Supplementary Material

Life Cycle Assessment and Environmental Impact Evaluation of CCU Technology Schemes in Steel Plants

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Table S1. Carbon capture source gas flow parameters.

Gas composition	unit	Exhaust from power plants	blast furnace gas	coke oven gas	Lime kiln flue gas	converter gas
CO_2	vol.%	20.0	24.0	6.0	19.4	20.0
CO	vol.%	-	22.0	10.0	-	59.0
H_2	vol.%	-	3.0	56.0	-	0.5
N_2	vol.%	-	51.0	4.0	61.0	20.0
O_2	vol.%	-	-	-	7.0	0.5
H_2O	vol.%	-	-	-	12.6	-
CxHy	vol.%	-	-	24.0	-	-
low heating value	MJ/m^3	-	3.1	16.4	-	7.5
temperature	℃	-	60.0	60.0	130.0	60.0
pressures	kPa	-	116.3	108.3	102.1	104.8
flow rate	kNm^3/h	-	1994.8	203.4	70.0	169.1

Table S2. List of benchmark steel mill LCI without CCU technology.

Input	Quantity	1 unit/ton of crude steel	Output	Quantity	1 unit/ton of crude steel
Bentonite	7.44159	kg	Crude steel	1000.00000	kg
Compressed air	15.75077	m^3	Carbon dioxide (emissions to air)	271.22706	kg
Compressed air	65.95028	m^3	Chemical Oxygen Demand	0.00010	kg
Bentonite	2.45×10^{-5}	kg	Dust	3.30477	kg
Electricity	41.94343	MJ	Nitrogen oxides	3.62749	kg
Fluorspar	2.00×10^{-6}	kg	Nitrogen, organic	7.07×10^{-6}	kg
Standard Coal	349.28203	kg	Respirable particulate matter	11.41177	kg
3 MPa Nitrogen	69.89844	kg	Sulphur dioxide	0.37104	kg
Oxygen	289.18403	kg	Waste water	1.11375	kg
Steam	716.86305	MJ			
Metallurgical Coke	537.55685	kg			
Natural gas	0.14850	m^3			
Small pieces of coke	62.81380	kg			
Process Water	69.32278	kg			
Recycled water	1.16466	kg			
Anthracite	39.83531	kg			
Washed Coal	1105.34344	kg			
Sinter Ore	1447.9155	kg			
Coke Oven Gas	31.44669	m^3			
Coke Powder	68.74205	kg			
Iron Ore	1488.59520	kg			
Blast furnace gas	737.61051	m^3			

Table S3. Life cycle inventory data for the MEA carbon capture process.

Input	Quantity	1 unit/ton of crude steel	Output	Quantity	1 unit/ton of crude steel
vapour	158.76980	MJ	Captured CO_2	985.00000	kg
Ethanolamine	0.00285	kg	CO_2 (emitted into the air)	0.00085	kg
Flue gas	0.05170	m^3	Dust	2.87×10^{-8}	kg
Exhaust gas	492.09190	m^3	Nitrogen oxides	2.32×10^{-7}	kg
Circulating water	7.17951	kg	Sulphur dioxide	1.45×10^{-7}	kg
Coke Oven Gas	198.41000	m^3			
Converter gas	119.24310	m^3			
Blast furnace gas	1812.76800	m^3			

Table S4. Life Cycle Inventory Data for Polymeric Membrane Separation CO_2 Processes.

Input	Quantity	1 unit/to of crude steel	Output	Quantity	1 unit/ton of crude steel
Membrane Materials and Modules	0.00013	kg	CO_2 (emitted to air)	0.0960	kg
Flue gas	0.05170	m^3	Chemical Oxygen Demand	1.97×10^{-5}	kg
Process Water	7588.08400	kg	Dust	3.25×10^{-6}	kg
Waste gas	492.09190	m^3	Nitrogen oxides	2.62×10^{-5}	kg
Coke Oven Gas	198.41000	m^3	Respirable particulate matter	7.62×10^{-8}	kg
Converter gas	119.24310	m^3	Sulphur dioxide	1.64×10^{-5}	kg
Blast furnace gas	1812.76800	m^3	Captured CO_2	985.0000	kg

Table S5. Life Cycle Inventory Data for Activated Carbon Based TSA Process Route for CO_2 Capture.

Input	Quantity	1 unit/ton of crude steel	Output	Quantity	1 unit/ton of crude steel
Flue gas	0.05170	m^3	CO_2 (emitted into the air)	9.841	kg
Process water	78.04886	kg	Dust	3.64×10^{-8}	kg
Waste gas	492.0919	m^3	Nitrogen oxides	0.32092	kg
Coke Oven Gas	198.41	m^3	PM	0.0858	kg
Converter gas	119.2431	m^3	Sulphur dioxide	0.25342	kg
Blast furnace gas	1812.768	m^3	Captured CO_2	985	kg
Activated carbon	91.27381	kg			

Table S6. Life Cycle Inventory Data for Carbon Utilization Process Routes for CO2-based Methanol Production.

Input	Quantity	1 unit/ton of crude steel	Output	Quantity	1 unit/ton of crude steel
electricity	17.90839	MJ	Calcium carbonate	138.00000	kg
Converter steel slag	153.33330	kg	Carbon dioxide	46.08870	kg
Compressed air	0.17111	m^3	CO_2 that is not used up at the capture stage	925.58710	kg
Process water	3066.66700	kg	Chemical oxygen demand	0.15333	kg
Captured CO_2	29.68794	m^3	dirt	0.00154	kg
Circulating water	2024.00000	kg	Nitrogen oxide	0.01553	kg
Ammonium hydroxide	0.00511	kg	Inhalable particulate matter	0.02300	kg
Calcium oxide	30.66667	kg	Silicon dioxide	13.25873	kg
Ammonium chloride	1.32480	kg	Sulfur dioxide	0.00869	kg
Coke oven gas	0.11438	m^3	Waste water	4.69×10^{4}	m^3
lectricity	0.00012	MJ	CO_2 (emitted into the air)	0.00030	kg
Aluminium oxide	0.00918	kg	Chemical oxygen demand	2.83×10^{-7}	kg
Condensate water	68.85000	kg	dirt	1.01×10^{-8}	kg
hydrogen	145.35000	kg	Methanol (volatile emission)	1.19×10^{-5}	kg
Zinc oxide	0.02291	kg	Nitrogen oxide	1.69×10^{-6}	kg
Captured CO_2	501.23136	m^3	Inhalable particulate matter	1.03×10^{-7}	kg

Cupric oxide power	0.04743	kg	Sulfur dioxide	4.81×10^{-6}	kg
			Waste water	0.00588	kg
			carbinol	765.00000	kg

Table S7. Carbon Utilization Process Route Life Cycle Inventory Data for CO2-based Methanol Production

Input	Quantity	1 unit/ton of crude steel	Output	Quantity	1 unit/ton of crude steel
electricity	0.00012	MJ	CO_2 (emitted into the air)	0.00030	kg
Aluminium oxide	0.00918	kg	Chemical oxygen demand	2.83×10^{-7}	kg
Condensate water	68.85000	kg	dirt	1.01×10^{-8}	kg
hydrogen	145.35000	kg	Methanol (volatile emission)	1.19×10^{-5}	kg
Zinc oxide	0.02291	kg	Nitrogen oxide	1.69×10^{-6}	kg
Captured CO_2	501.23136	m^3	Inhalable particulate matter	1.03×10^{-7}	kg
Cupric oxide power	0.04743	kg	Sulfur dioxide	4.81×10^{-6}	kg
			Waste water	0.00588	kg
			carbinol	765.00000	kg

Table S8. LCIA results of six different CCU schemes for steel mills.

Impact assessment category	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
TFAP/Molar H+ equivalent	0.4418	-0.7186	-0.8255	-0.7135	-0.2040	-0.4210	-0.1802
TAP/PNOF	1.96×10^{-9}	-3.18×10^{-9}	-3.66×10^{-9}	-3.16×10^{-9}	-9.03×10^{-10}	-1.86×10^{-9}	-7.98×10^{-10}
CCE/PDF	1.96×10^{-6}	-8.83×10^{-6}	-1.25×10^{-5}	-1.18×10^{-5}	5.75×10^{-6}	5.84×10^{-6}	5.90×10^{-6}
CCH/DALY	3.50×10^{-4}	-0.0016	-0.0022	-0.00209	0.0010	0.00103	1.04×10^{-3}
GWP100/Mass CO2 equivalent	246.9548	-1113.0861	-1573.2134	-1493.1299	724.9084	736.7526	743.8210
FETP/ CRUe	0	2.66×10^{-6}	2.66×10^{-6}	2.66×10^{-6}	0	0	0
HnCT/CTUh	0	1.21×10^{-13}	1.21×10^{-13}	1.21×10^{-13}	0	0	0
POFP/Mass C_2H_4 equivalent	2.74×10^{-2}	-0.0445	-0.0511	-0.0442	-0.0126	-0.0261	-1.12×10^{-2}
ADP/Mass Sb equivalent	4.77×10^{-9}	-7.66×10^{-9}	-5.82×10^{-9}	-7.34×10^{-9}	-1.93×10^{-9}	-1.68×10^{-9}	-1.68×10^{-9}
RI/Mass PM2.5 equivalent	2.06×10^{-2}	-0.0335	-0.0384	-0.0332	-0.0095	-0.0196	-8.39×10^{-3}