to anthropogenic CO_2 emissions. There are two main ways of producing steel, primary production which is done through mining of iron ore out of the ground followed by high energy processes to reduce the ore, and secondary production, which uses scrap metal - for example, from scrapped products or during the steelmaking process - to manufacture steel. Since not all grades of steel can be produced using secondary production, while steel demand is typically higher than supply of scrap, primary production routes are estimated to remain necessary in the future. The most common primary production route is the production of steel in an integrated steel mill which combines the two processes of i) iron creation in the blast furnace (BF), where melted iron ore is reduced using coal as reducing agents, and ii) steel manufacturing in the basic oxygen furnace (BOF), where oxygen (O2) is injected to remove unwanted elements. An alternative route is the direct reduction (DRI), where solid iron ore is reduced using hot gas (commonly natural gas), followed by an electric arc furnace (EAF), where the ore is molten into liquid steel[13]. The here considered emission reduction approaches can either be applied to the BF-BOF or DRI-EAF route. An overview of the emission reduction approaches with high emission reduction potentials included in this publication are the following:

- BF-BOF or DRI-EAF with Carbon capture and storage
- BF-BOF with Biofuels
- DRI-EAF using natural gas
- DRI-EAF using hydrogen

The cost data shown in section 4 represent combinations of these interventions if they can be implemented in combination.

2.3 Power plants

CO_2 capture can be used to decarbonize the power sector, mainly coal-fired advanced super critical pulverized coal power plants (ASCPC) and natural gas-fired combined cycle gas turbine (CCGT). In section 4 we present cost data for MEA post combustion capture for these plants.

2.4 Hydrogen production and consumption

To decarbonize industry (including many CO_2 conversion technologies), low emission hydrogen will be needed. Most mature routes to produce hydrogen are currently steam methane reforming (SMR) and autothermal reforming (ATR) which can be made more efficient using gas heat reforming (GHR). Both processes can be equipped with CO_2 capture to reduce emissions. Alternatively, water electrolysis using renewable electricity can be used. Additionally, we here added the costs for combined heat and power (CHP) plants, which can use hydrogen for electricity and heat production. We included the following options in this deliverable:

- SMR with flue gas capture
- ATR GHR with carbon capture
- Water electrolysis
- CHP

2.5 Direct air capture technologies (DAC)

Direct air capture (DAC) will play a crucial role in combating climate change. It involves capturing CO_2 from the air using a chemical sorbent, followed by releasing the CO_2 from the sorbent. We here included two widely discussed processes: a solid-sorbent processes, which tend to have small modular designs and a liquid-sorbent process (KOH-Ca looping). As technological learning will play a large role in the costs for DAC, we here differentiate between first-of-a-kind (FOAK) and n^{th}-of-a-kind (NOAK) plants. NOAK costs are projections from the current FOAK scale to gigatonne scale (meaning all plants build cumulatively have the capacity to capture 1 gigatonne of CO_2 per year)[14]. We here include the following options:

- Solvent-based DAC (FOAK)
- Solvent-based DAC (NOAK)
- Solid sorbent DAC (FOAK)
- Solid sorbent DAC (NOAK)

2.6 CO_2 transport

After the capture of CO_2, it needs to be transported either to facilities of usage (for CCU) or storage sites (for CCS). Suggested methods include pipeline, railways, or transport via ships. This can become costly and hence accurate estimates can improve decision making processes[15]. We included pipeline transport into this deliverable with the following options:

- Onshore CO_2 pipeline with different diameters
- Offshore CO_2 pipeline with different diameters
- CO_2 compressors

2.7 Geological CO_2 storage

To store CO_2 underground, it is injected in supercritical form using injection wells. Costs for construction and operation of injection wells is also presented in section 4.

3 Methodology/ How to use the presented data

To include emitters and interventions in network models, two kinds of data are needed:

- Mass and energy balance for each emitter/intervention combination
- Costs for each emitter/intervention combination

Both are presented in this deliverable for the technologies discussed in section 2.

The cost data given here can be employed to determine the levelized total cost of product, ΔLCOP (additional costs per tonne of product $\dot{m}_{product}$) in [€/$t_{product}$], which combines both total capital requirements (TCR) and operational expenditures (OPEX). This indicator expressed the additional costs to a process when an intervention (e.g., carbon capture) is added to the incumbent process. To calculate ΔLCOP, we use i (the interest rate) and the estimated lifetime of the plant lifetime L[16] (equations (1) and (2))

$$\Delta LCOP = \frac{\alpha \cdot TCR_{technology} + OPEX_{fixed} + OPEX_{var} \cdot \dot{m}_{product}}{\dot{m}_{product}} \tag{1}$$

$$\alpha = \left(\frac{i}{1-(1+i)^{-L}}\right) \tag{2}$$

As the data presented in section 4 only refers a specific plant size, TCR must be scaled, if used in a different size. To do so apply the following approach (equation (3))[17]:

$$TCR_{tech} = TCR_{tech} \cdot \left(\frac{capacity_{new}}{capacity_{old}}\right)^{s} \tag{3}$$

Typical scaling exponents can be found in Turner and Pinkerton [18], Turner and Samaei [19], IEAGHG [20], Towler and Sinnott [17].

In section 4 we present the cost data for interventions and existing plants (i.e., incumbent plants). To calculate costs and mass and energy balances the values must be added, as the costs and balances for interventions are presented as differences to the incumbent plants. Examples are shown as follows:

$$TCR_{cement\ with\ carbon\ capture} = TCR_{incumbent\ cement} + TCR_{carbon\ capture} \tag{4}$$

$$OPEX_{var,cement\ with\ carbon\ capture} = OPEX_{var,incumbent\ cement} + OPEX_{var,carbon\ capture} \tag{5}$$

$$\dot{m}_{cement,cement\ with\ carbon\ capture} = \dot{m}_{cem,incumbent\ cement} + \dot{m}_{cem,carbon\ capture} \tag{6}$$

Please note that this methodology shall only be applied when the table states “Incumbent” and “Intervention”.

4 Costs

This section presents the costs for the emitters and interventions listed in section 2, with all costs sourced from public information with references given in the tables. Costs for the ConsenCUS CO_2 capture and conversion technologies will be added to section 4.4 after they have been estimated in work package 6, tasks, 6.1 – 6.3. The mass & energy balances for each process are provided in section 5.

4.1 Cement

Type of intervention	**Where can this be installed?**	**Process**	**Capacity [Mt/a]**	**TCR [M€]**	**$OPEX_{fixed}$ [M€/yr]**	**$OPEX_{var}$ [€/t_{cement}]**	**Ref**
Baseline	Incumbent	Integrated cement plant	1	219	10	24	21
Intervention	for Cement plant	Carbon capture	1	53	3	32	21
Intervention	for Cement plant	Biofuels	1	0	0	38	22,23
Intervention	for Cement plant	Carbon capture and biofuels	1	53	3	70	21-23
Intervention	for Cement plant	CO_2 Mineralisation	1	64	4	15	24
Intervention	for Cement plant	Biofuels and CO_2 Mineralisation	1	64	4	42	23,24
Intervention	for Cement plant	Carbon capture, biofuels and CO_2 Mineralisation	1	77	5	52	21-24
Intervention	for Cement plant	Carbon capture and CO_2 Mineralisation	1	77	5	26	21,24
Major assumptions: Cement type ordinary Portland cement with a clinker content of 100%, a clinker replacement factor of 30% for mineralisation, price of electricity 62€/MWh, price natural gas 32€/MWh, price coal price coal 3€/GJ, price wood pellets 15€/GJ, carbon footprint electricity 417kgCO_2/MWh, carbon footprint coal 95 kgCO_2/GJ, carbon footprint natural gas 241kgCO_2/MWh.							

4.2 Steel

Type of intervention	Where can this be installed?	Process	Capacity [Mt/a]	TCR [M€]	$\text{OPEX}_{\text{fixed}}$ [M€/yr]	OPEX_{var} [€/t_{steel}]	Ref
Baseline	Incumbent	BF-BOF	2	1559	123	302	13,25-27
Intervention	for BF-BOF	Carbon capture	2	228	7	40	26
Intervention	for BF-BOF	Biofuel	2	0*	0	77	26
Intervention	for BF-BOF	Biofuel and carbon capture	2	228	7	118	26
New plant	for BF-BOF	DRI-EAF (gas) with carbon capture	2	1790	119	362	28
New plant	for BF-BOF	DRI-EAF (blue hydrogen)	2	1466	111	393	28,29
New plant	for BF-BOF	DRI- EAF (green hydrogen)	2	1466	111	744	29,30
Baseline	Incumbent	DRI-EAF (gas)	2	1466	111	352	28
Intervention	for DRI-EAF	Carbon capture	2	324	8	10	28
Intervention	for DRI-EAF	Blue hydrogen	2	0	0	41	28,29
Intervention	for DRI-EAF	Green hydrogen	2	0	0	391	29,30

***Biofuel bought as charcoal**

Major assumptions: Price of electricity 62€/MWh, price natural gas 32€/MWh, price coal price coal 95.4€/t_{coal}, price charcoal 340.3€/t_{coal}, carbon footprint electricity 417kgCO_2/MWh, carbon footprint coal 95 kgCO_2/GJ, carbon footprint natural gas 241kgCO_2/MWh.

4.3 Power plants

Type of intervention	Where can this be installed?	Process	Capacity/net power output [MW_e]	TCR [M€]	$OPEX_{fixed}$ [k€/MWh]	$OPEX_{var}$ [k€/MWh]	Ref
Baseline	Incumbent	ASCPC	776	1468	4.57	26.8	[31]
Intervention	For ASCPC	Carbon capture (MEA)	-106*	436	4.4	24	[31]
Baseline	Incumbent	CCGT	5229	603	5.46	50.5	
New plant	For CCGT	Carbon capture (MEA)	4467	328	2.93	14.7	[32]

*** As MEA capture uses heat and electricity it decreases the plant's capacity when installed. Note to calculate the total capacity the Invention and Baseline must be added e.g., the net power output for ASCPC with MEA capture is 776MW_e + (-168 MW_e) = 608 MW_e.**

**** Note the operational expenditures presented here are shown as cost per year not per unit of output (i.e., GWh)**

4.4 CO_2 Capture

Type of intervention**	**Point source**	**CO2 purity**	**Capacity [Mt_{CO2}/a]**	**$\alpha \cdot$TCR $/\dot{m}_{CO2}$* [€/t_{CO2}/yr]**	**$OPEX_{fixed}$ $/\dot{m}_{CO2}$* [€/t_{CO2}/yr]**	**$OPEX_{var}$ $/\dot{m}_{CO2}$* [€/t_{CO2}/yr]**	**Ref**
Capture plant	Cement kiln-off gas	22.4%	1.14	28.29	8.59	50.12	[33]
Capture plant	Iron and steel COG, BFS, PPS	26.4%	2.75	28.95	8.80	62.36	[33]
Capture plant	Refinery H_2 Production	44.5%	0.23	37.35	11.35	68.75	[33]
Capture plant	Fertilizer CO_2 stripper vent	97.1%	0.46	9.00	3.17	14.72	[33]
Capture plant Wetsus techn.	Cement kiln off gas	Tbd	Tbd	Tbd	tbd	Tbd	
Capture plant Wetsus techn.	Magnesia kiln off gas	Tbd	Tbd	Tbd	Tbd	Tbd	
Capture plant Wetsus techn.	CHP flue gas	tbd	tbd	tbd	Tbd	Tbd	

*** $\dot{m}_{CO2}$ represents the mass flow of CO_2 captured.**

**** note we do not present any mass or energy balance for these technologies in section 5.**

4.5 Hydrogen

Type of intervention	**Where can this be installed?**	**Type**	**Capacity in [MJ/30min]**	**TCR [M€]**	**OPEX$_{fixed}$ [M€]**	**OPEX$_{var}$ [€/t]**	**Ref**
New plant	/	SMR with flue gas capture	1800000	597.8	28.7	46.56	[34]
New plant	/	ATR+GHR with carbon capture	1800000	735.6	27.6	43.78	[34]
New plant	/	Water electrolysis	180000	101.7	3.1	86.8	[34]
New plant	/	CHP plant	10000000	1.6	0.03	/*	[34]

*** Cost for fuel (i.e., hydrogen) have not been added** as the hydrogen source can widely differ (e.g., blue, green). When using this function add the hydrogen costs to derive variable OPEX.
Major assumptions: Price of electricity 62€/MWh, price natural gas 32€/MWh.

4.6 Direct air capture

Type of intervention	**Where can this be installed?**	**Process**	**Capacity [Mt/a]**	**TCR [M€]**	**OPEX$_{fixed}$ [M€]**	**OPEX$_{var}$ [€/t]**	**Ref**
New plant	/	Solvent-based DAC (FOAK)	0.98	1663	66.8	2	[14]
New plant	/	Solvent-based DAC (NOAK)	0.98	571	37.6	2	[14]
New plant	/	Solid sorbent DAC (FOAK)	0.0009599*	11	3	115	[14]
New plant	/	Solid sorbent DAC (NOAK)	0.0009599*	1	0.4	69	[14]

***Cost for one module.**
Major assumptions: Price of electricity 30€/MWh produced by wind energy in the UK, price natural gas 24€/MWh produced in the UK, carbon footprint electricity (wind UK) 22kgCO_2/MWh, carbon footprint natural gas 45kgCO_2/MWh (upstream emissions without combustion as these are recaptured by the process).

4.7 CO_2 Transport

Type of intervention	Where can this be installed?	Type	Capacity [t_{CO2}/30min]	TCR/d* [M€/km]	$OPEX_{fixed}$ [M€/yr]	$OPEX_{var}$ [€/t]	Ref
New pipe	Onshore	12INCH	114.2	0.52	/	2.9E-09	34,35
New pipe	Onshore	16INCH	285.4	0.93	/	2.9E-09	34,35
New pipe	Onshore	24INCH	570.8	1.30	/	2.9E-09	34,35
New pipe	Onshore	28INCH	856.2	1.46	/	2.9E-09	34,35
New pipe	Onshore	32INCH	1426.9	1.62	/	2.9E-09	34,35
New pipe	Onshore	40INCH	2397.3	2.18	/	2.9E-09	34,35
New pipe	Offshore	12INCH	114.2	1.02	/	7.6E-09	34,35
New pipe	Offshore	16INCH	285.4	1.21	/	7.6E-09	34,35
New pipe	Offshore	24INCH	570.8	1.69	/	7.6E-09	34,35
New pipe	Offshore	28INCH	856.2	1.90	/	7.6E-09	34,35
New pipe	Offshore	32INCH	1426.9	2.11	/	7.6E-09	34,35
Type of intervention	**Where can this be installed?**	**Type**	**Capacity [t_{CO2}/30min]**	**TCR [M€]**	**$OPEX_{fixed}$ [M€/yr]**	**$OPEX_{var}$ [€/t]**	
New unit	/	Small CO_2 compressor*	63.5	2.20	0.09	4.06E-04	34
New unit	/	Large CO_2 compressor*	635.4	22.0	0.88	4.06E-03	34

***The capital costs are reported in TCR in M€ per distance (d) in km.**

****A compressor needs to be placed between onshore and offshore pipelines.**

Type of intervention	**Where can this be installed?**	**Type**	**Capacity [Mt$_{CO2}$/yr]**	**α·TCR/d [M€/yr/km]**	**OPEX$_{fixed}$ [€/km]**	**OPEX$_{var}$ [€/t]**	**Ref**
New pipe	Onshore	4INCH	0.29	0.01867	653	/	36,37
New pipe	Onshore	6INCH	0.66	0.01940	679	/	36,37
New pipe	Onshore	8INCH	1.39	0.02267	793	/	36,37
New pipe	Onshore	10INCH	2.1	0.02433	852	/	36,37
New pipe	Onshore	12INCH	2.37	0.02640	924	/	36,37
New pipe	Onshore	16INCH	4.93	0.03093	1083	/	36,37
New pipe	Onshore	20INCH	7.3	0.03467	1213	/	36,37
Type of intervention	**Where can this be installed?**	**Type**	**Capacity [Mt$_{CO2}$/yr]**	**α·TCR [M€/yr]**	**OPEX$_{fixed}$ [M€/yr]**	**OPEX$_{var}$ [€/t]**	
Pumping station*	/	4INCH	0.29	0.057065	0.01427	0.163**	36,37
Pumping station*	/	6INCH	0.66	0.128397	0.03210	0.163**	36,37
Pumping station*	/	8INCH	1.39	0.271059	0.06777	0.163**	36,37
Pumping station*	/	10INCH	2.1	0.410156	0.10254	0.163**	36,37
Pumping station*	/	12INCH	2.37	0.463654	0.11591	0.163**	36,37
Pumping station*	/	16INCH	4.93	0.962974	0.24074	0.163**	36,37
Pumping station*	/	20INCH	7.3	1.426629	0.35666	0.163**	36,37

*** A pumping station can be assumed to be placed every 100-200km, to regain pressure loss, if not analysed in depths.**

****Of which 0.09€/t comprise of cost for electricity.**

4.8 CO_2 storage

Type of intervention	Where can this be installed?	Type	Maximal injection rate [t_{CO2} / 30min]	TCR [M€]	$OPEX_{fixed}$ [M€]	$OPEX_{var}$ [€/t]	Ref
New plant	/	CO_2 injection well	57.1	75	/	/	[34]
New plant	/	Salt cavern storage	180	3616	14.5	/	[34]

5 Mass- and energy balances

5.1 Cement

Process	Supercr. CO_2 produced [t/t]	Emitted CO_2 [t/t]	Cement [t/t]	Electricity [MWh/t]	Natural gas [MWh/t]	Coal [MWh/t]	Biomass [t/t]	Mineral [t/t]
Integrated cement plant	0.00	0.86	1.00	-0.13	0.000	-0.87	0.00	0.00
Carbon capture	0.77	-0.48	0.00	-0.10	-0.85	0.00	0.00	0.00
Biofuels	0.00	-0.30	0.00	0.00	0.00	0.87	-0.19	0.00
Carbon capture and biofuels	0.77	-0.78	0.00	-0.10	-0.85	0.87	-0.19	0.00
CO_2 Mineralisation	0.00	-0.32	0.00	-0.09	-0.23	0.26	0.00	-0.39
Biofuels and CO_2 Mineralisation	0.00	-0.53	0.00	-0.09	-0.23	0.87	-0.13	-0.39
Carbon capture, biofuels and CO_2 Mineralisation	0.54	-0.80	0.00	-0.10	-0.63	0.87	-0.19	-0.39
Carbon capture and CO_2 Mineralisation	0.54	-0.59	0.00	-0.10	-0.63	0.26	0.00	-0.39

5.2 Steel

Process	Supercr. CO_2 produced [t/t]	Emitted CO_2 [t/t]	Electricity [MWh/t]	Steel [t/t]	Natural gas [MWh/t]	Coal [MWh/t]	Charcoal [MWh/t]
New BF-BOF	0.00	2.02	-0.36	1.00	-0.23	-5.34	0.00
Carbon capture	1.15	-0.85	-0.17	0.00	-0.94	0.00	0.00
Biofuel	0.00	-0.52	0.00	0.00	0.00	2.86	-2.86
Biofuel and carbon capture	1.14	-1.36	-0.17	0.00	-0.94	2.86	-2.86
New DRI-EAF (gas)	0.00	1.28	-1.23	1.00	-3.20	0.00	0.00
DRI-EAF (gas) with carbon capture	0.69	-0.63	-0.16	0.00	0.00	0.00	0.00
DRI-EAF (blue hydrogen)	0.00	-0.45	0.00	0.00	3.20	0.00	0.00
DRI- EAF (green hydrogen)	0.00	-0.59	0.00*	0.00	3.20	0.00	0.00
New DRI-EAF (gas) with carbon capture	0.69	0.66	-1.39	1.00	-3.20	0.00	0.00
New DRI-EAF (blue hydrogen)	0.00	0.84	-1.23	1.00	0.00	0.00	0.00
New DRI- EAF (green hydrogen)	0.00	0.69	-1.23*	1.00	0.00	0.00	0.00

5.3 Power plants

Process	Supercritical CO2 produced [t/MWh]	Emitted CO2 [t/MWh]	Electricity [MWh]	Natural gas [MJ/MWh]	Coal [kg/MWh]
ASCPC	0.00	0.734	1	0.00	284
Carbon capture (MEA) for ASCPC	0.855	0.094	1	0.00	363
CCGT	0.00	0.35	1	6182	0.00
CCGT with MEA capture (90%)	0.36	0.040	1	7151	0.00

5.4 Hydrogen

Process	Supercr. CO_2 produced [t/MJ]	Emitted CO_2 [t/MJ]	Hydrogen [MJ]	Electricity [MWh/MJ]	Natural gas [MWh/MJ]	Domestic heat [MWh/MJ]
SMR with flue gas capture	0.000059	0.0000066	1	0	-1.455	0
ATR+GHR with carbon capture	0.0000625	0.0000036	1	0	-1.368	0
Water electrolysis	0	0	1	-1.4	0	0
CHP plant	0	0	-1	0.39	0	0.31

5.5 Direct Air capture

Process	**Emitted CO2 [t/$t_{CO2\ avoided}$]**	**Supercr. CO_2 produced [t/t]**	**Electricity [MWh/t]**	**Natural gas [MWh/t]**
Solvent-based DAC (FOAK)	-0.93	1.3	-0.37	-1.46
Solvent-based DAC (NOAK)	-0.94	1.23	-0.31	-1.13
Solid sorbent DAC (FOAK)	-0.96	1	-1.64	0
Solid sorbent DAC (NOAK)	-0.98	1	-1.04	0

5.6 CO_2 Transport

Process	**Electricity [kWh/t_{CO2} per MPa]**
Pumping station*	0.44[38]
***"the specific design pressure drop is assumed to be 10 Pa/m for gaseous and 30 Pa/m for liquid trans-port in the feeders and distribution pipelines"[36]**	

6 References

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