AirClim

Strengthening EU climate policies

Discussion paper by Fredrik Lundberg

Strengthening EU climate policies

Discussion paper by Fredrik Lundberg

This briefing discusses possible options for strengthening EU climate policies by phasing out the worst industrial emitters, promoting alternative production methods for steel, iron and cement industries, introducing strict rules for the inclusion of further economic sectors in emission trading, allowing CO_2 tax systems at national level to complement ETS systems, setting up an innovation fund which focuses on renewable energy and energy efficiency and saving. The briefing also provides a critical analysis of current CCS and CDR projects around the world and presents the policy statements of CAN International.

Contents

About the author: Fredrik Lundberg is an energy policy specialist in Sweden. He has worked for more than 30 years as a consultant and researcher for NGOs and government bodies.

Cover illustration: Sven Ängermark/Monoclick.

Cover photo: veeterzy/Unsplash

Layout: Sven Ängermark/Monoclick

Language consultant: Malcolm Berry, Seven G Translations, UK

Published in summer 2022 by the Air Pollution & Climate Secretariat (Reinhold Pape).

Address: AirClim, Första Långgatan 18, 413 28 Göteborg, Sweden.

Phone: +46(0)31 711 45 15

Website: http://www.airclim.org.

The Secretariat is a joint project by Friends of the Earth Sweden, Nature and Youth Sweden, the Swedish Society for Nature Conservation and the World Wide Fund for Nature Sweden. The report is also available in pdf format at www.airclim.org. The views expressed here are those of the authors and not necessarily those of the publisher.

1. The 100 largest industrial plants emitters of greenhouse gases in the EU

Table 1

Rank	Country	Installation name	ETS activity code	Industry Type	ALLOCATION_2021	VERIFIED_EMISSIONS_2021	VERIFIED_EMISSIONS_2019	Free allocation % of emissions	Increase or decrease since 2019
1	AT	Voestalpine Stahl Linz	24	Steel	6859889	9399356	8812969	73,0	586387
2	DE	Integriertes Hüttenwerk Duisburg	24	Steel	14787768	7836786	7810779	188,7	26007
3	FR	ARCELORMITTAL MEDITERRANEE	24	Steel	6522097	6902092	7659332	94,5	-757240
4	NL	Tata Steel IJmuiden bv BKG 1	24	Steel	10224070	5957320	6272201	171,6	-314881
5	IT	Impianti di raffinazione	21	Refinery	2143510	5698903	6144137	37,6	-445234
6	ES	ARCELORMITTAL ESPAÑA, S.A.	24	Steel	5554006	5262482	5097167	105,5	165315
7	IT	Stabilimento di Taranto	24	Steel	6429669	5246390	5898625	122,6	-652235
8	DE	Glocke Duisburg	24	Steel	6357908	4894276	5108311	129,9	-214035
9	RO	Liberty Galati SA	24	Steel	3145944	4394990	4193464	71,6	201526
10	NL	Shell Nederland Raffinaderij B.V.	2	Refinery	2975436	4377123	4357580	68,0	19543
11	DE	Roheisenerzeugung Dillingen	24	Steel	6244534	4283764	4207263	145,8	76501
12	FI	Raahen terästehdas	5	Steel	2788289	4244717	3313833	65,7	930884
13	BE	ArcelorMittal Gent	24	Steel	7486112	3985551	-1	187,8	3985552
14	NL	Dow Benelux B.V. BKG 1	42	Chemistry	2482252	3911793	669506	63,5	3242287
15	BE	TotalEnergies Refinery Antwerp	21	Refinery	2410264	3788472	4004998	63,6	-216526
16	DE	Glocke Salzgitter	24	Steel	6044087	3735956	4115736	161,8	-379780
17	DE	PCK Raffinerie Glocke Schwedt	21	Refinery	1736265	3480163	3418710	49,9	61453
18	NL	Yara Sluiskil B.V. BKG 1	41	Ammonia	3393943	3190000	605596	106,4	2584404
19	SE	SSAB Luleå	24	Steel	2791623	3163263	1757348	88,3	1405915
20	DE	RUHR OEL GmbH - Werk Scholven - CO2-Glocke	21	Steel	2232165	3010072	3008236	74,2	1836
21	BE	BASF Antwerpen - 127	42	Chemistry	3132865	3004925	-1	104,3	3004926
22	AT	voestalpine Stahl Donawitz GmbH	24	Steel	1794520	2958608	2846643	60,7	111965
23	AT	OMV Raffinerie Schwechat	21	Refinery	1694477	2749644	2791040	61,6	-41396
24	PL	GÓRAŻDŻE CEMENT SPÓŁKA AKCYJNA	29	Cement	2375255	2577035	2669377	92,2	-92342

Rank	Country	Installation name	ETS activity code	Industry Type	ALLOCATION_2021	VERIFIED_EMISSIONS_2021	VERIFIED_EMISSIONS_2019	Free allocation % of emissions	Increase or decrease since 2019
25	PL	Rafineria	21	Refinery	3384766	2556613	2798447	132,4	-241834
26	CZ	Třinecké železárny	24	Steel	3961139	2532658	2650392	156,4	-117734
27	DE	Werk 1 und Werk 2	21	Refinery	1800550	2477090	2660258	72,7	-183168
28	NL	ESSO Raffinaderij Rotterdam	21	Refinery	2408446	2380054	2376261	101,2	3793
29	FI	Porvoon jalostamo	2	Refinery	1881191	2365210	2959750	79,5	-594540
30	PT	Refinaria de Sines	21	Refinery	1507213	2301572	2349393	65,5	-47821
31	ES	Repsol Petróleo S.A.	21	Refinery	1817145	2301019	2395846	79,0	-94827
32	DE	Einheitliche Anlage Bremen	24	Steel	4341968	2267241	2177297	191,5	89944
33	DK	Aalborg Portland A/S	29	Cement	1663537	2248048	2189152	74,0	58896
34	ES	Repsol Petróleo S.A. - Instalación de Tarragona	21	Refinery	1600417	2243777	2138172	71,3	105605
35	LT	Katilinė,amoniako paleidimo katilinės Nr.1 ir Nr.2	41	Ammonia	1846778	2208916	2696457	83,6	-487541
36	BE	Esso Raffinaderij	21	Refinery	1452353	2196298	2093011	66,1	103287
37	GR	ΜΟΤΟΡ ΟΪΛ (ΕΛΛΑΣ) - ΔΙΥΛΙΣΤΗΡΙΑ ΚΟΡΙΝΘΟΥ Α.Ε.	21	Refinery	1456543	2139025	2003519	68,1	135506
38	NL	BP Raffinaderij Rotterdam B.V.	21	Refinery	1463326	2117592	2151299	69,1	-33707
39	IT	Raffneria di Augusta	21	Refinery	1117467	2008361	1554810	55,6	453551
40	ES	Petróleos del Norte S.A.	21	Refinery	1521840	2003935	2144901	75,9	-140966
41	NO	Equinor ASA Raffineri Mongstad	21	Refinery	1010821	1993700	1706281	50,7	287419
42	GR	ΕΛΛΗΝΙΚΑ ΠΕΤΡΕΛΑΙΑ Α.Ε. ΔΙΥΛΙΣΤΗΡΙΟ ΕΛΕΥΣΙΝΑΣ	21	Refinery	1263154	1984311	1840525	63,7	143786
43	PL	CEMENT OŻARÓW S.A. -Zakład Cementownia Ożarów	29	Cement	1546377	1898857	2037498	81,4	-138641
44	DE	Kokerei Duisburg Schwelgern	22	Coke	553443	1897444	1947232	29,2	-49788
45	FR	RAFFINERIE DE GRAVENCHON	21	Refinery	1148413	1882721	1955196	61,0	-72475
46	FR	Raffinerie de Normandie (RN)	21	Refinery	1007184	1806568	2373732	55,8	-567164
47	DE	Raffinerie Wesseling	21	Refinery	1196364	1781694	1982154	67,1	-200460
48	DE	Roheisen-und Stahlerzeugung	24	Steel	2680442	1701551	1473970	157,5	227581
49	DE	Werk Flandersbach-Anlage zum Brennen v. Kalkstein	30	Lime	966796	1691601	1693137	57,2	-1536
50	SE	SSAB Oxelösund	24	Steel	1435245	1620919	2060577	88,5	-439658
51	DE	Mineralölraffinerie Leuna	21	Refinery	1850440	1600337	2044951	115,6	-444614

Rank	Country	Installation name	ETS activity code	Industry Type	ALLOCATION_2021	VERIFIED_EMISSIONS_2021	VERIFIED_EMISSIONS_2019	Free allocation % of emissions	Increase or decrease since 2019
52	IT	RAFFINERIA DI SANNAZZARO	21	Refinery	1262101	1597264	2443885	79,0	-846621
53	SE	Preemraff Lysekil	21	Refinery	1394301	1594959	1220342	87,4	374617
54	IT	Raffineria di Milazzo	2	Refinery	1359122	1539874	1772250	88,3	-232376
55	LT	Naftos perdirbimo produktų gamykla	21	Refinery	1227864	1501524	1599384	81,8	-97860
56	GR	ΕΡΓΟΣΤΑΣΙΟ ΚΑΜΑΡΙΟΥ ΒΟΙΩΤΙΑΣ	29	Cement	1357719	1484863	1504016	91,4	-19153
57	ES	Compañía Española de Petróleos S.A. - La Rábida	21	Refinery	1186129	1473025	1576687	80,5	-103662
58	ES	Compañía Española de Petróleos S.A. - San Roque	21	Refinery	1323694	1472642	1494578	89,9	-21936
59	NL	Zeeland Refinery N.V.	21	Refinery	1276019	1469808	1588718	86,8	-118910
60	GR	ΕΛΛΗΝΙΚΑ ΠΕΤΡΕΛΑΙΑ Α.Ε. ΔΙΥΛΙΣΤΗΡΙΟ ΑΣΠΡΟΠΥΡΓΟΥ	21	Refinery	914445	1460612	1247322	62,6	213290
61	DE	Raffinerie Godorf	21	Refinery	881506	1446356	1288360	60,9	157996
62	SE	Slitefabriken	29	Cement	1456455	1440165	1548979	101,1	-108814
63	DE	Ammoniakanlage 2	41	Ammonia	978728	1305788	1302923	75,0	2865
64	DE	Zementwerk Rüdersdorf	29	Cement	1162530	1256723	1208758	92,5	47965
65	ES	Repsol Petróleo S.A. - Instalación de Puertollano	21	Refinery	953711	1245672	1539541	76,6	-293869
66	FR	Raffinerie de Lavera	21	Refinery	961266	1216173	1382153	79,0	-165980
67	DE	Ammoniakanlage 1	41	Ammonia	960185	1215476	1083692	79,0	131784
68	CY	Vasiliko Cement Works Public Company Ltd - Vassilikos Cement Plant	6	Cement	1167885	1196620	1142452	97,6	54168
69	NL	Air Liquide Industrie B.V., vest. Botlek-Rotterdam	21	Refinery	779119	1164455	107273	66,9	1057182
70	ES	Bp Oil España S.A.U	21	Refinery	736583	1152334	1281569	63,9	-129235
71	DE	Ethylenanlage (Cracker) Boehlen	42	Chemisty	510928	1136385	767255	45,0	369130
72	DE	Ammoniakanlage	43	Ammonia	1062163	1115915	1408252	95,2	-292337
73	IT	Raffineria Isab Impianti Sud	21	Refinery	1174044	1115161	1385209	105,3	-270048
74	DE	Mineralölverarbeitung Burghausen	21	Refinery	881841	1108174	1131866	79,6	-23692
75	RO	SC Holcim (Romania) SA - Ciment Alesd	29	Cement	878182	1096758	1048635	80,1	48123
76	ES	Solvay I	44	Chemistry (Soda Ash)	715565	1091451	1142156	65,6	-50705

Rank	Country	Installation name	ETS activity code	Industry Type	ALLOCATION_2021	VERIFIED_EMISSIONS_2021	VERIFIED_EMISSIONS_2019	Free allocation % of emissions	Increase or decrease since 2019
77	GR	ΕΡΓΟΣΤΑΣΙΟ ΒΟΛΟΥ	29	Cement	1106255	1080587	1253334	102,4	-172747
78	DE	Drehöfen Deuna	29	Cement	858768	1071214	1031371	80,2	39843
79	HU	TVK	42		815088	1068877	988254	76,3	80623
80	DE	Raffinerie als Glocke	21	Refinery	682009	1067158	1079404	63,9	-12246
81	SK	Duslo, a.s. Šaľa	41	Chemistry	974764	1067003	985847	91,4	81156
82	IE	Irish Cement Limited (Platin Works)	29	Cement	903235	1065759	1056451	84,8	9308
83	DE	Zentralkokerei Dillingen	22	Coke	251072	1060361	988064	23,7	72297
84	SK	Rafinéria	21	Refinery	975710	1054576	962563	92,5	92013
85	DE	Werk Lägerdorf	29		899463	1052647	1083490	85,4	-30843
86	RO	SC Holcim (Romania) SA - Ciment Campulung	29	Cement	797829	1042156	1039764	76,6	2392
87	DE	RUHR OEL GmbH - Werk Horst - CO2-Glocke	21	Refinery	593793	1016652	949077	58,4	67575
88	DE	Zementwerk Burglengenfeld	29	Cement	710880	1010091	905431	70,4	104660
89	PL	KGHM Polska Miedź S.A. Oddział Huta Miedzi Głogów	28	Non-Ferrous Metals	838819	1006823	1042310	83,3	-35487
90	LT	Katilinė, cemento klinkerio gamybos krosnys	29	Cement	733419	997056	965272	73,6	31784
91	DE	Zementwerk Karsdorf	29	Cement	743110	964238	902251	77,1	61987
92	SK	Danucem Slovensko a.s., cementáreň Rohožník	29	Cement	785717	957552	935434	82,1	22118
93	DE	Raffinerie Heide GmbH	21	Refinery	536800	943963	956972	56,9	-13009
94	PL	Dyckerhoff Polska Sp. z o.o.	29	Cement	813061	943385	967650	86,2	-24265
95	IT	Cementeria di Robilante	29	Cement	635951	933726	758869	68,1	174857
96	IT	Italcementi-Cementeria di Rezzato	29	Cement	755545	918742	932099	82,2	-13357
97	DE	Ethylenanlage OM6	42	Chemisty	776455	917875	849690	84,6	68185
98	FR	Lafarge Holcim Ciments- Usine de St Pierre La Cour	29	Cement	807767	909642	871483	88,8	38159
99	HU	Nitrogénművek Zrt.	41	Ammonia	788376	903128	811610	87,3	91518
100	PL	LAFARGE CEMENT S.A. CEMENTOWNIA MAŁOGOSZCZ	29	Cement	979544	895521	1226139	109,4	-330618

1. The 100 largest industrial plants emitters of greenhouse gases in the EU

The top industrial emitters in the EU are almost entirely in the steel, cement and refinery industries. The #1 was Voestalpine Stahl Linz in Austria, which emitted 9.4 million tonnes of CO_2 in 2021. All the top four emitters were steel mills. Of the top 100 almost all were in the steel, cement and refinery industries, while the rest produce ammonia and other chemicals.

Although emissions from the power producers are plummeting, the industrial emissions have roughly remained the same since 2008. The table on page 3-6 shows changes between 2019 (before the pandemic) and 2021. It is generally not impressive.

The simplest explanation is that they are not improving because they don't have to. The emissions-intensive industries receive free allocations, which roughly cover their emissions. The table shows the percentage of free allocations.

Background: industrial emissions make up a big share of overall emissions

Greenhouse gas emissions from the EU are dominated by power plants. The top 10 emitters in 2021 were all coal power stations[1]. The top 10 emitters are all located in Poland and Germany, and most of them use lignite.

CO_2 from power plants is largely a solved problem. We know what to do, we know how to do it, and we are doing it, but not fast enough.

Everybody knows that coal, oil, shale and peat have to go.

It is a solved problem. All electricity could be supplied by renewables, efficiency, existing hydro and storage. Some people think that nuclear can or should be part of the solution. That is also the way things are going. Renewables, mostly wind and solar, supplied much more electricity (730 TWh) to the EU than coal in 2021. If hydro is also included in the renewables category, they together accounted for 37 percent of EU electricity. If the UK and Norway are also included – as they are closely integrated in the European electricity system – it is a still bigger share. Efficiency is doing its bit, too: EU electricity consumption peaked in 2008 and has slowly declined since. The electrification of cars, heating (electric heat pumps instead of fossil heat) and some industries has, so far, been more than offset by more efficient use of electricity such as better lighting, fans, pumps and refrigerators.

Emissions from power and large heat plants are also a politically solved problem.

Emissions trading, which began in 2005, did not contribute much to emission cuts until 2018, when prices were raised through political intervention. They were raised again in 2021 because of the rising prices of imported natural gas. But right now, or for the near future, ETS is an effective instrument. It may take some time, because the supply chains for wind power, photovoltaics and batteries were disrupted during Covid and the war in Ukraine, and because of desperate and often counterproductive political interventions in the electricity market by member states and because power companies hedge by selling much of the electricity at fixed prices. But the supply chains will be repaired, sub-

---

[1] See https://ember-climate.org/insights/research/top-10-emitters-in-the-eu-ets-2021/#supporting-material-downloads

sidies will not be sustained, and fixed price contracts at low prices will end successively, replaced by new fixed contracts at much higher prices. There will be a strong supply increase for renewables and efficiency as well as a strong demand.

Industrial emissions, on the other hand, are supposedly addressed by the ETS, which is more or less the only instrument for reducing them. But this has not worked. There is no downward trend.

There are essentially two kinds of industry. One is manufacturing industry, which produces cars or furniture, for example. The direct emissions are relatively small, even for very big factories. They use electricity for their machinery, lighting and ventilation. They use gas, oil or district heat for heating. The electricity does not emit any greenhouse gases at the point of use, and it is not used in very large quantities anyway. Siemens, an engineering giant with 300,000 employees globally, emitted 352 kilotons[2] of CO_2 in 2021, also globally.

The other kind is process industry or energy-intensive industry, such as oil refineries, cement factories, iron and steel, other metals, ammonia plants and some other chemicals production. They are large point sources of CO_2 and some are also producers of other greenhouse gases that can opt into the ETS. They are also often huge consumers of electricity.

The technical difference between the two kinds of industry is far from easy to tell.

Iron and steel are produced from ore (iron oxide) with coal and coke as reductants. It looks (and smells) like coal combustion, very much like a coal power station.

An oil refinery uses oil to provide heat for distillation. It looks and smells very much like an oil power plant.

A cement factory uses fossil fuels to heat up the limestone to a very high temperature. Those fossil fuels are combusted just as they are in a power or heat plant and they emit CO_2 in exactly the same way. When the mineral calcium carbonate (CaCO3) is heated, it emits CO_2, leaving behind calcium oxide (CaO), which is used as cement to make concrete. The latter emission is not literally "from fossil fuels", but the limestone itself is a fossil, usually from ancient corals. The CO_2 is very much like the CO_2 from fossil fuels. Its fossil origin can be corroborated by C_{14} dating, just like oil, coal and gas, but unlike biomass.

The official EU text[3] says in its definitions:

(11) "combustion emission" means greenhouse gas emissions occurring during the exothermic reaction of a fuel with oxygen.

That would cover all emissions from refineries, the steel industry (including coking), other metals production, the chemicals industry and fuel emissions from cement factories.

The real differences between "combustion" CO_2 and "process emissions" are purely legal

---

[2] https://new.siemens.com/global/en/company/sustainability/sustainability-figures.html#!/siemens/en/umwelt/

[3] Regulation (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions etc

and economic. Process emissions evade the Polluter Pays Principle. They get free allocations, often close to 100 percent, and sometimes even more, as can be seen in the table.

Three categories dominate non-power ETS emissions:

Iron and steel, cement and refineries (code 24). Together these account for 64 percent, and if categories like coke production (code 22), roasting or sintering of ferrous ore (code 23) and processing of ferrous metals (code 25) are included in iron and steel production the total is even higher, about 129 Mtons.

Cement (code 29). If lime production, which also involves the quarrying of limestone, is included it adds another 27 Mtons, taking the total to 137 Mtons.

In a few cases the activity codes are wrong and installation names not very informative, so information as to what they are doing has been found elsewhere.

Emissions by group

activity code		Mton CO_2eq 2021
20-99	Total ETS excl. aviation	1308
10	aviation	27
20	"combustion" = power and big heat plants	799
21-99	ETS excl. "combustion" and aviation	509
24	pig iron or steel production	113
29	cement	110
21	refineries	106
41	ammonia production	18

https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

https://euets.info

https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/latest-emissions-data/

2. Iron and steel emissions. How they can be cut, and why CCS is not a major option

The huge emissions from the steel industry can be virtually eliminated by using hydrogen from green power, or from other electric processes. CCS is not used, not needed and not likely to be a mitigation option.

The main climate issue for iron- and steel-making is the CO_2 emissions from the use of coke and coal to reduce ore (iron oxide) to elemental iron in blast furnaces. For every atom of iron product, about 1.5 molecules of CO_2 are emitted. Every ton of steel produced in 2018 emitted on average 1.85 tons of carbon dioxide, equating to about 8 percent of global carbon dioxide emissions[4]. The steel industry generates between 7 and 9 percent of direct emissions from the global use of fossil fuel, according to worldsteel.org[5].

The competing, but much less widely used, technology is Direct Reduced Iron, which usually uses (fossil) natural gas as the reducing agent, and which then also emits smaller but still large amounts of CO_2. Fossil fuels are also used for heating the steel before rolling it. Electric arc furnaces have indirect CO_2 emissions, depending on the source of electricity, and often also have direct emissions from fossil fuels used to assist the melt.

The Swedish Hybrit project was launched in 2016 to replace coal with hydrogen in steel production. It was the first of its kind. Now many of biggest steel companies in the world are going in more or less the same direction.

Just a few years ago the climate strategy of the global steel industry specifically or heavy industry in general could be summarised in three letters: CCS. Or rather in six letters "Say CCS", as nothing much actually happened. After almost 20 years of hyped-up talk, no CO_2 has been captured anywhere in the world from the production of steel, cement, glass, aluminium or paper pulp and very little from power plants.

The big EU ULCOS project (ultra-low-CO_2 steel-making), which began in 2004, eventually sank without a trace. Its main message was to keep blast furnaces, keep coal and coke, but add CCS.

Only months after the Paris climate agreement, in April 2016, Swedish steel-maker SSAB, iron ore miner LKAB and power producer Vattenfall launched a new decarbonisation strategy: to produce hydrogen with renewables and use the hydrogen to reduce iron oxide ore pellets to sponge iron. This was a bolt out of the blue, a radical departure from the previous strategy.

Four years later, McKinsey, found a very different situation[6]:

"All major European steel players are currently building or already testing hydrogen-based steel production processes, either using hydrogen as a PCI replacement or using hydrogen-based direct reduction."

---

[4] Worldsteel, as quoted from https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

[5] https://worldsteel.org/wp-content/uploads/Climate-change-and-the-production-of-iron-and-steel.pdf

[6] https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

ArcelorMittal is the second-biggest steel producer in the world. It does the same thing as SSAB and is also trying another very different no-carbon tech. The company states that it is

"exploring iron ore reduction technologies using hydrogen and electrolysis, both of which could deliver significant carbon reductions if powered with clean electricity. In March 2019, we launched a €65 million pilot project in Hamburg, Germany to test hydrogen steel-making on an industrial scale, with an annual production of 100,000 tonnes of steel. At the same time, we have been exploring direct iron ore reduction using electrolysis for a number of years. We lead the EU-funded Siderwin project, which is now constructing an industrial cell to pilot the technology."

The company aims to have the Hamburg plant operating in 2025[7], which is one year before SSAB and LKAB also aim to have their (ten times bigger) hydrogen steel demo plant operating[8].

The Siderwin technology dissolves the ore, for example iron-rich residues from bauxite. It works at low temperature (110 degrees C)[9] and is expected to reach industrial scale[10] by 2030. If it achieves this it will still rely on green electricity.

Chinese Baowu, now the world's largest steel producer, has a hydrogen partnership with Linde, a global industrial gases company, "with the aim of beating the Swedish steel maker SSAB to commercialising clean steel production", according to an article in the Australian Financial Review[11], which considers this as potentially bad news for exports of Australian coking coal.

The coming competitivity of hydrogen, and the shrinking market for coking coal, was also recently pointed out by a Friends of the Earth report on a possible new coal mine in Cumbria, England.

According to its energy campaigner, Tony Bosworth: "The UK steel industry will only buy a small percentage of the Cumbrian coal, and with European steelmakers already moving to greener steel production, the market for this mine is declining before it has even opened."[12]

The third biggest steel producer, NSSMC (Nippon Steel), is also working with hydrogen (as well as CCS) and also boasts a new steel for hydrogen infrastructure.

It is too early to say "problem solved" for CO_2 from steelmaking, but it surely looks as if green electricity and green hydrogen can do the job, whereas CCS is going nowhere.

---

[7] https://www.reuters.com/business/sustainable-business/arcelormittal-gets-support-green-steel-plant-hamburg-2021-09-07/

[8] https://www.lkab.com/en/news-room/press-releases/lkab-invests-msek-700-in-preparations-for-sponge-iron-in-gallivare/

[9] https://physicstoday.scitation.org/doi/10.1063/PT.3.4791

[10] https://www.siderwin-spire.eu/sites/siderwin.drupal.pulsartecnalia.com/files/documents/SIDERWIN_Webinar_20211124_QuestionsAnswers.pdf

[11] https://mailchi.mp/6b6b882ebe44/coal-power-fell-in-2019-use-of-us-coal-plants-slides-further-chinese-steel-giant-pursues-hydrogen-1604990?e=48a7230869 (Original behind paywall.)

[12] https://friendsoftheearth.uk/climate/market-cumbrian-coal-declining-fast

Hydrogen is getting much more attention for reasons aside from steel production, such as short-term and long-term (seasonal) storage to balance wind and solar, or for ships, trains (one in operation[13] in Germany August 2022), trucks and buses. The implication is that hydrogen will be produced by electrolysis using renewable electricity, abundant and cheap wind and solar.

As of 2022, the era of cheap renewables has moved considerably closer. In 2021 solar and wind together produced more electricity, globally, than nuclear. They had trebled their output in seven years. Wind and solar became still more competitive after the autumn 2021 energy price hike (in Europe, at least) and even more so since the war in Ukraine. So far, wind power has been predominantly onshore, but the potential of offshore wind, including floating wind power, has even greater potential. As for photovoltaics, the EU raised its 2030 target from 420 GW (set in 2021) to almost 600 GW (set in May 2022[14]).

Natural gas is now perceived as both dirty and a security risk (as it always has been). It is also scarce and expensive, at least if it is not bought from Russia.

One effect of the Russian invasion of Ukraine is that "blue hydrogen" from natural gas with CCS has lost its appeal.

It is conceivable that hydrogen can be produced from nuclear power, but new nuclear takes a long time to build and is very expensive. It is difficult enough to finance any nuclear power plant, and it will be even more difficult to finance a nuclear plant partly intended for hydrogen production. Wind and solar have much lower operating costs than nuclear, as they use no fuel, have no waste to dispose of and need fewer people for operation and maintenance.

It can be concluded that future hydrogen will be green. Future power is, increasingly synonymous with solar and wind.

SSAB produced a small amount of green steel for delivery to Volvo group[15], the world's third-largest lorry and bus manufacturer. Volvo makes green steel a selling point.

SSAB and LKAB have moved forward their plans. They intend to decarbonise completely[16] by 2030, 15 years earlier than they initially said. Their blast furnace in Oxelösund, south of Stockholm will be shut down by 2025, and the remaining two in Luleå and Brahestad (in Finland) will be closed by 2030.

SSAB and LKAB are no longer alone in Sweden, or even in the province of North Bothnia. A new company – H2Green Steel – was set up in 2020, aiming at production by 2024, with an output of 5 million tonnes of green steel by 2030. This is a very optimistic schedule, and there are several other question marks, but the project is backed by several members of the Swedish industrial and financial elite, so probably something will happen.

---

[13] https://www.pv-magazine.com/2022/08/26/the-hydrogen-stream-germany-launches-worlds-first-operating-hydrogen-trains/

[14] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=COM:2022:221:FIN&from=EN

[15] https://www.volvogroup.com/en/future-of-transportation/going-fossil-free/green-steel-collaboration.html

[16] https://www.ssab.com/en/news/2022/01/ssab-plans-a-new-nordic-production-system-and-to-bring-forward-the-green-transition

ArcelorMittal is also trying a more evolutionary method: using an increased proportion of hydrogen in a blast furnace[17] at its Dofasco steel plant in Hamilton, Ontario, Canada.

Baowu is doing something similar and has also set up a Global Low-Carbon Metallurgical Innovation Alliance that includes ArcelorMittal, BHP Group, Rio Tinto, Vale, Fortescue Metals Group, Tata Steel, Thyssenkrupp, Angang Group, HBIS Group and Shagang Group.

It is too early to judge whether some of this is just greenwashing and playing for time. That depends on how visions are translated into hard quantitative targets.

Tata Steel Nederland has *said it wants "to be* CO_2 *neutral before 2045 and to emit between 35 and 40% less* CO_2 *before 2030. This will largely be achieved via the hydrogen route. We are replacing the blast furnaces with modern technology that uses hydrogen or gas instead of coal," according to Hans van den Berg, CEO of Tata Steel Nederland*[18].

Energy company Uniper aims to build a 1,000 MW electrolysis plant (the capacity equivalent of a standard nuclear reactor) in Wilhelmshafen in Germany, to be supplied by offshore wind electricity. Uniper is also involved in another hydrogen project, to produce ammonia from green hydrogen. Salzgitter, a big European steel producer, will use some of the hydrogen for green steel production. One of its customers is Miele[19], the domestic appliances producer. Another customer is Volkswagen[20], with green steel deliveries slated for 2025.

Salzgitter is trying to take an evolutionary path, with natural gas direct reduction being replaced by hydrogen as quickly as possible.

A similar approach has been taken by steelmaker Ovako in Hofors, Sweden, close to Sandviken. They use hydrogen and LPG in various mixtures to heat up the steel before rolling it. This is not a big deal in itself, but they see themselves as part of a much larger picture: hydrogen production is used to balance the grid, hydrogen is used for transport, and the factory produces district heat[21]. (See illustration below.)

This is an important point. If the transition of steel can lay the foundation for a hydrogen economy, many other actors will follow suit and use hydrogen for other purposes. It is largely a question of when green hydrogen can compete with all fossil fuels, and first of all with current fossil hydrogen production. A number often used as a target is 2 USD/kg or 6 cents/kWh, 60 cents for a litre of petrol.

---

[17] https://www.ft.com/content/cce5439a-3c26-4331-9455-094edb638df4

[18] https://www.danieli.com/en/news-media/news/tata-steel-chooses-energiron-dri-technology-take-major-step-green-steel-production_37_751.htm

[19] https://www.salzgitter-ag.com/en/newsroom/press-releases/details/miele-opts-for-green-steel-from-salzgitter-ag-18926.html

[20] https://www.salzgitter-ag.com/en/newsroom/press-releases/details/volkswagen-group-and-salzgitter-ag-sign-memorandum-of-understanding-on-supply-of-low-co2-steel-from-the-end-of-2025-19456.html

[21] https://www.ovako.com/en/newsevents/news--press-releases/ovako-press-release-detail/?releaseId=B4ADD5355036AA5F

The US government is more ambitious than that. It has set a target[22] of 1 dollar/kg by 2031.

The development of green steel interacts with developments in other fields, especially solar, wind and hydrogen for other purposes.

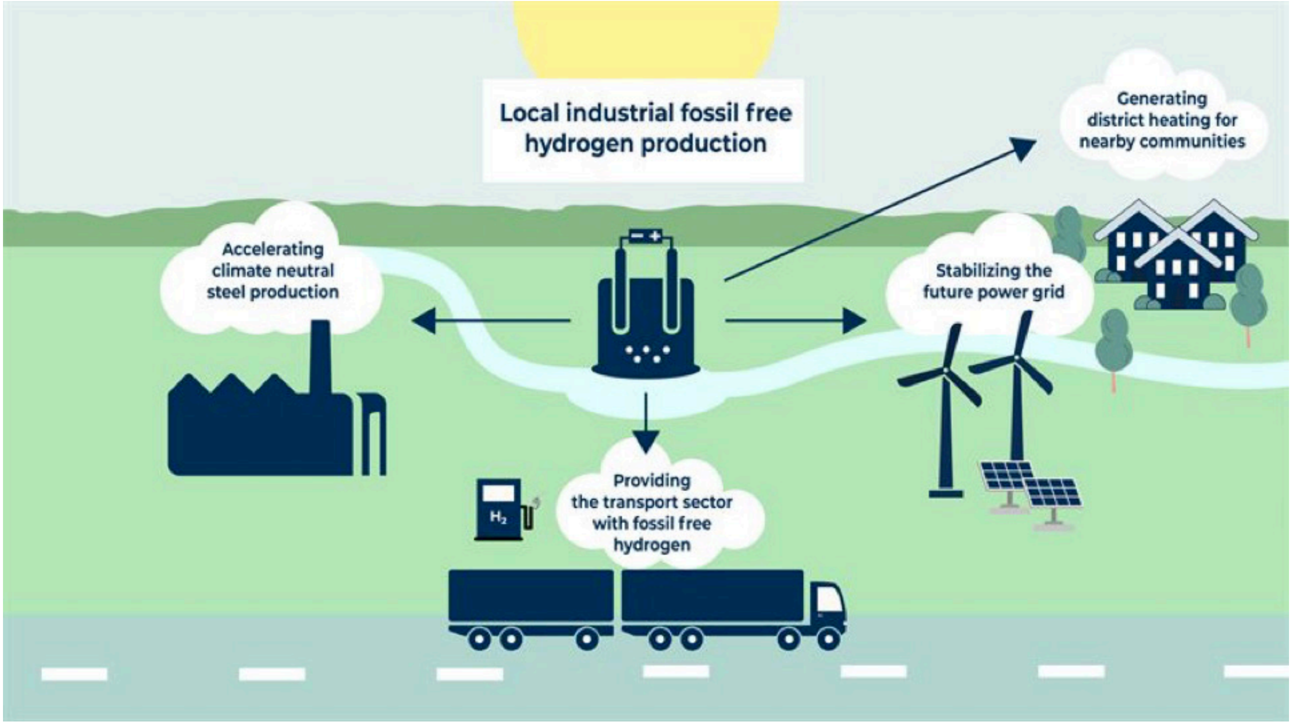
The electrolysis of water, storage of hydrogen (as gas or liquid), pipelining of hydrogen gas, and production of ammonia or methanol from hydrogen are well-known technologies with about a century of experience. But the required scale and speed of development are challenging and will require innovation, for example to develop cheap, efficient and reliable catalysts without rare metals, as well as cheap and safe small-scale hydrogen storage, better fuel cells etc.

This development is indeed taking place, at breakneck speed. Hydrogen projects are mushrooming all over the world.

The biggest PV producer in the world – Longi – established its hydrogen company in March 2021 and began producing electrolysers in October 2021. It expects a capacity of 1.5 GW in 2022 and 5–10 GW by 2025[23].

The EU set a target in 2021 to reach one million tonnes of hydrogen by 2024 and ten million tonnes or 40 GW of electrolysers by 2030. As they have stepped up the renewable targets for 2030, there is a good chance of overachievement for green hydrogen.

SSAB and LKAB took a big risk in 2016. By May 2022, they should be much more confident that they made the right choice.



---

[22] https://www.energy.gov/eere/fuelcells/hydrogen-shot

[23] https://www.longi.com/en/news/pv-magazine-of-longi/

CO_2 emissions from the cement industry can be reduced without CCS

Cement emits about 2.3 billion tons[24] of CO_2 per year: 1.4 Gtons from the process, 0.6 Gtons from fuels used to heat the kilns and 0.3 Gtons indirectly from (fossil) electricity. This amounts to around 7 percent of global emissions.

Cement is a 300 USD billion market[25] and concrete is a 1 trillion market. EU emissions from cement production are of the same magnitude as total CO_2 emissions from an entire country such as the Czech Republic or Belgium.

It is a growing business[26], at about 7 percent per year in 2010–2017. It continued to grow[27] between 2017 and 2021, though at a slower rate of less than 3 percent per year worldwide and with a decrease of 3 percent in the EU.

Cement emissions are of two kinds. One is CO_2 from the core process, which drives out CO_2 from the limestone (a carbonate) to create cement clinker. Limestone is a fossil-rich rock.

The other part is CO_2 from fossil fuels, such as coal, used to heat the limestone.

Both these emission sources can be radically reduced using well-known methods, as noted by the IPCC 2022 report (see below) and by other work quoted in this paper.

This huge potential reduction has however not materialised.

Emissions from cement-making, as recorded by the EU Emissions Trading System (ETS), fell from 116.8 million tons of CO_2 in 2019 to 110.4 million tons in 2020, but this can largely be explained by Covid lockdowns in the second quarter of 2020. 2021 data are incomplete but indicate more or less a return to 2019 emissions.

Money for nothing

One reason for the lack of progress is the lack of incentives.

The cement industry is part of the ETS but has roughly 100 percent free allocation. This may be hard to believe, but it is true.

Allocations and emissions ETS, Mtons of CO_2

Allocation 2019	114.2
Actual emissions 2019	116.8
Allocation 2020	112.0
Actual emissions 2020	110.4

It has had even more generous allocations in the past[28], for example a 120 percent free allocation for 2013. The EU climate policy was actually handing out money to some of the worst offenders without any conditions.

---

[24] https://www.globalefficiencyintel.com/new-blog/2021/global-cement-industry-ghg-emissions

[25] https://www.aggbusiness.com/ab9/news/lafargeholcim-expands-reduced-co2-cement-offering

[26] https://www.prnewswire.com/news-releases/global-cement-market-report-2018-2023-largest-players-are-lafarge-holcim-anhui-conch-jidong-development-and-heidelberg-cement-300635392.html

[27] https://ourworldindata.org/grapher/annual-co2-cement?tab=table&time=2017..latest&facet=none

[28] https://www.i4ce.org/wp-core/wp-content/uploads/2016/06/rapport-I4CE-chapitre-3.pdf p54

The ETS policy for cement shows the strength of cement lobby, with Cembureau in Brussels as its rather loud voice.

In 2015, Cembureau claimed that "the current EU ETS[...] will de-industrialise Europe before it decarbonises European manufacturing".[29]

Such intransigence is not just a thing of the past. The cement lobby has also stopped all meaningful climate measures for the future, at least through 2030.

The allocation is based on benchmarks, now set at 693 kg CO_2/t for grey clinker and 957 kg CO_2/t for white cement from 2021 – a reduction of 9.5 percent and 3 percent respectively compared to phase III[30], i.e. from the benchmarks for 2013–2020 to the period 2021–2030.

Theoretically, the industry should have some incentive to cut emissions and sell the surplus, for example by cutting coal use and replacing it with waste fuel or electricity. But there is little evidence for this so far. The 2021 emissions of the cement companies that reported on time, which was most of them, fell by about 1 percent from 2019 to 2021, from 98.7 Mton to 93.1 Mton.

The use of Portland cement (burned limestone) may possibly have decreased slightly between 2019 and 2021 and been replaced by other cementitious materials.

Nevertheless, the market for lower-carbon cement is growing, Heidelberg Cement states in its Annual Report 2020:

"We have made further progress in the CO_2 of cements with less clinker, thereby achieving a reduction in both CO_2 emissions and costs. In several countries, the proportion of blast furnace slag, fly ash, and limestone in cement has been increased, thus reducing the clinker content."[31]

If the cement industry does not shrink its carbon footprint of its own accord, it may be forced to do so by external competition from the construction industry.

The construction industry has actually started to market green concrete products32. Their customers often want certified "green buildings" or the like, and using low-carbon construction materials is a relatively simple way to get green points in the certification scheme.

Start-up companies are producing and marketing "green" cement, for example of volcanic origin[33].

The decline in cement-making emissions may also to some (small) degree have been due to the use of completely different materials, such as wood, rock, or by reducing the cement-to-concrete ratio in some applications.

---

[29] https://carbonmarketwatch.org/wp-content/uploads/2021/06/Survival-guide-to-industry-lobbying_WEB.pdf p8, link to Cembureau is dead.

[30] https://cembureau.eu/media/m2ugw54y/cembureau-2020-activity-report.pdf p17

[31] quoted after https://www.airclim.org/acidnews/co%E2%82%82-emissions-cement-industry-can-be-reduced-without-ccs

[32] https://www.skanska.se/49f09f/siteassets/vart-erbjudande/produkter-och-tjanster/betong/gron-betong/product-sheet-green-concrete-english.pdf

[33] See for examplehttps://greencement.com/

Hype for CCS

One thing that has clearly not cut emissions is carbon capture and storage. Though widely hyped since at least 2007, by Cembureau[34] and others, there is still not a single cement plant in the world that uses CCS. Heidelberg Cement aims to capture 0.4 million tons per year at its Norcem plant[35] in Norway, starting in 2024. This is about 0.4 percent of the cement emissions in the ETS. (Norway participates in the ETS, though it is not a member of the EU.)

CCS or not, the industry, the EU, its member states and other nations have very modest ambitions for reducing emissions. The IEA 2020 World Outlook does not foresee any change in the core process by 2030, only a modest decrease in CO_2 intensity from 0.54 to 0.48 tons of CO_2 per ton of cement between 2018 and 2030 – or one percent per year.

This is echoed in a recent report from Agora Energiewende – Breakthrough Strategies for Climate-Neutral Industry in Europe:

“Several European cement companies are working on commercialising CO_2 capture technologies and long-term CO_2 storage before 2030. We assume that by 2030 around 10 cement plants that are close to the Atlantic Ocean or to navigable rivers could be connected to long-term CO_2 storage sites that are currently being developed in the Netherlands and Norway. This could reduce emissions by 9 Mt CO_2 by 2030.”

The reason why Agora Energiewende accepts such slow progress is that they accept the industry’s view on investment cycles:

“Given the long technical lifetimes of cement plants – between 50 and 60 years – each reinvestment decision should devise an individual decarbonisation roadmap that is in line with achieving climate neutrality by 2050.”

But Agora Energiewende has high hopes for later CCS:

“In the future, the development of a CO_2 infrastructure could also pave the way for negative emissions via BECCS. By using a large share of sustainable biomass in its fuel mix and sequestering the biogenic carbon share, cement works that are connected to a CO_2 infrastructure can generate negative emissions.”

Other emitters are cutting their emissions

An alternative view would be that Portland cement has to go the same way as other emitters: phase out emissions as soon as possible.

Coal use is falling fast.

Fossil gas is now even more controversial in the EU since the war in Ukraine. “Heat pumps for freedom and peace” is not just a nice quip by Bill McKibben. It is also likely to happen.

The EU aluminium industry cut its fluorinated gas emissions[36] from 20,783 kton CO_2eq in 1990 to 407 kton in 2020. As for CO_2 emissions from aluminium, there is now a

---

[34] https://www.sintef.no/globalassets/sintef-energi/cemcap/ecra_ccs_project_poster_v3.pdf

[35] https://www.norcem.no/en/CCS

[36] https://di.unfccc.int/detailed_data_by_party 2.C.3 Aluminium Production

credible plan to eliminate them completely by substituting burnable petcoke anodes with inert electrodes[37].

As for the steel industry, see further below.

Does the bell now also toll for cement? The management consulting firm McKinsey hints at it:

"Cement makers are approaching a moment of truth. Challenges such as decarbonisation, ongoing value-chain disruption, and competition against the construction ecosystem's entire patchwork of players all loom large. With the right mindset, decarbonisation and reinvention can go hand in hand: just as automakers increasingly view their role as providing mobility, not just making cars, cement companies could likewise be in the business of providing construction solutions. As climate pressures increase and sales of traditional cement and concrete face threats, the combination of new thinking, innovation, and new business models will be critical to helping ensure a profitable – and greener – future."[38]

Research, development, demonstration and commercialisation for alternative binders – the cements that glue sand and pebbles together to make concrete – is not pursued with anyway near enough vigour, and even when promising research is produced, it is not implemented and scaled up.

The reason is simple. The current cement producers want to continue doing what they do: mining limestone at the quarries they own, burning limestones in the kilns they own, milling and sorting it into the grades the construction industry is familiar with and transporting and selling the cement to more or less the same customers as they now have.

The same shortcomings – insufficient research and slow implementation – also apply to alternative materials such as granite for foundations, wood or brick or glass for panels and wood for beams. The same could also be said regarding alternative new processes.

Change is always difficult. For a cement quarry/kiln/harbour it means scrapping existing capital and investing in something completely different somewhere else.

Magnesium cement (Sorel cement) or geopolymers could replace Portland cement for many applications, but this would require different quarries with new machinery, new people and new marketing channels.

The cement industry is resistant to change. It can resist because it is so oligopolistic. Holcim Lafarge is the biggest cement producer in the world, and Heidelberg is the fourth largest. One example: Heidelberg is the only producer in Sweden and practically the only supplier, and produces cement at just two sites. They have their own harbours in several cities.

Their resistance to change is a natural thing, but it does not prove that change is impossible, just that it takes a lot of political resolve and tenacity to change.

Oil for transport is increasingly challenged by electricity, directly or via hydrogen. The strong resistance of both the oil industry and automotive industry has been broken.

---

[37] https://elysis.com/en/start-of-construction-of-commercial-scale-inert-anode-cells

[38] https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

The coal industry also resisted change, but was essentially defeated by the 2015 Paris Agreement, at least in Europe. After a slow decline for years, it was *halved* in five years.

The following tables shows coal power, in TWh, produced in the EU-27 from 2007 (before the Financial Crisis) to 2022:

2007	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
870.7	773.3	759.4	722.4	732.5	688.2	669.0	625.7	475.1	373.4	439,8	461,2

Source: BP statistics 2021, Energy Institute Statistical Review of World Energy 2023

The uptick in 2022 was result of a temporary gas-to-coal substitution in the wake of the Ukraine war, and was reversed during the last months of 2022, according to an analysis by Ember[39].

Back in 2007, the EU saw CCS as the solution, and offered several billions to that end, but not a gram was captured. Some people thought natural gas was an alternative to coal, but gas power output was essentially unchanged from 2007 to 2020. Some hailed nuclear power as the saviour, but nuclear output dropped more than 20 percent from 2007 to 2020.

It was not gas power, CCS or nuclear power that killed coal. It was wind, solar and efficiency.

The Paris Agreement also made an impression on another supposedly "hard-to-abate" industry: ore mining and steelmaking. A few months after the meeting, in April 2016, steel company SSAB and miner LKAB, both in Sweden, went for decarbonisation by green hydrogen. They then envisaged 2040–2045 as the end date for coal, coke and blast furnaces. In January 2022 they accelerated the zero-carbon target to 2030. Several other steel companies are following in their footsteps towards green hydrogen, produced by wind and solar.

The coal industry said it would use CCS but did not do so. The steel industry said it would use CCS on large projects such as ULCOS and HIsarna but has not done so either.

Words fly up, their thoughts remain below

The cement industry says that it will do CCS, but all it has to show for it is the Norcem project, which is under construction, but not even in the EU. It is at least 95 percent funded by Norwegian taxpayers and will not easily be replicated.

The oil industry and oil countries are the driving force behind CCS. They try to present themselves not as the problem, but as the solution. They, which in Europe means Norway, claim they can bury the CO_2 beneath the seabed: problem solved!

The oil industry is quite separate from the cement industry, but with vanishing prospects for power CCS and steel CCS, cement seems to be the best bet to keep CCS alive and with it the justification for the whole fossil industry.

It is still not ideal, but cement CCS is simpler and cheaper than the much-hyped Bio-CCS, because the CO_2 stream from cement kilns is relatively pure and the industry is more homogenous and bigger in scale than the motley crew of paper pulp plants, mixed waste CHP, ethanol distilleries etc.

---

[39] https://ember-climate.org/insights/research/european-electricity-review-2023/

Portland cement has admittedly a number of advantages. It is cheap, it is well-known, it has high alkalinity (high pH), which is a prerequisite for reinforced concrete if the reinforcement (re-bars) are made of unalloyed steel. And the construction industry is used to it.

Dozens and dozens of alternatives

There are many different alternatives to carbon-emitting cement, for example:

- Less cement per volume of concrete, as so much cement is not needed everywhere
- Less concrete through better design (a new reinforced concrete bridge weighs less than an older bridge
- Less clinker (the most CO_2-intensive form of Portland cement) per volume of cement
- Other binders for concrete: fly-ash, slag, volcanic ash[40], crushed lava[41], olivine[42] rice husk and barley husk ashes[43], silica fume[44], crushed limestone (not burnt, not CO_2-emitting), and clay-based geopolymers[45]. Some of them are already used extensively. The remaining potential is still big. Volcanic cement[46] use "is abundant in certain locations and is extensively used as an addition to Portland cement in countries such as Italy, Germany, Kenya, Turkey, China and Greece". Some of the alternative binders: slag, fly-ash and pozzolans have a negative cost according to the McKinsey report quoted above. The IPCC WG3 report says that calcinated clay and limestone alone have a 40–50 percent GHG reduction potential at near-zero cost[47], and that this could take place not by 2100, 2050 or 2025, but "today". The calcinated clay or metakaolin is a very common mineral.
  The IPCC also says that "magnesium or ultramafic cements" may cut GHG to negative by 2040, but at unknown cost. Negative means that the life-cycle of such a cement would draw down more CO_2 than it emits. Ultramafic means minerals with high alkalinity.
  Question: if it can be done by 2040, why not by 2025 or 2030? (See discussion in Strunge et al: Towards a business case for CO2 mineralisation in the cement industry[48]).
  Magnesium cement has zero process emissions according to an RMI report[49].

---

[40] https://www.researchgate.net/publication/328211405_Clay-Based_Materials_in_Geopolymer_Technology

[41] https://energypost.eu/cement-replacing-limestone-with-volcanic-rock-could-slash-energy-use-and-emissions-by-two-thirds/

[42] https://pubs.acs.org/doi/10.1021/acs.iecr.2c00984

[43] https://www.researchgate.net/publication/273423709_Beneficiation_of_the_huge_waste_quantities_of_barley_and_rice_husks_as_well_as_coal_fly_ashes_as_additives_for_Portland_cement

[44] https://www.norchem.com/applications-sustainability.html

[45] https://www.researchgate.net/publication/328211405_Clay-Based_Materials_in_Geopolymer_Technology

[46] https://en.wikipedia.org/wiki/Pozzolana#Modern_use

[47] IPCC WG3 report April 2022 Chapter 11, p 1197.

[48] https://www.nature.com/articles/s43247-022-00390-0#Sec9

[49] https://rmi.org/insight/net-zero-decarbonization-in-chinas-cement-industry/ p29

- Better optimised aggregates, i.e. the sand and pebbles that the cement binds together. If aggregates are "multi-sized and well dispersed" you need less cement. According to the IPCC WG3 this can cut emissions by up to 75 percent at near-zero cost, and can be done "today"[50].
- Recycling of concrete is not a practical substitute for a large percentage of cement. It can either be downgraded to gravel or mixed to new concrete with a substantial addition of new binders. The mass of demolished concrete is so enormous that this may still be of some importance, and recycling is always preferable to landfilling.
- A concrete building reabsorbs some CO_2 during its lifetime, and this is often used as a climate selling point by the cement industry[51]. The quantification of how much CO_2 is absorbed, and when, is very difficult and is presently not credited against emissions in the IPCC guidelines. Industry-sponsored research[52] has asked the IPCC to "update" its guidelines in this respect, but the world will not be saved by creative accounting.
- Alternative reinforcement for reinforced concrete: by using ceramics, glass, polymer (plastic) fibres, hemp[53], stainless steel, or even graphene[54], a lower pH can be accepted, and less cement[55] is needed. If iron rebars are replaced with fibres it would reduce indirect emissions (those from iron production) from concrete very significantly.
- The combination of clay-based concrete and aluminium reinforcement may reduce the carbon footprint by 60–80%[56,57].
- Concrete can be recycled[58] according to a new standard (in Sweden, at least) and used as a filler and to some extent reduce the demand for new Portland cement, with other good environmental side effects (less quarrying for aggregate) and at negative cost[59].
- Other materials can replace concrete, some for niche applications in buildings, others more generally: wood, brick, stone (e.g. granite, for foundations), glass, steel, foam glass[60] (for foundations), aerogel[61], MgO boards[62], and asphalt. Asphalt

---

[50] IPCC WG3 report April 2022 Chapter 11, p1197

[51] See for example https://cembureau.eu/about-our-industry/innovation/recarbonation/

[52] https://www.ivl.se/download/18.34244ba71728fcb3f3f8f9/1622457897161/B2309.pdf p8

[53] https://www.sciencedirect.com/science/article/abs/pii/S0950061822015306

[54] https://emps.exeter.ac.uk/engineering/staff/mfc204/commercialization

[55] https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.714.394&rep=rep1&type=pdf https://www.sciencedirect.com/topics/engineering/steel-rebar

[56] https://www.sintef.no/en/latest-news/2023/green-and-everlasting-concrete-is-no-longer-a-distant-dream/

[57] https://www.hydro.com/en/about-hydro/stories-by-hydro/dare2c-how-aluminium-can-help-solve-concretes-sustainability-challenge/

[58] https://www.sis.se/nyheter-och-press/nyheter/cementen-tar-ett-viktigt-kliv-mot-cirkular-ekonomi/ (in Swedish)

[59] https://www.mckinsey.com/industries/engineering-construction-and-building-materials/our-insights/the-circular-cement-value-chain-sustainable-and-profitable Exhibit 3

[60] https://en.wikipedia.org/wiki/Foam_glass

[61] https://www.aerogel.se/en/

[62] https://www.fortunebusinessinsights.com/magnesium-oxide-boards-market-103006

is of fossil origin but the alternative use may be as a fuel, in which case it emits its carbon. However, when it is used for construction it does not, whereas traditional concrete has a large carbon footprint.
Wood alone could substitute for concrete and steel as building materials and "could provide a technical mitigation potential of 0.78–1.73 Gt CO_2" per year in a study quoted by the IPCC[63]. Obviously, the availability of wood is limited, but there are still many low-diversity industrial wood plantations around the world. The use of paper may be reduced, while bio-power may be reduced, or replaced by biomass that cannot be used for construction materials, such as residues from food and the food industry. The International Code Council allows for the construction of wood buildings up to 18 storeys tall[64] (according to changes made in 2021). A 25-storey wooden building, Ascent MKE in Milwaukee, USA, holds the present world record.

- Other production methods: recycling CO_2 from the cement[65] into the fresh concrete may reduce the carbon footprint of cement. Or maybe not[66], depending on circumstances and assumptions.
- Other CCS or CCU. If carbon capture has a chance outside natural gas processing, cement may be the best chance. Cement kilns produce a relatively pure stream of CO_2. If that CO_2 can be fed into a nearby process such as methanol production from hydrogen, it might make economic sense to transform the hydrogen into a more convenient fuel. The CO_2 will eventually be released into the atmosphere, so it will not in itself reduce emissions, but may help the transition to green hydrogen. If that works out it will be as a minor niche in mitigation, but carbon capture and use cannot be ruled out. Complete carbon capture and storage, on the other hand, is a hopeless proposition, as transport by ship plus storage costs seem insurmountable, and transport by pipelines is incompatible with the necessary rate of greenhouse gas emission reduction; there is simply no way to build a pipeline infrastructure within 10–20 years.
- Other production methods: 3D-printed foam concrete[67] which uses less material (as it has holes in it), and has the same strength as well as much better insulation properties. Ordinary concrete is a very poor insulator, so if used in a building more energy is required for heating and cooling that building.
- Other sources of heat, if heat is needed: electric[68] instead of fossil fuels, waste or biofuels. Such a project was announced early 2019 and is said to be implemented by 2030.

---

[63] IPPCC WG3 report chapter 7 p805

[64] https://www.architectstraininginstitute.com/can-wood-building-materials-replace-steel-concrete/

[65] https://www.carboncure.com

[66] https://www.nature.com/articles/s41467-021-21148-w

[67] https://www.weforum.org/agenda/2022/01/eth-zurich-3d-printer-concrete-carbon-emissions

[68] https://group.vattenfall.com/press-and-media/pressreleases/2019/vattenfall-and-cementa-take-the-next-step-towards-a-climate-neutral-cement

Question: Why would it take 11–12 years to build an electric kiln?

"Until a very low GHG emissions alternative binder to Portland cement is commercialised, which does not look promising in the near to medium term, CCS will be essential for eliminating the limestone calcination process emissions for making clinker, which currently represent 60 percent of GHG emissions in best available technology plants," says IPCC WG3 in the executive summary of chapter 11. Further down in the text, the message is quite different, as seen above.

The cement lobby has been successful not only in delaying action

One of the works quoted in the IPCC WG3 report is Haber et al[69]: Environmental impacts and decarbonisation strategies in the cement and concrete industries in *Nature Reviews Earth & Environment.* It points to great technological potentials to cut CO_2 emissions but the tone is subdued.

"As the construction sector has proven to be very slow-moving and risk-averse, we focus on minor improvements that can be achieved across the value chain, such as the use of supplementary cementitious materials and optimising the clinker content of cement."

"By engaging all stakeholders in the construction sector, immediate greenhouse gas savings on the order of 50 percent could be reached without heavy investment in new industrial infrastructure or modification of existing standards."

Where is Elon Musk?

Well, what could be achieved if we do need heavy investment in new infrastructure and if modification of existing standards is seen as necessary?

Where, so to speak, is an Elon Musk when you need him? Henry Ford did not aim for realistic growth, taking the horse and cart industry into consideration. The iPhone was not the result of extensive market research. The wind and solar industries did not get where they are now by being modest and polite. Nor did the nuclear crowd. The atom bomb came from nowhere to detonation in three years. And so on. The cement industry is strong, but it is not invincible. It took a long time to break the back of the European coal lobby, but now even Poland has admitted that coal will have to go.

The cement industry has had at least 35 years to improve its climate act. It could have adapted by doing more research, diversifying the selection of materials, and by moving up the value chain. It could not have saved every quarry and kiln, nor indeed most of them, but it could have rescued much of the huge transport and marketing apparatus it controls. But it has done next to nothing. Just like the coal industry, it opted first to deny responsibility, then to delay and defocus action.

It has come to be a question of crude power. Either you save Portland cement as we know it or you save the climate as we know it.

Apart from the raw power struggle, an all-out effort to phase out Portland cement faces one major factual challenge: that immediate substitution might be dangerous, and for that reason a modification of standards is not possible.

But there are several ways to design and construct a building element (a foundation, an internal non-structural wall or a facade), a bridge, a harbour or a road. In some cases,

---

[69] https://www.nature.com/articles/s43017-020-0093-3

such as a skyscraper, there is a clear need for conservative or at least extremely well documented designs. However, the requirements for a bungalow or a garage, a pavement, a transformer building, a bus stop or a parking lot are much less stringent.

Some of these alternatives to traditional cement are mutually exclusive, but some can be combined. 3D-printed lightweight concrete can save 70 percent compared to standard concrete, but if the cement formula reduces clinker content by 50 percent (ash, slag etc) the combination would reduce emissions by 85 percent. Electric heating may offer a further reduction, so -90 percent is within reach, without using an extra gram of alternative materials, such as wood, brick etc.

Policy instruments

Cement production and use can be cut drastically, but this is too complex for a regulatory approach alone, even though regulatory aspects are very important. Existing regulation favours existing materials, processes and designs.

Economic instruments are clearly needed to handle the diversity of mitigation options, and these instruments need to be much more effective than the present ETS.

Cement producers now receive about 100 percent free allocation. There is little incentive or deterrent to make them change. Worse still, the producers and consumers of alternative materials and processes will not earn any money by cutting their emissions.

The best thing would be to do away with free allocation totally and immediately. The competition from non-European companies is probably not that strong. It costs a lot to transport large volumes long distances, if there is enough freight capacity and customers are willing to immediately change from suppliers they trust to new untested suppliers.

A border adjustment tax or Carbon Border Adjustment Mechanism (CBAM) is now planned[70] from 2026 and the Commission "is now seeking to phase out free allocations"[71], though many details remain to be clarified. Still another option is Ecodesign-type requirements for cement, with less carbon per ton of building material permitted for each year ahead.

If the price of cement, currently around €100 per ton, suddenly had to include the cost of emissions – about 0.6 ton of CO_2 per ton of cement[72] at a price of €90 per ton CO_2 – it would add an extra 54 euro to the cost, or 54 percent. The very worst emitters would not survive, and the remainder would at least have to switch fuels and reduce the extra cost to something like 30–35 percent.

That would not be the end of the world. The price of cement is not a large part of the cost of construction. Oil, gas and coal prices have varied much more. The price of coffee has varied by more than a factor of two a few times over the 10 last years.

Construction companies, architects and engineers would soon find ways to avoid some uses of cement, and look more actively for alternative materials and methods.

---

[70] https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698889/EPRS_BRI(2022)698889_EN.pdf

[71] bid

[72] https://www.linkedin.com/pulse/co2-emission-from-cement-industry-whats-best-estimate-claude-lorea/

The problem with a stick-only approach – internalising carbon cost – is that it takes a long time for the new alternatives to step up production and marketing and to clear hurdles, some of which are just mindsets and some of which are hardened into legislation.

This calls for subsidies to accelerate the introduction of new materials and methods, requirements for government buildings etc. That could be achieved within a couple of years, while the slower process of ETS reform ferments.

Limited scope for CCS: too little, too late, too expensive

CCS can only be of minor importance for decarbonising cement.

Transport by ship is expensive, and so is storage. The Norwegian Longship project is expected to cost about €500/ton for the full chain over 10 years for capture and transport by two ships and storage[73]. Many cement factories are a long distance from suitable storage, and there is not much economy of scale for building 1000 ships instead of two. The two ships each transport 200,000 tons per year. To decarbonise global cement production by shipping captured CO_2 would take 11,500 ships, or twice as many if the distance between cement factory and is twice as long. This is still not a complete system. Some cement production is not close to a harbour for big ships. The CO_2 would have to be piped to the coast or shipped via a big river.

The absurd cost of €500/ton may be reduced somewhat but not by very much, unless pipelines take the place of shipping.

A complete system for capture, transport, piping and storage is decades away, even if money was no obstacle. Most infrastructure projects – roads, railways, natural gas pipelines, power lines etc. – take a long time and often meet resistance both from the public at large and from local and regional politicians, even if there is a good case for the societal benefit. In democratic countries, and even in some not-so-democratic countries, CO_2 pipelines are likely to meet more local resistance, for all the usual reasons plus the fact that a CO_2 pipeline rupture can kill all the people (and animals) in a valley.

Another problem is that CCS takes a lot of space, with large pipes, compressors, hazardous chemicals[74] etc. The producer may find it difficult to make room for it, without taking undue risks for its employees, neighbours or the environment.

There may be a niche for capturing CO_2 from cement, if the CO_2 is used for something else, e.g. electro-fuels or even CO_2-cured[75] cement. This does not require a complete system of transport and storage, and may make economic sense. But it is irrelevant at the billion-ton scale.

All the alternatives above could deliver emission cuts within 1–10 years, rather than the several decades CCS would take.

---

[73] Some of the cost calculations are in Norwegian, but https://ccsnorway.com/costs/ shows that the order of magnitude is correct. The estimate (P50) for the whole project was 18.7 billion NOK, and was increased by 0.9 billion in the budget for 2022, which means 4,900 NOK/ton, about €490/ton.

[74] https://pubmed.ncbi.nlm.nih.gov/23999744/

[75] https://www.aggbusiness.com/ab9/news/lafargeholcim-expands-reduced-co2-cement-offering

Norcem (a Heidelberg subsidiary in Norway) aims to capture 400,000 tons. But its emissions (2019) are closer to 900,000 tons.[76] This is typical for CCS projects: they capture half the emissions while the other half goes up into the air. That is also the case at the Norwegian Snohvit and Sleipner sites and the Australian Gorgon project for natural gas processing. The capture rate is often described as around 90 percent, but that is only for specific streams of CO_2 that are fed into storage, while other parts of the factory just vent it through chimneys.

Obviously, it would be much more expensive to capture all the CO_2 than about half of it.

The IEA is very enthusiastic about CCS, but in their recent report on cement[77], they are not exactly banking on it. They expect global emissions to remain level from 2020 to 2030.

This is clearly not good enough.

Long investment cycles? Really?

Cembureau, the EU cement lobby, wants money now in order to reach net zero by 2050. The argument goes that the industry has "about a 30-year funding cycle"[78]

Indeed, cement industry investors are used to long cycles and long pay-back times. That does not mean they are entitled to operate their equipment for decades in the future. The low cost, low risk, low R&D budget business model is not the only conceivable one. Manufacturers of mobile phones, cars, solar cells, cosmetics, clothes and so on cannot even consider a 30-year planning horizon. The East German car producer Trabant tried, and produced essentially the same car – the Trabant 601 –from 1964 to 1990.

The East German lignite power stations also intended to have a long future, which, alas, they got. with unchanged very high emissions of CO_2, though retrofits reduced SO_2, NOx and particle emissions. Many of them are still running. The East German nuclear power programme, on the other hand, was shut down unceremoniously within months after the fall of the Berlin Wall.

If there is a (political) will, there is a way.

A 1.5 degree world with China

A 1.5-degree-compatible future will have to look something more like what happened to coal power in the EU between 2015 and 2020: a 50 percent decrease within five years. If we start here, in the EU, the world will follow. That is what we must assume.

China is the big problem for cement, but it may also be the big opportunity. China is by far the biggest producer, with 55 percent of global production, according to the IEA, and India comes in second place at 8 percent.

---

[76] https://www.norcem.no/no/CCS_Brevik

[77] https://www.iea.org/reports/cement

[78] ENDS 23-05-04 https://www.endseurope.com/article/1821870/why-backers-net-zero-cement-projects-calling-new-policy-funding

Some of the decarbonisation of cement in China will be achieved by using indigenous resources and talent, but it clearly matters what other advanced nations do with regard to low-carbon cement and low-carbon construction. The EU and other rich regions can choose to lead the way.

If the carbon border adjustment mechanism works as intended, it may create an opportunity for low-carbon cement production in the EU and in China, or whoever gets there first.

Not likely

Because there are many ways to reduce emissions from the cement industry, an investment in CCS is not just expensive, it also carries a market risk. There is a risk that the demand for traditional Portland cement will erode or collapse in the local market, as better and cheaper building materials or solutions become available.

It would look stupid to build a 1 Mton/year carbon capture plant and harbour, with associated contracts for shipping and storage, and then, ten years after the investment is agreed, have just half a million tonnes of emissions to capture.

This means that the investment will have to be amortised faster, which makes it even more difficult to finance.

Governments or the EU can get a cement CCS plant built – but only with very large subsidies. Unsubsidised cement CCS does not exist, and does not appear likely in the future.

(This article was updated in September 2023)

4. Inside or outside ETS? New sectors

The whole idea of the ETS was that it would be certain to deliver emission cuts where it was applied, and that it would do so at least cost. But it was not nearly ambitious enough, so the initial year to reach zero was 2067, and that was only for about half of and 40 percent of GHG emissions. It was created so as to minimise costs rather than to achieve results.

It had a large number of loopholes and was essentially useless from 2005 until 2017. Many coal power plants are gone since 2005, but they died from old age or from the Large Combustion Plant Directive opt-outs, not because of the ETS.

Plans to improve the system by including more sectors, often proposed by neoclassical economists and businesses that wanted to avoid climate action, did not acknowledge the failure to deliver, or that it was the solution to the wrong problem, i.e. minimising costs. The costs were low enough. There are still power stations with emissions of 1200 grams/kWh operating at base load in Poland and Germany.

From 2018 and especially 2021, the ETS gained teeth. With prices above €80, it should have stopped the worst emitters, if it had not been for the fact that the high EUA prices are mainly the result of high gas prices, so gas power still cannot compete with coal power.

(Land) Vehicles excluding air transport

Cars, trucks, off-road vehicles, buses and ships are major sources of CO_2 and N_2O.

This is a strong reason for not including them in the ETS. If they were included in ETS as **substitutes** for existing instruments, it would make driving much cheaper, and increase emissions. If the cost of ETS were added **on top of** existing instruments (petrol tax, car tax, CO_2 emission performance standards for cars and vans, company car taxation etc.) it would not make much difference. A **new fossil-fuelled car** costs about €70 for 100 km, most of which from depreciation. If it lives up to the emission performance standard of 95 grams/km, it uses 3.7 litres of diesel at €1.64 or 4 litres of petrol at €1.7, a cost of €6–7 per 100 km. That is what it costs now. If a CO_2 price of €80 per tonne were **added**, for the diesel car it would amount to 11 kg per 100 km, and a cost of less than one euro/100 km. It would not influence the choice of car, and it would not influence behaviour. Even if it uses twice as much fuel, which is quite possible for some plug-in hybrids, it is still not very much.

It is also very difficult to see how it would be politically possible to just add a CO_2 cost via ETS without changing any other instruments. It is, as shown, no big deal for people who can afford a big new car. They can either pay for the fuel or buy a Tesla and pay nothing.

For the majority of people, who drive older cars with often higher CO_2 emissions, it would be a substantial extra cost without much of a choice. (Think Yellow Vests.)

The dynamic effect of including transport in the ETS may be to increase the EUA price. This makes it harder to reduce free allocations for steel, cement etc. The cars will take room from industry.

As of late January 2022 the markets believe that the EUA price will remain high until 2030. If that holds, the idea of including transport is not as bad as it used to be, when the EUA price was €5 or €20. But markets are not always good at guessing. There have been EUA crashes to near zero before. If wind, solar and batteries are built out fast and we run into a recession, EUA prices may drop dramatically.

The present instruments are more stable.

Air transport

The air transport lobby was very successful with the 2012 inclusion in the ETS on absolutely ridiculous terms, a get-out-of-jail-free card for next to nothing. New aeroplanes should have similar requirements as cars, year by year, gram by gram, while existing planes should pay for 100 percent of their emissions with no offsetting. Use as many instruments as it takes to cut CO_2 and high-altitude emissions!

Sea transport

Emissions were 149 Mtons (slightly less than air transport) from international navigation and 23 Mtons from domestic navigation in 2019.

Inclusion of ship emissions would usually be an improvement, especially if EUA prices stay high.

But this is a complex process, it will take time (earliest 2026, see below) and the results are very uncertain:

"Our findings indicate that this could generate a total cost increase for the included shipping sector in the range of 0.17 up to 12.4 billion euro. This is based on the assumptions that 5 percent of allowances would be auctioned at a price level of 25 EUR in the lower case, and 100 percent would be auctioned at a price level of 70 EUR in the upper case. To set these cost increases in context, they would generate a price increase of between 0.6 and 33 percent per tonne of marine gas oil at the current fuel price (EUR 630)."[79]

How can anybody make a good investment decision on how to fuel their next ship based on such weak information? How can shipbuilders guess what the markets will want? They will probably just wait and see.

If sea transport is included in the ETS, it must not be *instead of* specific action.

Much more policy is needed to decarbonise shipping, which is likely to involve either hydrogen or hydrogen derivate fuels, such as ammonia.

Buildings emissions

Buildings emit very large amounts of CO_2, and indirectly other GHGs through the energy use they use for heating, cooling, lighting and ventilation. One building may have a climate footprint several times that of another building of the same size and for the same purpose.

Those emissions are, however, to a large extent already covered by the ETS; this is true for electricity and district heating, at least.

---

[79] https://www.ivl.se/download/18.34244ba71728fcb3f3fb2f/1591706118483/C521.pdf

Very few EU buildings have anyway near the thermal integrity that should be required. This is a field that calls for a lot of political intervention. Strict energy standards for new and renovated buildings now make it much easier to phase out fossils and nuclear. It is very uneconomic to first build a huge surplus of wind and solar to supply leaky buildings and then insulate them.

There are easy ways out, such as redefining energy requirements in terms of "primary energy" instead of energy losses, so as to favour district heating and CHP, or to put some solar panels on top of a poorly insulated building. The target must be that every house should be a good house, with a few exceptions for historical buildings. Heat pumps are an important improvement on gas heat, but a better insulated house needs a smaller heat pump and will not need as much peak power.

It will cost a lot of money to renovate all Europe's buildings, but it will save even more money, as well as nature.

Construction companies cannot be trusted to take a long-term view for the common good. Unless they are forced to do the right thing, through heavy fines or jail sentences, they will save money for themselves right now – and let the future users of the buildings pay dearly for the next hundred years in extra energy costs.

Including the building sector in the ETS would not solve the problem but it would create a lot of irritation or even unrest because it would be considered unfair.

The minimum energy performance standard (MEPS) is a much better approach.

Agricultural emissions

Agriculture emits CO_2 from some soils. The emissions are difficult to measure, and not suited for ETS. Government should examine whether other regulations or incentives could be used to encourage farmers to cut these emissions, by switching to other produce.

Cattle farming and rice paddies are big GHG sources. They are difficult to monitor, and difficult to do anything about for the individual farmer. Such emissions are not suited for ETS. Governments should define remedial action, and develop instruments such as education for farmers and support for investment.

N_2O from fertiliser, manure and leguminous plants makes a big contribution to GHG emissions. It is difficult to measure and not suited for ETS. Effective instruments that are currently in use, or have been used include: fertiliser tax, education of farmers and investment support for fermentation tanks that generate biogas from manure.

Forestry direct emissions

Forestry products are a big source of CO_2.

In a simplified theory, CO_2 from forests is carbon neutral; new trees pick up the CO_2 emitted from the felled forest will turn into new trees. This would make it suitable to subject wood or biomass combustion to ETS. BECCS would not emit and then not have to pay. If the forest is turned into paper, it will burn within a year and pay for it, but if it it will not return as CO2 into the atmosphere for a century.

But this is oversimplified. When an area is clear-cut, some CO_2 from soil and moss, and nitrogen, as well as methane in wet areas, are emitted immediately. There is also the time factor to consider. A 70-year-old forest will take 70 years to regrow.

But wait a minute. If the forest is *not* cleared, what happens? That depends on what kind of forest it was and what is planted instead. And it depends on when that happens. The trees do not grow so fast in an old forest, but it keeps on storing carbon in the soil.

Creating incentives to log is clearly problematic. Creating incentives not to log can also be problematic. Timber is needed, and some forests are less valuable than others. All these factors cannot be captured in one dimension.

Forest carbon sink

If forests were part of ETS, new forests, for example on derelict land, would be credited for the carbon they store.

This has been widely criticised by NGOs for decades as for third-world credits. But the same problems of permanence and double counting apply to forests in Europe. Fires, inundations, change of owners. Should we allow logging in the Białowieża National Park (in Poland) and compensate for it with short-rotation forest on farmland?

Saving carbon in the ground is a very complex issue and should not be governed by a single factor such as the ETS price. Everything else being equal, an ETS price of €80 should give a strong incentive to leave forests alone, while a price of €20 would make it OK to cut them down.

The management of forests is already largely governed by world market prices for timber, paper and energy. This short-termism is not good for the climate, nor for biodiversity or other ecosystem services that forests can provide.

Methane from waste

Methane from landfills is a fairly big GHG source, though declining in Europe. All waste CH_4 emissions from waste were 121 Mtons in 2019, compared with 225 Mtons in 1990.

Existing instruments seem to work, so there is no reason to include methane from waste in the ETS.

F-gases

The main F-gas emissions are from HFCs in fridges and heat pumps as replacements for ozone-depleting CFCs. Emissions peaked in 2014 and decreased 16 percent by 2019. The problem has been addressed with administrative instruments with some modest success. More of the same can eliminate the source. No ETS inclusion.

Some F-gas emissions are in the ETS, notably PFC from primary aluminium production. They have a residence time in the atmosphere of up to 50,000 years. ETS inclusion was not a good idea, as it inflated benchmarks and free allocation, and did not help to transform the industry.

5. Carbon content labelling – and CBAM?

Summary: EU emissions from heavy industry, especially cement and steel, are not reined in by emission trading, because they receive large amounts of free allocation. The emissions are large, in the EU and globally, but though radical emission reduction is technically possible and at no excessive cost, it is not happening now, due to lack of incentives.

This can be fixed with either a rapid phaseout of free allocations or with a Carbon Border Adjustment Mechanism, CBAM, both of which have drawbacks.

A rapid phaseout of free allocations is probably a good idea. Imports are probably not as big a problem as they are said to be. Emissions and costs may be about the same all over the planet, and it may not be easy or cheap to shift supply chains to distant countries. But the heavy industry lobby will be very difficult to tackle. They will demand a very slow process, with lots of exceptions and exemptions.

CBAM would obviously be a great improvement for the climate. Either it would protect EU industries from dirtier imports, or the imported steel, cement etc., would have to become cleaner. If for example Chinese manufacturers of steel wanted to qualify for the EU market without being slammed with a hefty CBAM duty, they might start green steel production for export and perhaps also for the Chinese market, depending on the rules for the indigenous emission trading system.

Although a well-designed CBAM would cut emissions in the EU and globally, it is not likely to happen very fast.

A third way would be an administrative instrument, analogue to energy labeling in the Save/Ecodesign directives.

Examples of evolutionary and revolutionary emission reduction techniques are suggested.

Two of the very big CO_2 emitters, globally and in the EU, are steel and cement. Together they emit some 15 percent of global GHG emissions.

CO_2 is emitted during cement-making when fuel is burned to heat limestone and then from the limestone itself; when calcium carbonate emits CO_2 to become calcium oxide.

CO_2 is emitted during iron- and steel-making as a result of the reduction of ore (iron oxide) to metal with coal in blast furnaces.

With the right incentives, both the cement and steel industries can reduce emissions.

Incentive structure

Free Allocation for a large share of the emissions (the present situation) takes away the incentive for the cement and steel industries to decrease their carbon emissions. EU cement emissions actually increased from 2012 to 2019, from 75 to 78 Mton CO_2. The iron and steel industry improved slightly, from 100 to 87 Mton CO_2 during the same period.

CBAM would remove the incentive problem, but is complicated, would take a long time to implement and carries a risk that in the end it will not be allowed by the WTO/US/China.

Just **doing away with free allocation, before CBAM** is in place, would give steel and cement producers incentives for both gradual emission reduction and the phasing-in of radically different processes: coal-hydrogen substitution for steel production and cements that do not use burnt lime. But the risk, or perceived risk, is that they will be killed by high-carbon competition from non-EU countries.

Another way: Ecodesign steel and cement?

The Ecodesign regulation, which originated in the SAVE programme in 1992, introduced EU labels for appliances such as fridges so that consumers could see if a fridge was energy efficient (A) or not (G). It also meant a ban on the sale of fridges with an efficiency rating lower than G, which applied equally to EU produced and imported fridges. The directive was successively amended, new ratings were defined for the best products, such as A+++, and the entire rating scale was eventually reformed. The worst performers were banned. The same happened for incandescent bulbs in 2012 and for halogen bulbs in 2018 or so.

The bans were accepted, as they were not considered discriminatory by the WTO.

A similar approach to carbon emissions from cement and steel might be faster and easier to implement than CBAM, especially if it is known that the permitted carbon content will be cut every year according to some formula.

Illustrative example of a scheme, tons CO_2/ton steel

	grade A	**grade G**	**non-permitted**
2022	<.2	1.8	>1.8 or grade G
2023	<.15	1.7	>1.7
2024	<.1	1.6	etc.
2025	<.1	1.4	"
2026	<.1	1.2	"
2027	<.1	1.0	"
2028		0.8	"

The Ecodesign approach is an *administrative* instrument intended to prohibit the sale of some high-C products. It is to some degree also an *economic* instrument, because low-C products will be worth more money. It may also become a *normative* instrument, so that a company can't produce or use products that are much inferior than those its competitors use, just as it is wise to avoid slave labour, injuries and deaths at work, and money-laundering.

One consequence is that those steels and cements that have the highest carbon footprints are forced out of the market. Another consequence is creating a green market. It is worth something for e.g. a construction company to only use grade A–B cement and steel. It is not just that it can look good in their Annual Report. The end customer of a building, for example the future landlord, can use this as a selling point for the future tenants, especially for commercial tenants. It would also count for something in existing voluntary systems such ISO 14001, Green Building Council, LEED and others. In a next step it would also be an advantage for obtaining finance (cheaper loans) because some lenders have such requirements, which may (or not) be coordinated under the Green Taxonomy.

Some of the biggest customers for steel and cement are government agencies responsible for the construction of infrastructure. They can set standards for carbon footprints in their procurement, as the Swedish Transport Administration is now doing.

All 14001-certified companies are required to show continual improvement, and producing or using improved cement and steel may be a simple and relatively cheap way to comply.

How can they do it?

There are several ways to shrink the carbon footprint of steel and cement.

Steel. The easiest way to comply is to use more scrap steel. There is not a lot more scrap iron available, so the first effect would be to reallocate rather than to cut emissions. But a secondary effect is that steel producers will speed up their research, development, demonstration and investment for other sources of low-C steel. Also, scrap iron prices will increase, which will stretch the resource somewhat. With an increasing inflow of scrap and unchanged steel demand, something has to give: the oldest, least-efficient blast furnaces.

Even with the continued use of blast furnaces there are possibilities to recirculate exhaust gases, to cut heat losses, to use coal/coke more efficiently. The room for improvement through investment is limited, but some are better and some are worse, and the latter will go first.

The main revolutionary technology is to produce steel with hydrogen as a reducing agent instead of coal/coke. Several companies have started working on this since Swedish steel producer SSAB and miner LKAB launched their Hybrit project in 2016.

Steel production with hydrogen is often thought to be further into the future, though some investors think it can be done pretty soon. This "hydrogen steel" fits well with scrap steel (electric arc) production, and can be mixed with scrap.

Both scrap mix-in and hydrogen steel can be produced by companies in non-EU countries, and be sold in the Union. The only requirement is that imported steel would follow the same methodology as EU steel. This is pretty straightforward. It can usually be inferred from their annual reports.

Cement. Alternative combustion fuels (biomass instead of coal), some electric heating instead of fuels and the mixing-in of slag, fly-ash, possibly volcanic ashes are the evolutionary ways to reduce carbon footprint.

Further on there are other materials that do not emit CO_2 at all, such as clays and lime (not burnt), which to some degree can be mixed with Portland cement, or even replace it totally.

Carbon-grading of cement into grades A–G, with stricter requirements every year, will:

a. create a market for green cement
b. make better use of the ash and slag resource
c. make cement producers look for other resources such as volcanic ash, and
d. create a strong incentive for research, development and demonstration of low-carbon cement, and most importantly,
e. eventually lead to a ban on the sale of the worst cements, with annually increasing requirements.

This instrument will not solve everything. It may for example be a good idea to replace concrete with wood, to replace concrete with asphalt or to use other reinforcement materials, such as glass, carbon fibres or stainless steel, instead of the now usual mild steel rebars, but this will not be solved by this suggested scheme.

At some stage in the future this instrument might totally be replaced by emission trading or a CO_2 tax.

Meanwhile, there is bound to be some overlap.

While not optimal, an Ecodesign type of instrument may still have the potential to cut emissions substantially in Europe and globally, compared to not using it.

Steel and cement are not the only materials where a carbon-labelling scheme could be considered, but they are the most important, followed probably by aluminium.

6. CO_2 tax systems should complement the ETS

Sweden has relatively low CO_2 emissions, due to a large number of policy instruments introduced since 1991. The European Emissions Trading System (ETS) did not contribute at all between 2005 and 2017 – in fact rather the opposite.

In the early 2000s, Sweden showed that CO_2 emissions have become decoupled from GDP growth. Although it is one of the richest countries, Sweden had much lower CO_2/capita emissions (4.18 tons) than the US (13.68 tons) and other European countries (e.g. Germany 7.72 tons or Belgium 7.24 tons) and well below the global average (4.62 tons).

This low *level* can partly be explained by specific geographical and historical reasons. Sweden is a large and rainy country, so it has a lot of hydro power. With its large land area, it has a lot of room for wind power. It is a country with large forests, so it has a lot of biomass. Sweden also has had and still has a lot of nuclear power. But it is, for these reasons, also host to a lot of energy- and emission-intensive industry. Sweden is a big producer of paper, pulp, iron ore, steel, aluminium, refined petroleum products (big net exporter, increasing), cement, lime and other carbon-intensive industry.

Even though Sweden has some geographical and historical advantages compared to the average European country, that does not explain the downwards *trend*.

Neither can the trend be explained by a shift from industry to services. Sweden has the same hydro and a lot less nuclear power than it did 25 years ago. The emission-intensive industries have fewer employees than before, but production output has either increased (paper, pulp, iron ore, non-ferrous metal ores, aluminium) or remained at about the same level over the last few decades.

Sweden is also a big net exporter of electricity, which was not the case 20 or 30 years ago. Sweden exports about 25 TWh every year.

Obviously there is some embodied carbon in imported goods but it is doubtful whether this exceeds its exports. The economic modelling for consumption-based emissions is very difficult. A crude description would be that Sweden exports millions of tons of steel and imports electronics.

Sweden's total CO_2 emissions fell from 52 Mton in 1990 to 32 Mton in 2020, according to the IEA. This decrease is not the result of good luck or creative accounting or moving the emissions somewhere else. It is in all likelihood a real improvement.

Much of it is the result of climate and energy policy.

Pioneering CO_2 tax

When Sweden introduced a substantial CO_2 tax in 1991, it was pioneering. This tax was partly scrapped by 2010, because of the EU ETS. Other instruments had to be invented and implemented to keep emissions on a downward slope.

Examples:

Green certificates introduced in 2002 initially created a market for biopower primarily, in combined heat and power (CHP), both in industry and for district heating. After a few years wind power took over. In 2020, Sweden produced 28 TWh of wind energy, and was the fourth-largest wind energy producer in the EU-27 as well as having the fastest growth.

There have been several investment support schemes, known as LIP, PFE, KLIMP, Klimatklivet, Industriklivet, which have supported lower-carbon investments or efficiency, largely (and in some cases only) for ETS companies. Notably, the Swedish government has committed to a transition from fossil fuels to green hydrogen in the iron mining and steel industries.

Various support schemes for photovoltaics have contributed to late but rapid expansion.

A tax on fossil fuels for district heating was introduced in 2019.

There has been limited development of offshore wind power in Sweden, but the connection cost will be much reduced in 2022.

Sweden has a high electricity tax for households (but not for industry). In 2022 it is .36 SEK/kWh or about €36/MWh. The main purpose is to bring in money for the government, but it has also helped to keep electricity consumption down, and thus interfered with the ETS.

Such measures are practical recognition that the ETS is not the only solution.

Good guys all over!

In June 1988 the Swedish Parliament approved what may have been the first climate target in the world. It was against the backdrop of the Brundtland "Only One Earth" report to the UN in 1987, and the US Senate hearings in early 1988.

Another background factor was that the Social Democrat government had declared that it would start phasing out nuclear power. The leading opposition party, the Moderates, a conservative and pro-business party, was against this. They saw the climate as a new argument for nuclear power, and motioned that the CO_2 emission level would not be allowed to increase above the present level.

The motion was carried because all three opposition parties to the right were joined by the Left party, which was against nuclear power and also the arguably greenest party in Parliament.

The Left Party thought, unlike the government, that it would be possible to both phase out nuclear and keep CO_2 down.

Whether the Moderates acted in earnest or just for political tactics is not a meaningful question. They said what they said and did what they did, and that changed Swedish politics for good.

The motion was not very specific. It did not, for example, give a base year that would form the emission ceiling, and this happened to be of great importance. Neither was it known how it would be accurately measured.

The Social Democrats, after the defeat in Parliament, did not try to use the lack of precision to water down the decision or wait it out. They did their best to implement it.

Possibly their ambition to do something serious was reinforced by the election a few months later, in which the environment featured highly, and which for the first time brought the Green Party into the Parliament.

The main instrument to keep CO_2 emissions down became a CO_2 tax, as first proposed by the Swedish Society for Nature Conservation in 1988. This was approved in June 1990 by a large majority in Parliament and became effective in January 1991.

The tax to be levied was .25 SEK/kg CO_2, which is about €42/ton in 2022 money. The EU ETS did not reach €42 until 2021, and spent much of the time between 2005 and 2017 at about €5 or lower.

So far this is an edifying tale about how *all* six political parties acted in a constructive way – which does not happen every day.

Not exactly perfect

But...

1. The tax exempted power, despite the dominance of hydro, nuclear and to some extent biomass power. The electricity-intensive industries, especially paper and pulp, were political heavyweights and were not willing to pay any more for electricity.
2. It exempted peat, a very CO2 intensive fuel used in district heating
3. Some of the new CO2 tax was compensated for by lowering previous energy taxes. The total petrol tax thus remained the same as before.
4. CO_2-intensive industries, such as steel, other metals, mining, cement, lime, refineries, chemical industry and even the forest industry were (in practice) exempt from the tax.

On the other hand, the tax was very effective as an instrument to shift domestic heating from oil to either biomass, electric heating, heat pumps or district heating. This was reinforced by the energy tax, which was levied on fossil fuels but not on biomass.

The SEK .25/kg also applied to industry, except for energy-intensive process industries, so an industry that used oil, gas or coal for heating would have to pay the tax, or switch to district heating. This applied to large companies such as Volvo, Saab, Scania, SKF and ABB.

This was a bit of a shock for industry, which had successfully lobbied for low energy prices and taxes, and they did so again. In 1993 the industry tax was lowered from SEK .25 to .08/kg CO_2, while the "general" tax was raised to .32 SEK under the new government led by Carl Bildt (Moderate). The 1991 crisis hit Sweden hard, with falling GDP for three years.

A benevolent interpretation of the change would be that the government said, "we can't let our industry lose out in competition against untaxed companies in other countries, but we can do a little better than our neighbours".

Later on, the CO_2 tax was raised again. It is now about SEK 1.15/kg, equivalent to about €115/ton Some of the exemptions were removed and some were added.

In 2008 the CO_2 tax was reduced by 85 percent for **combined heat and power** within the ETS, and the energy tax was removed. The CO_2 tax was completely removed in 2013, and because of all the exemptions, very little energy tax remained.

In 2008, the CO_2 tax was also lowered to 94 percent for **district heating** (without power), and in 2014 to 80 percent, then increased to 91 percent in 2018. The full energy tax also applies to fossil fuels.

The CO_2 tax **for industry** was cut to 85 percent in 2008, and the energy tax was removed. In 2011 the CO_2 tax was completely removed.

And this, alas, is a very simplified description!

It is pretty hard to discern causes and effects.

It is nevertheless clear that an admittedly flawed system based on a relatively high CO_2 tax and energy tax was followed by an even more flawed system: ETS with low prices, free allocation and much reduced energy tax.

What the tax achieved and did not

The effects of the CO_2 tax can be summarised as follows:

1. (Outside ETS) The CO_2 tax had little influence over **transport emissions**, as could be expected (because the taxation level remained the same, but some of the energy tax was *renamed* as CO_2 tax). Later declines in petrol and diesel use were due to other reasons, such as promoting ethanol, rapeseed oil, biogas and electricity.
2. (Outside ETS) The CO_2 tax and the pre-existing energy tax on oil had a dramatic long-term influence on **heating of houses, flats and commercial buildings**. Oil use in that segment fell from 40 TWh 1990 (and much higher before that) to 10 TWh 2020[80]. The 30 TWh of oil was replaced by better insulation, heat pumps and more district heating. The population grew by 20 percent between 1990 and 2020. There was a small increase in biomass and electricity use in the sector.
3. (Inside ETS) In district heating there was a fairly strong incentive to switch fuels from coal, oil and gas to biomass, and (unfortunately) waste. Total district heating grew from around 40 to around 56 TWh from 1990 to 2020. Of this, some 15–20 TWh was coal, oil and gas before 1990 and less than 2 TWh by 2020[81].
4. (Inside ETS) Much of the district heating was combined heat and power. The electricity part was exempt from the tax, which provided an opportunity for tactical allocation of what was what. Some of the heat was imported as waste heat from industry, with a similar allocation problem.

A side effect of the growth in bioenergy for district heating was that the forest industry (mainly **paper & pulp**) started to realise that useless by-products such as bark, sawdust, twigs etc., were actually a resource. If they could sell them for district heating, they might as well produce more for their own use. Their emissions were about 3 million tons of CO_2 in the mid-1990s but dropped to less than 1 million ton in later years.

Today there is open debate about whether biomass is really carbon neutral. But the historical context has to be recognised. From 1974 and for the next 40 years or so, there was general assent in Sweden for the idea of replacing oil with biomass, first to reduce dependency and to reduce other pollution (SO_2) and later as a method to reduce CO_2. Biomass was also seen as a major route for the phaseout of nuclear power, which was agreed by Parliament in 1980, to be fulfilled by 2010. Sweden had the most nuclear power per capita in the world. It is still at or near the top. The decision was cancelled later, but by 2021, 6 out of 12 reactors were still operating. In the 1980s and 1990s wind and solar were not deemed capable of replacing a significant part of some 70 TWh/year of nuclear; only by 2010 did total wind power correspond to one reactor.

---

[80] https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=198022 (from excel document in Swedish)

[81] https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=198022 (from excel document in Swedish)

The incentive for switching from oil to biomass and for more efficient use of district heating was weakened in 2013, when district heating and CHP plants were given large numbers of free allocations in the ETS. I don't know how that happened in the Brussels corridors, but the district heating lobby in Sweden acted (and probably were) surprised. As indeed they should. CHP plants were not only able to avoid the CO_2 tax in 1991; they were now actually being paid for their fossil (or biomass) emissions.

District heating, CHP, CO_2 tax and ETS

There are a number of measures for cutting emissions from district heating and CHP. The climate policy of various instruments should be judged by how well they have performed in each respect:

1) Efficiency: improved insulation, better windows, heat recovery from exhaust air and improved control systems.

The district heating companies had little incentive to make efficiency improvements in order to save heat, as it would diminish their sales.

District heating is a monopoly, for obvious reasons. There is however some competition from heat pumps, but only marginally. There is also some competition from Energy Performance Contracting companies, and many district heating companies have an EPC department in-house.

Despite few incentives for the district heating industry, efficiency improvements are taking place. Landlords and housing cooperatives may want to cut their costs, or have other motives: a better indoor climate, environmental concerns, or brand issues such as qualification for Green Building certification, at gold or platinum level.

We can't know how the CO_2 tax and energy tax would have influenced efficiency if left alone. It is however sure that the years of low-price ETS and free allocations did nothing to advance efficiency. And the waterbed argument – that if you cut emissions in one place they will rise somewhere else – tends to make every effort meaningless, at least among the Very Serious People, especially the neoclassical economists. Sweden did have a rather innovative and well-financed energy efficiency programme from 1991 until 1998 as a result of a political agreement between the government and two centrist parties. This paved the way for a revolution in domestic appliances, including a procurement competition for energy-efficient fridges, which Electrolux (the global leader in white goods at the time) felt it had to win, did win, and transformed its products. It also paved the way for cheaper and more efficient heat pumps (which contributed to a boom in the following years) and for efficient windows, which led to changes in building codes and green building standards.

The ETS ideology that the market can fix everything – just you wait! – is detrimental to energy efficiency policy, which has to tackle the multiple barriers that exist between the best product and the best-selling product.

Aside from and before the ETS, in another part of Brussels, the SAVE Directive of 1992 (and later Directive on Energy Efficiency) recognised that administrative instruments can be very efficient in delivering energy efficiency for 30 years, as you can see from the energy label on every fridge.

2) Fuel shift from fossils to biomass or waste.

If biomass is considered carbon neutral, a shift from coal, oil, gas and peat is incentivised both by the ETS and by the CO_2 tax, and such a change has taken place. But mixed waste is not only cheaper than biomass such as wood chips or pellets, it has a "negative price": the seller pays the combustor to rid of it. The result of a low CO_2 price was investment in expensive-to-build but dirt-cheap-to-operate waste incineration plants. CO_2 from waste combustion increased from 1.2 Mton in 2004, before the ETS to 2.9 Mton in 2019. It is not easy to say what would have happened without the ETS (and its subsidies) but with a high CO_2 tax and energy tax, but it could not have been nearly as bad.

3) Shift from fuels to electricity.

District heating companies can either use heat to produce electricity (CHP) or electricity to produce heat with heat pumps. Some of them (e.g. Stockholm Exergi) do both.

When nuclear power was a big issue, increased use of electricity was not perceived as an efficient use of energy. Now there is a growing surplus of wind power, and big heat pumps seem a much better idea. If electricity is cheap and clean, the heat will also be cheap and clean, i.e. from scratch, in a level playing field.

But if a company has recently invested in waste CHP, it takes very strong incentives to make it write off that capital and start building new heat pumps. The ETS is not the solution. It is the problem.

Sweden has been successful in using heat pumps to heat buildings outside the district heating network. This was due to factors that are not relevant here, such as high oil prices and an investment subsidy for household heat pumps, some of which were policy and others just luck. The CO_2 and energy taxes did their part, and have kept doing so, as they are outside the ETS. Installations of ground heat pumps peaked in 2006 but have remained high ever since.

Within the ETS, for industry and district heating, energy production from heat pumps has not grown. It peaked in 2002 at almost 8 TWh and dropped to just above 4 TWh in later years.

The ETS has incentivised waste CHP at the expense of large heat pumps, and thus increased CO_2 emissions.

Administrative instruments outlawed

Before the ETS, the Land and Environment Courts, or rather their predecessor, the Board of Concessions for Environmental Protection BCEP (if the translation is correct), could stipulate conditions for greenhouse gas emissions when granting a licence for a company. This was expressly prohibited by the Emission Trading Directive 2003/87/EC, point 21 in the preamble:

"Directive 96/61/EC should be amended to ensure that emission limit values are not set for direct emissions of greenhouse gases from an installation subject to this Directive and that member states may choose not to impose requirements relating to energy efficiency in respect of combustion units or other units emitting carbon dioxide on the site, without prejudice to any other requirements pursuant to Directive 96/61/EC."

The option to use courts of law for climate policy was not widely exploited.

The licences are granted for many years at a time, the courts are cautious of introducing new ways of thinking, climate policy was relatively new, and heavy industry is also politically influential. The courts were supposed to weigh environmental considerations against other interests.

But there was still the option.

Sweden's biggest emitting cluster is the iron, steel and mining industry, including the blast furnaces of SSAB in Luleå and Oxelösund, and the three LKAB mines in the north, which supply SSAB. LKAB is also a large exporter of ore pellets. Together SSAB and LKAB emit 5–6 million tons of CO_2 per year, some 15 percent of Swedish CO_2 emissions.

In a ruling by the Board of Concessions for Environmental Protection concerning SSAB Luleå in the late 1990s, the company was required to investigate how it could cut its CO_2 emissions. The company was not required to use Best Available Technique. It was even less required to cut its emissions, but it had to think, and present the results to the court by a certain date.

But it was a start.

It is easy to envisage a dotted line ahead, if it had been left to the Swedish courts to translate climate policy targets into quantitative and qualitative requirements of CO_2 emissions.

This was not to be.

"Double instruments" dogma

The directive took a very clear stand against "double instruments", according to the neoclassical economics doctrine.

The philosophy was as follows: Any decrease in emissions anywhere in the ETS system will be followed by an increase somewhere else (the "waterbed effect"), so trust the system, don't try to influence it.

This is not only extremely depressing for anybody who is trying to do something for the climate.

It is also wrong.

The ETS is a political construct, which can be changed by political decisions, as indeed it was several times. The changes up to 2017 were often designed so as to make the system even less effective, such as the loophole of the Linking Directive and the inclusion of air traffic on extremely favourable conditions.

But sometimes our leaders have moved to fix the leaks and to bring the system in line with climate targets.

Another flaw was that for a long time the ETS was not a climate policy instrument at all. The price collapsed to near zero in 2007 and again in 2012. The EU Allowance (EUA) price remained well below €10 per ton through early 2018. This was not even a real incentive to shift from coal power to gas power.

The incentive in the power sector was too small, although it did exist from 2013, as free allocation was stopped.

Free allocation has continued in other industry sectors such as cement, steel, metals, lime, paper and pulp. In theory, the companies could make money by cutting their own emissions and selling their EUAs to other companies, but there is little evidence, or reason to believe, that they do so. A cement factory may cut its core emissions by switching from lime to another mineral from another quarry and another process, but then most of its machinery becomes useless, and the workforce is in the wrong place. It is a very big transition. As long as it gets its free allocation it will not make this transition unless it sees other strategic advantages.

Member states that wanted climate action (not that they were very many) had to sidestep the ETS. They had no stick to use against coal power, so they used carrots for wind, solar and efficiency. So did the whole EU, for example with the NER300 and Covid recovery. Some coal power stations, and some other dirty industries were indeed killed off, but not because of their CO_2 emissions or the ETS. They were killed by the 1988 Large Combustion Plant Directive and its stipulations on SO_2, NOx, dust etc., which took a long time to kick in, but finally did so.

But this made EUAs still cheaper, and Sweden was very active in the 2017 reform, sometimes even called the Swedish proposal, which scrapped more than 2 billion EUAs. One reason why Sweden, rather than Poland for example, took this initiative was that Swedish emissions were already relatively low and decreasing.

Other Nordic countries

The OECD summarised the introduction of CO_2 taxes in the Nordic countries as follows[82], with a European Community CO_2/energy tax proposed by the Commission as a reference.

	$/tC1990-92	$/ton CO_2	inflator	€2022/ton CO_2
	OECD	Convert 44/12	2.06	$1=€0.95
Finland 1990	7	2	4	3
Norway 1991	155	42	87	83
Sweden 1991	150	41	84	80
Denmark 1992	57	16	32	30
Eur prop tax	90	25	51	48

The OECD report from 1993 shows the complexity of exemptions even back then, and over the first few years:
"For all Nordic countries except Finland, there are extensive exemptions and tax reliefs which make the effective carbon tax rate (average carbon tax paid on all emissions) considerably lower than the nominal rates. Furthermore, revisions to the original carbon tax systems have been implemented in Norway, Sweden, and Finland since 1991. The 1993 effective carbon tax rates are: 120 US$/ton carbon in Sweden; 74 US$/ton carbon in Norway; 25 US$/ton carbon in Denmark; and 13 US$/ton carbon in Finland. This can be compared with the EC combined energy/carbon tax proposal of about 90 US$/ton carbon by the year 2000."

---

[82] https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(93)120&docLanguage=En They then counted CO2 as carbon (C) which is 12/44 the weight of CO2

This proposed European Community Tax came to nothing, but the \$90 quoted would be about €50/ton CO_2 in today's money, a level not reached by the ETS until 2021.

In its stead came the ETS, agreed in 2003, which took effect in 2005 but had little consequence until early 2018. Sweden and Norway were fairly close to the proposed tax; even Denmark was not that far away.

The Danish tax, along with other climate instruments, had a remarkable influence on emissions, which were cut to less than half between the early 1990s and 2020, largely by almost eliminating coal power, which was mainly replaced by wind and solar power. Denmark was the global pioneer in wind power, even before Germany, and leads the way in energy efficiency and solar power. Arguably, Denmark achieved more global CO_2 emissions cuts through its wind power efforts than the entire EU with the ETS. In 1994, Denmark produced almost a third of global wind energy. Vestas and Orsted are still global leaders.

Finland had a lower tax, and reduced its CO2 emissions less than Denmark. It also bet heavily on new nuclear power, especially Olkiluoto 3, which did not deliver any electricity between 2009 (when it was planned to start commercial operation) and 2021, and not much in 2022 either. Instead, Finland imported electricity from Sweden, Russia and Estonia (Estonian electricity had the highest carbon intensity in Europe, possibly in the whole world). Finland is one of the last countries in the world to use peat for electricity83.

The failed nuclear effort did not help the development of wind power, but that development nevertheless took off from about 2014, and reached 8 TWh in 2020.

Norway's CO_2 tax had one spectacular result. It made Norway a pioneer of CCS in 1996, from LNG gas processing, though few other countries have followed in its footsteps.

Norway's big carbon footprint comes from the *consumption* (in other countries) of its gas and oil exports, which have not been influenced by the tax. The oil and gas *production* emissions are still huge, and Norway is one of the few countries that has increased its CO_2 emissions from 1990 to 2020 (from 27 to 36 Mtons).

Norway did not have any CO_2 from power in 1990, so the tax could not reduce those emissions.

The bottom line: The CO_2 tax and associated tax changes in the Nordic countries had some effect, as did other national instruments, and some common EU instruments (energy labelling, the Large Combustion Plant Directive).

The EU "flagship" for its climate policy did not deliver any emission cuts for many years. It expressly blocked climate emission legislation. The theory behind the ETS, that "double instruments" should be avoided, was proven wrong.

In order to stop dangerous climate change you have to throw everything you have at it, double instruments, triple instruments, whatever it takes.

Denmark has now made a point of this[84] by adding a CO_2 tax on top of the ETS, constituting a total carbon price of about €150/ton CO_2.

---

[83] https://yle.fi/news/3-12409412

[84] https://www.ansvarligfremtid.dk/en/danish-pension-industry-in-support-of-government-proposal-for-ambitious-carbon-tax-reform/

7. The innovation Fund needs to focus on renewable energy, efficiency and saving

EU promotes false solutions in Innovation Fund

Ingress: Carbon Capture and Storage (CCS) featured highly when the European Innovation Fund for innovative low-carbon technologies awarded its first seven large-scale projects.

The Innovation Fund will invest about €38 billion[85] between 2020 and 2030 for the demonstration of innovative low-carbon technologies.

€38 billion is a great deal of money, and that is a low estimate. The funding comes mainly from the sale of 450 million CO_2 allowances in the emission trading scheme, and assumes a CO_2 price of €75/tonne. Futures for CO_2 allowances by 2025 are, as of early October 2022, trading for €80/tonne, increasing to €113 by 2030. There is also some unspent money left from a 2009 programme, NER-300, which was also mainly for CCS.

It now looks likely that the Innovation Fund will surpass 45 billion euro. This was quite unexpected. At the time of the Innovation Fund's instigation in June 2019 that would have been expected to be less than €10 billion.

The total project funding is even bigger. The EU only covers at most about half. The remainder is supplied by member states or private funding.

Much like its failed predecessor, NER-300, the Innovation Fund "focuses on highly innovative technologies and big flagship projects". There is also funding for smaller projects, but that is a minor part (estimated at max. €7.5 billion in total capital cost), so the important part is the big projects. The awards for the first seven large-scale projects were announced in April 2022, and will share €1144 million, if investment decisions are made by the applicants.

Four projects include CCS, two of which are controversial "blue hydrogen" projects, i.e. hydrogen produced from fossil gas. One project, ECOPLANTA, is for processing waste to methanol, which is two steps down the waste hierarchy: not reduce, not re-use, but recycle.

Two of the projects are uncontroversial, at least on the surface. One is the hydrogen-steel project HYBRIT in Sweden (which AirClim and Acid News have often written about.) and another is TANGO, for a big solar cell factory in Italy. So 5 of the 7 awards and more than 75 percent of the funding should raise eyebrows among NGOs, and indeed anybody who wants to avoid a waste of public money. Several projects will not contribute to decarbonisation in an effective way, and are examples that are unlikely to be replicated on any meaningful scale. Some projects can be construed as a lifeline for the fossil industry.

---

[85] https://ec.europa.eu/clima/eu-action/funding-climate-action/innovation-fund/what-innovation-fund_en

				EU funding M€
TANGO: Italian PV Giga Factory	Solar energy	Italy	Solar PV B-HJT cells and tandem modules manufacturing 3 GW	117
K6 Programme	Cement and lime	France	CCUS (CO_2 incorporated in concrete)	153
BECCS Stockholm: Bio Energy Carbon Capture and Storage by Stockholm Exergy	Biofuels and biorefineries	Sweden	Bio Energy Carbon Capture and Storage (BECCS)	180
ECOPLANTA: Reduction of CO_2 emissions from municipal non-recyclable waste to produce methanol	Chemicals	Spain	Waste to chemicals and fuels (methanol)	106
HYBRIT demonstration: Swedish large-scale steel value chain demonstration of hydrogen breakthrough iron-making technologies	Iron and steel	Sweden	Hydrogen-based iron- and steel-making, 500 MW electrolyser, electric arc furnace	143
SHARC: Sustainable Hydrogen and Recovery of Carbon	Hydrogen	Finland	Hydrogen with electrolysis and with CCS (green and blue hydrogen)	88
Kairos@C: Building strong momentum for massive decarbonisation in the EU through a unique end-to-end CCS project	CO_2 capture and storage	Belgium	Carbon capture and storage	357
Total				1144

Much the same concept was launched in 2007–2009, when the EU wanted to build 12 full-scale CCS plants by 2015. It was a total flop according to a report[86] from the EU auditors in 2018. No carbon – not a gram – was captured, but the EU did not lose very much money either. Most projects failed and the EU got some money back. There were not many takers in the first place, which was embarrassing for the EU. A parallel CCS support scheme, the European Energy Programme for Recovery, also failed dismally, as for CCS, according to the auditors. (But it helped achieve a break-through for offshore wind power!)

The CCS dud 15 years ago has not stopped the EU Commission, member states or the Parliament – and often the very same people – from trying the same thing again, though now at a much larger scale.

To help them to distribute some of these billions, the EU set up an assessment project called NEGEM (negative emissions) with funding from Horizon 2020 (from the EU research budget). They are part of the same fossil/CCS network. NEGEM connects several huge CO2 emitters and CCS lobbyists, a cooperation between Shell, Italian gas giant Snam, Finnish oil company ST1, UK power company Drax (which burns biomass from the US), a few research organisations, three (3) branches of the pro-CCS International Energy Agency, Oxford and Cambridge universities (both recipients of considerable fossil company funding) and the Zero Emission Platform ZEP[87]. Some of these are "partners", some described as "international collaborations"[88].

---

[86] https://www.endseurope.com/article/1648572/auditors-criticise-failure-ccs-support
original https://www.eca.europa.eu/Lists/ECADocuments/SR18_24/SR_CCS_EN.pdf

[87] https://www.negemproject.eu/wp-content/uploads/2021/06/NEGEM_D1.4.pdf p49

[88] https://www.negemproject.eu/partners/

ZEP can be described as a front organisation for Big Oil and the Norwegian Longship, a system for transporting CO2 from harbours in Europe to storage sites under the Norwegian North Sea, initially from a Heidelberg Cement factory in Norway.

ZEP members are:

- Northern Lights (Norwegian company that aims to commercially transport and store CO2 under the ocean floor in the Norwegian North Sea)
- Equinor (Norwegian oil and gas company, owns part of Northern Lights)
- Total Energies (French oil and gas company, owns part of Northern Lights)
- Bellona Foundation pro-CCS Norwegian NGO
- SINTEF (Branch of the Norwegian government)
- BP
- ExxonMobil
- Fortum Oslo
- Heidelberg Cement, the world's fourth-largest cement producer and part of the Norwegian Longship CCS project.

They include many of the same companies that receive or expect money from the Innovation Fund, in particular Fortum Oslo, Northern Lights and associated oil companies, Equinor and Heidelberg Cement. This is not to say that there is corruption, just that the people involved share similar views on what is the problem and what are the solutions.

Two of the projects are for "blue hydrogen" – producing hydrogen from fossil gas with carbon capture – a technology which most or all NGOs disapprove of.

"#BlueHydrogen is about as blue as the end of a smoke stack. Don't be fooled, it's just another excuse for the fossil fuel industry to keep pumping out pollution to destroy our planet", commented Greenpeace[89].

The "innovative low-carbon technologies" are, so far, largely CCS, but also include green hydrogen steel and solar panels, though their lobby organisations are not represented in the NEGEM assessment. The beneficiaries are mainly heavy carbon emitters more or less trying to reinvent themselves, refineries, chemical industry, and power industry. Another beneficiary is the Norwegian CCS industry, as much of the captured CO_2 is to be shipped to and stored in the Norwegian North Sea.

Kairos@C in the Port of Antwerp, Belgium plans to collect CO_2 from two hydrogen plants, two ammonia plants and an ethylene oxide plant. The CO_2 will then be sent by ship to Norway or possibly somewhere else in the North Sea.

The project dates back[90] to at least 2010. It just goes on and on.

The companies involved are BASF (German chemical giant), Air Liquide (French gas company that produces oxygen, nitrogen, argon, CO_2 and other gases), and a consortium of Antwerp@C that includes Borealis (Austrian plastics producer), ExxonMobil (oil and gas), INEOS (British chemical company, also in fracking), Fluxys (Belgian, fossil gas), the Port of Antwerp and Total (oil and gas).

---

[89] https://twitter.com/hashtag/BlueHydrogen?src=hashtag_click

[90] https://cordis.europa.eu/project/id/241381/reporting

The seven projects pre-selected and forwarded by the Innovation Fund funding are said to reduce CO_2 emissions by 14 million tonnes. As for the hydrogen and ammonia plants, CCS is a choice not to produce green hydrogen and green ammonia by electrolysis.

"It is better to focus on efficiency, innovation and electrification", commented Joeri Thijs, spokesperson for Greenpeace Belgium[91].

"Capturing carbon from fossil processes and dumping it underground, as BASF wants to do, is to shoot twice and miss both. Either you succeed and you have invested a lot of money, much of which is tax money, in continuing a fossil system. Or you fail, and the CO_2 still ends up in the atmosphere due to leaks in the system. We therefore ask for a different approach: directly reducing CO_2 emissions at the source", Thijs said.

TANGO is a project to develop next-generation solar cells. It will develop an industrial-scale pilot line for the manufacture of innovative and high-quality bifacial heterojunction (B-HJT) photovoltaic (PV) cells. It is led by Enel Green in Catania, Italy. Heterojunction means that the cell has two or more layers that capture the light more efficiently. HJT cells also degrade slower over their lifetime.

ECOPLANTA is a project for transforming municipal solid waste (household garbage) into methanol instead of sending it to landfill. The plant will process some 400,000 tonnes of non-recyclable municipal solid waste from nearby municipalities and will produce around 220,000 tonnes of methanol annually. This methanol will be used as a feedstock to produce renewable chemicals or advanced biofuels, cutting GHG emissions by some 200,000 tonnes each year and reducing waste that would otherwise end up in landfills, according to Enerkem, a small company in the waste business that is working on this project with Suez Recycling, Recovery Spain and oil giant Repsol.

The project does not involve CCS, but Enerkem claims to be in the business of "carbon recycling". This is conceptually closer to CCUS than it is to the waste hierarchy of reduce, reuse, recycle, where recycle is supposed to mean making paper from paper and plastic from plastic, rather than recycling carbon atoms. The plastics industry's preferred hierarchy is 1) landfill or burn 2) molecular recycling 3) recycle, reuse, reduce.

The K6 Program intends to produce cement with CCS in France. It is backed by Air Liquide (again) and the German cement lobby organisation VDZ, which aims to keep on using Portland cement as a construction material, rather than new materials or other cements.

HYBRIT in Sweden is a pioneering project to replace coal and coke with green hydrogen for reducing iron oxide ore to steel in north Sweden. The hydrogen is to be produced by wind power, which is rapidly being expanded.

BECCS@STHLM is also in Sweden, see article below.

The **SHARC** Sustainable Hydrogen and Recovery of Carbon project in Finland will replace fossil hydrogen at Neste's refinery with green and blue hydrogen. The exact mix of green and blue is not known, but the whole concept of blue hydrogen (fossil + CCS) is contested. Neste is an oil and gas company, majority-owned by the Finnish government and is linked to Fortum and Norwegian Equinor in several ways.

---

[91] https://www.nieuwsblad.be/cnt/dmf20211122_98527353

Name	Activity	Companies	Location	Nations	CO_2 avoided first 10 years	CCS
Kairos@C	Chemical industry, CO_2 hub,	Port of Antwerp,	Antwerp	Belgium, Netherlands, Norway	14.2	yes
TANGO	Solar cells	Enel	Catania	Italy	21	no
BECCS@STHLM	bioenergy CHP CCS	Stockholm Exergi	Stockholm	Sweden, Norway	7.8	yes
Ecoplanta	waste to methanol		Taragona	Spain	3.5	no
K6	cement		Dunkirk	France	8.1	yes
Hybrit	Hydrogen for steel, ore		Gällivare, Luleå	Sweden	14.3	no
Sharc	refinery Hydrogen		Porvoo	Finland	>4	yes and no

Second round much the same

In July 2022, the second round of Innovation Fund Preselected Large Scale Projects was published. There are 17 projects, with a budget of €1.5 billion[92]. A detailed analysis is still needed, but a first impression shows the same mixture of the good, the bad and the ugly as in the first seven projects.

Once again they include another big solar cell factory, green hydrogen, biofibres (to replace plastics), massive offshore wind turbines (30*15 megawatts) battery production and battery recycling. But there is also a lot of plastics recycling, biofuels and CCS, CCS, CCUS.

Some of the projects look pretty far-fetched, such as waste to hydrogen and methanol from cement. Such ideas may look great in a PowerPoint presentation for EIB bankers, but are they likely to work well, scale up and be replicated on a commercial scale?

Many of the companies involved are well known to the NGO community: Fortum, Shell, Neste, RWE, Holcim, Lafarge, Air Liquide etc. If you believe they are part of the green transition, fine. But some of us suspect that they are greenwashing what they already do: digging up fossils and processing them. There may even be *both* genuine transformation *and* greenwashing combined in the same project.

Four of the projects are in the cement industry and none of them aims at replacing Portland cement with alternatives that do not emit CO_2.

The third call for the Innovation fund will award even more money, €3 billion.

Case study: Stockholm BECCS

BECCS@STHLM is a CCS project for storing CO_2 from a biomass power and heat plant in Stockholm, Sweden and the top receiver of Innovation Fund money in the first round of projects. The CHP plant was built in 2016 for burning biomass. It now burns residues from the forest and forest industries – branches, tops, bark and sawdust – of

---

[92] https://ec.europa.eu/clima/eu-action/funding-climate-action/innovation-fund/large-scale-calls_en#overview-of-the-second-call-for-large-scale-project-proposals

which just under 60 percent comes from Swedish forests. It does however import substantial amounts (just below 30 percent) from the Baltics[93]. It has also used coal, especially in 2018, when supplies of wood fuel were disrupted.

Power CCS is a big bet. After 50 years of CCS (Val Verde/Terrell enhanced oil recovery with CO_2 started operation in Texas in 1972), and some 20 years of CCS as climate hype, there are only two big *power* plants that use CCS in the entire world. One of them is Boundary Dam in Canada. It burns coal, and some of the CO_2 is used for enhanced oil recovery. It has shown poor performance and high costs. The second is Petra Nova in Texas. It was suspended in 2020, after three years of operation, for similar reasons. There is no natural gas power station anywhere that uses CCS.

Capturing carbon from biomass power is no simpler than it is from coal or gas power, and transport by ship to Norway will cost a lot more than dumping the CO_2 in a nearby oil well.

There is also no large-scale *heat* plant using CCS anywhere in the world, and obviously no combined power and heat plant, which involves more complex construction (more tubing, valves and heat exchangers) than "just" a power plant. The reason why combined power plants are built at all is that it saves fuel. A power plant has an efficiency of 30–60 percent. A combined heat and power plant can have an efficiency of 90 percent. But this is only possible if there is a large and simultaneous demand for hot water, such as a district heating system or nearby industry. For most power plants, it is not an option to use the heat. A district heating system is expensive to build. Combined heat and power is only efficient under certain assumptions. And it comes at a cost. It is not very flexible, as people want their homes warm regardless of whether the price of power is high or low. The hot water is of little use for half the year, and if buildings are well insulated it may only be useful for a few months.

Combined heat and power also means a lot of heat but less electricity.

As for the BECCS@STHLM project, it will produce even less electricity with the same amount of wood input, according to an email to Acid News from Stockholm Exergi, though no specific data was supplied. The reason is obviously that electricity is used for capture and compression of the CO2, and some of the energy will reappear as low-temperature heat. This is betting on low electricity prices and high price for district heat, which looks very doubtful by August 2022.

When Stockholm Exergi applied for the project, 50 percent of Stockholm Exergi was owned by Stockholm City Council (as it still is), and the other half by Fortum. Fortum is a Finland-based power, heat and gas company. In 2020, Fortum acquired Uniper, with the personal blessing of president Vladimir Putin[94] . Uniper was essentially the dirty (fossil and nuclear) parts of German Eon, with the clean parts retaining the name Eon after a 2016 split. Fortum and Uniper have assets in Finland, the Baltics, Russia, Norway, Germany and Sweden, much of it fossil and nuclear. It is majority-owned by the government of Finland. Uniper is well known to the climate NGO community after it sued the

---

[93] Source: email from Stockholm Exergi to Acid News 2022-02-22

[94] https://www.reuters.com/article/us-uniper-m-a-fortum-russia-idUSKCN1TC1EX

Dutch government[95] in 2021 over the country's planned coal phase-out concerning its coal power plant Maasvlakte. It also claims to be Europe's second-largest nuclear power producer. And it is one of the top CO_2 emitters, at 48.8 million tons in 2020.

Fortum sold its share of Stockholm Exergi on 30 June 2021 (to finance its acquisition of Uniper), but the new owners (pension funds) are unlikely to change their general strategy or the strategic focus on CCS. Fortum Oslo has a similar ownership (half-owned by Oslo city) and applied to the Innovation fund for CCS from its mixed waste CHP plant; it did not qualify in the first call.

Stockholm Exergi supplies Stockholm and adjacent towns with district heat, cooling and some electricity. It ran the nation's only coal power (and heat) plant until 2020. They had to stop as the red-green government introduced a tax on fossil fuels for combined heat and power. The tax was implemented in spite of furious lobbying from Fortum/Stockholm Exergi and their allies. After they lost that battle, they immediately took credit for phasing out coal.

Stockholm Exergi now uses three sources of heat: mixed waste, biomass (mainly residues from the forest industry such as sawdust and chipped branches), and heat pumps.

The wood CHP plant was a step forward when it was conceived in the 2000s and commissioned in 2016. Bioenergy was accepted as a major alternative to fossils and nuclear power by the political parties and NGOs from 1980 until recently.

Sweden is a large country, largely covered with forests. It also has a strong forestry lobby, dominated by paper and pulp companies and forest owners.

Biomass is seen as CO_2-free in national climate targets and in the reports to the EU and UN. The rationale is that if the biomass is not used, it will emit its carbon contents into the atmosphere anyway, or that the carbon released when the biomass is burned equals the carbon sucked up by growing trees.

Whether this is really true for a whole forest, including the soil and undergrowth, over a perspective of a few decades (for example until 2045, the Swedish net-zero target year) is widely debated, and the results also depend on what the forest products are used for. Paper usually emits its carbon within a year. Planks in buildings may store the carbon for several decades.

The biomass "carbon neutrality" accounting principle had at least the advantage of being simple.

But Sweden used the Kyoto Protocol and its Land Use and Land Use Change (LULUCF) articles 3.3 and 3.4 to subtract 2.13 million tons per year because the forest carbon growth is larger than the carbon content of the felled trees, every year.

Sweden now intends to use BECCS as a principal means of attaining its (national) net-zero 2045 target, and the Stockholm Exergi project is likely to receive large sums of money from the Swedish government as well as from the EU.

---

[95] https://www.uniper.energy/news/uniper-seeks-judgement-for-the-future-of-maasvlakte

CO_2 from biomass is currently accounted for as zero in the emissions trading system, so at present Stockholm Exergi will not save any money by not emitting it. Assuming a price of €100/tonne on average, and 8 million tonnes of CO_2 stored the difference would be 800 million euro over the first ten years in their balance sheets. An investment decision to go ahead, which is said to be expected in 2023, is unlikely unless all decisions are settled.

Problems with BECCS

To justify funding the Stockholm Exergi project, the EU must believe that the technology will, or at least can be, replicated on a large scale. There are several questions over this.

FERN is an NGO "whose mission is to achieve greater environmental and social justice, focusing on forests and forest peoples' rights in the policies and practices of the European Union". It listed Six Problems with BECCS[96] in a Briefing Note 2018. They are summarised here:

1. BECCS may not deliver large-scale carbon dioxide removals

Biomass is not carbon neutral, because not all logging is sustainable. Emissions from the logged land, logging machinery, transport, and CO_2 capture and storage reduce the climate benefit.

2. BECCS has technical barriers and is expensive

In several climate scenarios, BECCS is supposed to be scaled up massively and very fast. This was unproven in 2018, and is still unproven in 2022. The cost was difficult to estimate in 2018. Since the Norwegian Longship project we at least have a benchmark, which is about €500 per ton, but that is closer to a storage site and uses a purer stream of CO_2 than most BECCS projects can be expected to produce.

3. BECCS would require a huge amount of land and push up the price of food

This may not be true for an individual BECCS plant such as in Stockholm, but there is an inevitable conflict of interest if BECCS goes from million-ton scale to billion-ton scale. (As for example in the International Energy Agency Net Zero scenario of 2021.)

4. BECCS would harm biodiversity

This problem also comes with the scale. "The areas considered to have good potential for dedicated bioenergy crops overlap with protected areas, especially in central Europe, the Mediterranean, the United States of America, Central America, South-East Asia and Central Africa", according to FERN.

5. BECCS would take a huge amount of water and threaten planetary boundaries

Some of the biomass, from bio-crops, will require a lot of water, which is already a scarce resource in many parts of the world (though not in Sweden). Carbon capture from thermal power plants also uses more water than power plants without CCS, as even more recent research[97] underscores.

---

[96] https://www.fern.org/fileadmin/uploads/fern/Documents/2021/Six_problems_with_BECCS.pdf

[97] https://chemistry.berkeley.edu/news/new-research-shows-hydrological-limits-carbon-capture-and-storage

6. BECCS is a barrier to energy transition

FERN sees BECCS as a way to blur distinctions between renewables and fossils, as does the switching of fuel from coal to biomass in power plants. "Bioenergy without CCS is already offering a life-line to coal, as many coal power plants are being converted to allow the co-firing of biomass and coal." Recent development points in the same direction. Fortum Oslo wants to keep burning mixed household waste: biomass and plastics, instead of applying the solar, wind and waste hierarchy. Stockholm Exergi has similar ambitions.

8. CCS in the real world: insignificant and not benefitting the climate

Analysis of CCS projects around the World in the last years:

Little new CCS in near future

Real world CCS operations are scarce. Most CCS is used either for Enhanced Oil Recovery or for natural gas processing. They are part of the fossil industry. That is not about to change in the near future.

In April 2022 there were five larger projects – each at least 0.4 Mtons captured per year – under construction according to the pro-CCS Australian think tank, the Global CCS Institute and its database CO_2RE.

Two of them are in Norway, involving the capture of 0.4 Mton/yr at a cement factory, plus a storage facility.[98]

Of the three non-Norwegian projects, one is the ZEROS project in Texas, about which there is little detail[99]. This is a "proposed" project (for operation in 2023), not yet under construction. A "diverse range of waste fuels" will be burned in two 120 MW boilers.

Sinopec Qili in China is a chemical plant, and will use the CO_2 for enhanced oil recovery. It will send 0.5 Mton of CO_2 per year into the ground, but the extra oil would emit roughly the same amount. It is said to be operational in 2021. However, it was still "under construction" in April 2022 according to CO2RE.

Guodian Taizhou, also in China, is a 4000 MW coal power station which at full utilisation emits some 20 Mtons per year. Of this, 0.5 Mton would be captured and mainly used for enhanced oil recovery. It is said to be operational "in the early 2020s".

Santos Cooper Moomba CCS in Australia is another gas processing plant, aiming to capture 1.7 Mton/year from 2023. It has been under consideration since at least 2006, but was announced at the Glasgow COP. It is eligible for carbon credits under a government scheme, and has also received a direct federal subsidy. It has been called a "scam"[100] by the Australia Institute as it may be used for enhanced oil recovery.

A Louisiana project for blue hydrogen is also listed in the CO2RE database as being under construction for "expected" operation in 2025–26, which is vague indeed, so it cannot really be considered as under construction.

At best, all projects now classified as under construction (excluding Louisiana) would store 4 Mtons per year. For comparison, global CO_2 emissions are about 31,500 Mtons/yr. The shift to renewables has reduced global CO_2 emissions by 1,348 Mtons between 2016 and 2020, and by 440 Mtons in 2020 alone, according to the IEA[101].

---

[98] As of August 2022, there are four Norwegian projects in CO2RE, though one is just storage and one is just shipping for the cement factory CCS. Hafslund waste incineration plant near Oslo has been added. It is in the design phase rather than in construction

[99] It is also invisible elsewhere on the internet as of August 2022.

[100] https://australiainstitute.org.au/report/santos-ccs-scam/

[101] https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020

Australia ex-PM: CCS a scam and a con

Australia is the top world coal exporter and has long been very supportive of CCS, having spent several billion dollars on the technology and on propaganda for it.

Not all of its politicians agree.

"Now this is a scam and a con. CCS is a proven failure," said Malcolm Turnbull, prime minister of the right-centre Liberal government between 2015 and 2018, according to the Canberra Times.

Turnbull was talking specifically about "blue hydrogen", which is made from fossil fuels with the CO_2 captured and stored, but also about CCS in general.

Renewable power avoids 229 times more carbon than CCS

Most CCS projects use the CO_2 for enhanced oil recovery, which makes it uncertain if the net result is less or more CO_2 into the atmosphere.

In early 2022, there were only five major projects where the CO_2 does not enhance oil but goes into dedicated geological storage.

Of those, three are from natural gas processing: the Norwegian Sleipner (the eight-legged horse of the pagan god Odin), Norwegian Snøhvit (Snow White), and Gorgon in Australia.

One is a US ethanol plant, Illinois Industrial Carbon Capture and Storage. And finally, there is Shell's Quest in Canada, which produces hydrogen from, and as part of, its oil sand (or tar sand) operations.

The five projects together capture, at most, 8 million tonnes of CO_2 per year.

Renewable electricity can avoid about 1.8 billion tonnes of CO_2eq, or more than 200 times more than CCS.

Renewables, which consist primarily and increasingly of wind and solar power, produced 3,657 TWh in 2021 globally, according to BP statistics. That does not include hydro or solar hot water.

Assuming that renewables displace a mix of mainly coal and gas power and a small share of nuclear, about 0.5 Mton is avoided for every TWh of renewables. (Old coal power stations often emit more than 1 Mton per TWh.) This would amount to avoided emissions of 1,829 Mton CO_2eq.

CCS excluding enhanced oil recovery could not have produced more than 8 Mtons, as that figure represents full use of capacity, and no capacity was added during 2021. A recent study by Zhang et al.[102] demonstrated that the "full capacity" assumption is an overestimate of 19–30 percent, so avoided emissions (gross, not net of indirect emissions) should be 6–7 Mton.

CCS Australia: Oil & gas industry asks for more

The Australian Petroleum Production and Exploration Association (APPEA) – a leading lobby group for the oil and gas industry – has called for more government support to be provided to carbon capture and storage projects from the Morrison government.

---

[102] https://pubs.acs.org/doi/10.1021/acs.estlett.2c00296

Their one project so far is the Gorgon LNG CCS, which came far too late and captured far too little CO_2 to meet the conditions for government approval back in 2009. Chevron and its partners have agreed to buy carbon credits likely to cost more than 180 million USD as a penalty for failing to meet a five-year target for carbon capture and storage, according to Reuters. This is on top of the 2.3 billion USD investment in the CCS plant. Reuters also said that by November 2020 Gorgon had captured 5.5 million tonnes, which indicates that it operated at about half capacity during the first two years and a few months.

Though CCS is hardly a success story so far, the APPEA wants more of it and more taxpayer money, this time for "blue hydrogen", i.e. hydrogen produced from natural gas with CCS.

Other Australian companies are betting on green hydrogen, electrolysis of water from wind and solar electricity. The plans are huge, with a project pipeline of 69 GW of electrolyser capacity (equivalent to 69 nuclear power reactors), according to Rystad Energy. This is ahead of Europe, where green hydrogen projects are also popping up at bewildering speed. It is too early to tell how many of the plans will eventually materialise.

Australia is heading for a war between Blue and Green hydrogen, of global significance. The Blues fired the first shot in January 2022 with a project for hydrogen from brown coal to be exported on a liquid hydrogen ship to Japan. The project is being led by a Japanese-Australian consortium including Japan's J-Power, Kawasaki Heavy Industries, Shell and AGL.

A "world-first that would make Australia a global leader", commented Prime Minister Scott Morrison.

But as Tim Baxter, a senior researcher for climate solutions at the Climate Council told the Guardian: "Hydrogen derived from fossil fuel sources, like what is being shipped out of the LaTrobe Valley, which is derived from some of the world's dirtiest coal, is really just a new fossil fuel industry."

poison

400 Canadian scientists protest against CCS support

"We urge you to not introduce the proposed investment tax credit for CCUS because it will constitute a substantial new fossil fuel subsidy. As well as undermining government efforts to reach net-zero by 2050, the introduction of this tax credit would contradict the promise made by your government to Canadians during the election period to eliminate fossil fuel subsidies by 2023 as well as our international commitments under the Paris Agreement."

This is the beginning of a letter signed by more than 400 climate scientists and other members of academia to Chrystia Freeland, Deputy Prime Minister and Minister of Finance in Canada, sent in January 2022. Freeland is a member of Justin Trudeau's government, and of the same Liberal Party.

The group of academics includes two IPCC lead authors and are from diverse fields, including physics, chemistry, engineering, economy, and philosophy, and more.

"Despite the billions of taxpayer dollars spent by governments globally on CCUS, the technology has not made a dent in CO_2 emissions," they write.

Canada has long supported CCS, with several past and future projects, mainly for enhanced oil recovery. Policy favouring CCS, as well as nuclear, is also supported by the right-wing Progressive Conservative Party, the biggest opposition party.

Canada claimed to be a climate leader at the COP in Glasgow.

This is not reflected in the data. Canada had only 4 TWh of solar and 36 TWh of wind in 2020. Its greenhouse gas emissions increased from 602 Mtons to 730 Mtons between 1990 and 2019 according to the UNFCC data. Its coal production has decreased, but gas has increased some 70 percent and oil production almost trebled since 1990, much of it from tar sands.

Boundary Dam CCS far below capacity

Boundary Dam #3, the world's only coal power CCS project since PetraNova in Texas was shut down indefinitely, has not lived up to expectations.

"The carbon capture facility at Boundary Dam was designed to capture 3,200 metric tons of CO_2 daily, or slightly more than 1 million metric tons annually. It has barely achieved that goal on any single day and has never done so over any extended period," according to David Schliessel at the Institute for Energy Economics and Financial Analysis. His analysis covers the period up to Q1 2021.

During the rest of 2021 performance has been even worse, according to SaskPower, which operates Boundary Dam. To judge from its charts, it captured less than half of its designed capacity of one million tonnes a year.

The company's website asks the question "Why Carbon capture and storage on coal?" and answers:

"By capturing and safely storing CO_2 emissions before they reach the atmosphere, we can help ensure a brighter future for both our province and the world."

This defence of coal (in this case brown coal) is not up to date, as the Canadian government has promised to phase out coal power by 2030 and has gone a long way towards doing so. It produced more than 100 TWh in 2005 and no more than 36 TWh in 2020.

SaskPower has decided not to retrofit the sister plants Boundary 4 and 5 with CCS, as there was "simply no business case" to do so. It has already shuttered one and will shutter the other by 2024.

SaskPower is not transparent on where the captured CO_2 ends up. Some of it goes to enhanced oil recovery and some is supposed to go into geological storage, but it gives no data on how much goes to which, nor how much actually goes straight up into the air.

The economics of the project were criticised early on and Canada's parliamentary budget office concluded that it would double the cost of electricity. That was in 2016 when the poor performance was not yet known.

Enel CEO does not believe in CCS

Francesco Starace, CEO of the giant Italian power company Enel, sees CCS as a lost cause.

The company brought forward its net zero emissions pledge by 10 years to 2040 in November 2021, but it is not betting on carbon capture as a way of achieving it.

"We have tried and tried – and when I say 'we' I mean the electricity industry," Starace said to the business TV channel CNBC.

"The fact is that it [CCS] doesn't work, it hasn't worked for us so far. And there is a rule of thumb here: If a technology doesn't really pick up in five years – and here we're talking about more than five, we're talking about 15, at least – you better drop it."

Enel is a heavyweight in European power and in global green power, and Starace was president of the European power lobby Eurelectric from 2017 to 2019.

Enel is the biggest power company in the world, by revenue, according to Power Technology, ahead of Electricité de France (though it produces less electricity). It operates plants of all kinds from Russia to Chile, and claims a strong focus on renewables, from which it got just above 50 percent of its generation in 2020. Its GHG emissions per kWh were 214 grams per kWh in 2020, slightly less than the EU average of 230 grams. Enel has set a target to cut this to 148 g per kWh in 2023 and below 82 g per kWh by 2030 in its 2020 sustainability report. It plans to phase out all coal power by 2027.

CCS Institute: Less CCS in operation in 2021 than 2020

The CCS Institute, a think tank, or PR organisation, for the CCS Industry in Australia publishes an annual report, Global Status of CCS, on developments in the field.

Not much has happened, it appears.

Since the start of Gorgon LNG CCS in Australia in 2019, four years late, there has been no further new CCS capacity in the world up to September 2021. The capacity declined somewhat in 2020 and stayed there during 2021 to judge from a diagram of worldwide capture capacity, at about 37 Mton/year.

The drop during 2020 can be attributed to the coal power retrofitted CCS plant Petra Nova in Texas, with a capacity of 1.4 Mtons per year. It was suspended in 2020.

Most of the 37 million tonnes are for enhanced oil recovery. Capture *capacity* does not mean that 37 Mtons were actually captured.

If any other major CCS project was brought into operation, it is not included in the CCS Institute's database. The database does however contain a long list of "completed" projects and a few examples of "operation suspended", one of which is Petra Nova. (See AN2/21.)

The Global Status report 2021 did not have much news, but it did carry a two-page endorsement of CCS by HRH Prince Charles. The message conveyed is that "The sooner we include carbon capture use and storage technologies into the fold of wide-spread decarbonisation initiatives, the more likely we will be able to achieve Paris agreement climate targets and get to net zero emissions".

Poking fun at CCS

A rather rude but fairly well researched, and seriously funny video about CCS, especially in Australia can be watched here:

https://www.youtube.com/watch?v=MSZgoFyuHC8

Midwest Carbon Express – huge CCS pipeline project

A 2000-mile Midwest Carbon Express project intends to coalesce the carbon dioxide emissions from 31 ethanol plants in five states and ship it to North Dakota[103]. The project, announced last summer, with additional detail in January 2022, is led by agribusiness leader Bruce Rastetter, who is a well-known donor to the Republican Party, and his companies Summit Agricultural Group and Summit Carbon.

One corner of the proposed grid goes to Decatur, Illinois where agri-giant ADM now has an ethanol plant with CCS. It is the only significant bioenergy CCS (BECSS) plant in the world, and one of only five major CSS plants in the world that is not used for enhanced oil recovery. Its permit only runs until 2022 and for a maximum of 5.5 Mtons stored, so its future is far from secure.

The Summit Carbon pipeline network would capture and transport up to 12 Mtons of CO_2 per year, which would make it the biggest CCS project in the world, by far.

The environmental movement and other groups of farmers, indigenous people, scientists etc.,[104] are against the project for various reasons. The Sierra Club in Iowa, which is at the centre of the project, has stated that

“CCS is a false solution in this instance because:

It does not address other emissions or forms of pollution from fossil fuel extraction and industrial agriculture

It will allow for the extension of fossil fuel extraction through enhanced oil recovery

Fails to acknowledge CO_2 is incredibly dangerous and a pipeline leak or break could poison surrounding communities and first responders.”

The Sierra Club Iowa claims to have found strong indications that the CO_2 will be used for enhanced oil recovery.

Even if it is actually heading for dedicated geological storage, it is not a big net sink for CO_2. Ethanol from corn without CCS is only 46 percent less carbon intensive than gasoline, according to a recent study from Harvard and Tufts quoted by agribusiness sources. Whether that would be better or worse after a proposed CCS scheme depends on a number of assumptions about the fate of the captured CO_2, sources of energy for heat and electricity and agricultural practices.

---

[103] https://www.thedickinsonpress.com/business/massive-midwest-pipeline-a-test-for-north-dakotas-carbon-capture-goals-hits-landowner-snags

[104] https://grist.org/protest/across-the-midwest-an-unlikely-alliance-forms-to-stop-carbon-pipelines/

9. CDR is not working

European Commission public consultation
Critical remarks on "Certification of carbon removals – EU rules"

The EU Commission sent out a questionnaire in April 2022 about Carbon Dioxide Removal (CDR) certification[105], which it intends to adopt in the fourth quarter of 2022. This questionnaire framed the issue and the questions in a way that could only result in the answers the Commission, i.e. this specific corner of the Commission, wants.

This clearly demonstrates that the governance system is not fit for purpose. It is not open in the democratic sense. It is not open in the scientific sense.

"The European Climate Law requires greenhouse gas (GHG) emissions and removals to be balanced within the European Union at the latest by 2050, with the aim of achieving negative emissions thereafter. Each single tonne of CO_2eq emitted into the atmosphere will have to be neutralised by a tonne of CO_2 removed from the atmosphere."

The other possibility, to cut emissions as much as is needed, without any overhang to address after 2050, is mentioned nowhere.

"The establishment of the certification framework will be an essential stepping stone towards the transparent recognition of activities that remove carbon from the atmosphere in an environmentally sound manner," the Commission states. It presupposes that this is possible, and as if double-counting, non-permanence and the moral hazard (of less mitigation) are simple legal problems that must be solved, and if they must be solved they will be solved.

The Commission engages in voodoo thinking when it comes to technical removal options. As for Direct Air Capture, there is no evidence that it will work on a very large scale. It should go without saying that it will cost a lot less to cut fossil emissions in the first place than to first emit and then try to collect the CO_2 from the air.

In its responses, CAN Europe has taken a clear stand against integrating CDR with emission trading.

"Removals need to be addressed under a separate target and scaled up via separate policy instruments. No offsets must be allowed."

CAN Europe has also expressed deep concerns about large scale Bio-CCS: "BECCS should be avoided."

The Commission, however, presents a full smorgasbord of options for CDR (my comments in italics), of which the respondents are to choose whether they should be put to use by 2030, 2050 or never.

- Biochar *(unlikely on required scale; economic, ecological and human costs may be overwhelming)*
- Direct air capture with long-term or permanent carbon storage *(speculative, impossible on required scale)*

---

[105] documentation at https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13172-Certification-of-carbon-removals-EU-rules/public-consultation_en

- Bioenergy with carbon capture and long-term or permanent storage *(speculative on relevant scale, at a large environmental and human cost)*
- Geological storage of non-fossil CO_2 (*completely irrelevant*)
- Bio-based products with long lifetime (*including for construction*) (*is the scale relevant and for how many decades, on average for products such as an Ikea kitchen chair and a wood facade?)*
- Utilisation of non-fossil CO_2 in long lifetime products (*speculative and unlikely, other than wood, see above*)
- Enhanced rock weathering (*speculative, unproved for required scale*)
- Other

What these options have in common is that they do not capture carbon, or do not exist or will not exist on a meaningful scale.

This is not a consultation. The Commission is herding the sheep (respondents) where it wants them.

As for Direct Air Capture, CAN Europe checked "no opinion". There is good reason to instead respond "never". It is obviously much more expensive to scavenge CO_2 molecules from the air than to avoid emitting them in the first place, for example by using less fossil power or by converting a blast furnace from coal/coke to hydrogen direct reduction sooner rather than later. The energy (especially electricity) needed for DACCS could be better used to replace fossil power now, rather than for picking up the pieces sometime later. There is no evidence that DACCS can ever be an economic option.

The other big part of CDR is of course Bio-CCS. CCS has not been demonstrated at scale for anything other than a few projects for natural gas processing and enhanced oil recovery. Despite strong political support in many countries over many years, as well as large subsidies from taxpayers and substantial private effort, CCS has gotten nowhere. Bio-CCS is even more demanding, economically, than fossil CCS. It is an irresponsible idea to keep emitting CO_2 and hope to later recapture it through afforestation and BECCS.

The economics of BECCS is different from DACCS: afforestation and other natural sinks are often very cheap. The limits to how much it could be used is not the marginal cost, but how much land is available. Land use cannot be optimised just for carbon, as this would be devastating for food production, biodiversity and other important societal but less quantifiable values. If economic incentives, such as €100/ton CO_2 were to be introduced, the consequences would be unpredictable.

More forests and restored wetlands are good for the climate and for many other reasons, but natural sinks can only remedy and compensate for the previous harm we have done to natural ecosystems. We cannot plant trees simply to keep coal power plants operating for another few years.

It is the scale of BECCS foreseen by the IPCC and other integrated assessment models that inflates the land use conflict.

10: CCS and Geoengineering positions of Climate Action Network International

https://climatenetwork.org/resource/can-position-carbon-capture-storage-and-utilisation/

https://climatenetwork.org/wp-content/uploads/2019/09/CAN-SRM-position.pdf

Climate Action Network

Position: Carbon Capture, Storage and Utilisation

January 2021

Climate Action Network (CAN) is the world's largest network of civil society organizations working together to promote government action to address the climate crisis, with more than 1300 members in over 120 countries.
www.climatenetwork.org

Introduction[1]

Climate change is one of the biggest challenges facing humankind in this century. The Paris Agreement seeks to respond to the climate crisis by providing a collective framework for nationally determined actions with the goal of limiting global average temperature increase to 1.5°C above pre-industrial levels. The aim is to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century. In practice, achieving this goal means greenhouse gas emissions must decrease to as close to zero as possible by mid-century at the latest.

CAN's vision for a safe climate centers on rapid and deep economy-wide decarbonisation of all countries and a transition to a just, equitable, and sustainable future. A range of solutions and climate mitigation tools can help achieve this vision, including, renewable energy, energy efficiency, forest conservation, ecosystem restoration, sustainable reforestation, and reduced meat consumption as well as shifting to sustainable consumption patterns by the global rich and middle classes. CAN urges a global Just Transition to 100% renewable energy, supported by ambitious energy conservation and efficiency measures by mid-century at the latest, conducted earlier by richer countries and essential to meet the Paris Agreement goal.

Carbon Capture and Storage (CCS) is a technology promoted by some as essential to limiting global average temperature increase to 1.5°C. Many climate models produce scenarios, including CCS in the power and industrial sectors, bioenergy with CCS (BECCS), direct air capture with CCS (DACCS), and carbon capture and utilisation (CCU), to either limit warming and/or account for overshooting of the 1.5°C target through the removal of carbon dioxide emissions from the atmosphere. Other scenarios model ways to limit warming without overreliance on or any CCS.

---

[1] Environmental Defense Fund (EDF) does not support all aspects of this document. EDF believes we cannot afford to a priori reject the CCS potential.

The Integrated Assessment Model scenarios with low or no CCS deployment require considerable increases in energy efficiency and near-term rapid fall in energy demand to meet commitments under the Paris Agreement.[2] Climate models show that if the current pace in global energy demand growth and emission reductions continue, the pathway to limit warming at 1.5ºC without CCS will be out of reach within some years. The path we take is a societal choice, with significant implications for intergenerational equity, social and economic justice, land use rights, access to energy, sustainable development, and our ultimate effectiveness in decarbonising our economies.

As detailed in this paper, CAN prioritizes ambitious climate mitigation to meet targets under the Paris Agreement. CAN is concerned that CCS risks distracting from the need to take concerted action across multiple sectors in the near-term to dramatically reduce emissions. Overall, to meet the 1.5ºC limit, richer parts of society must consume less, and all must consume efficiently, and sustainably. This will provide space for the globally poorer parts of society to ensure their legitimate space ensuring social and economic well-being for all.

Carbon Capture and Storage (CCS) types and deployment

CCS encompasses a range of carbon capture, storage applications. This paper focuses on the following: CCS in the power and industrial sectors, BECCS, DACCS. Additionally, this section considers related issues concerning Enhanced oil and gas recovery [EOR/EGR] and carbon capture and utilization (CCU).

Fossil Fuel/Industrial CCS

Whilst in different stages of development, as further discussed in Appendix 1, many CCS applications are still largely unproven at scale. Despite billions in public support over the past decade,[3] there are 51 large-scale CCS projects across the globe, of which 19 are operating and most are pilot-scale projects that demonstrate only a part of CCS (e.g., capture but not storage).[4] These figures include operational carbon capture projects in the power and industrial sectors but do not include BECCS or DACCS facilities in operation, which are briefly discussed below.

Collectively, currently operational CCS projects (excluding EOR operations) are injecting and storing less than 5 million tonnes of CO_2 ($MtCO_2$) per year.[5] The International Energy Agency (IEA), which counts only two large-scale CCS projects operating in the power sector with a combined capture capacity of 2.4 million tonnes of CO_2 per year, [6] notes the technology remains well off track to reach the 760 $MtCO_2$ by 2030 and about 2.8 Gt CO2 by 2050 storage rate outlined in IEA's own Sustainable Development Scenario.[7]

BECCS

---

[2] Grubler, A., Wilson, C., Bento, N. *et al.* A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. *Nat Energy* **3,** 515–527 (2018). https://doi.org/10.1038/s41560-018-0172-6

[3] *See* Appendix 2.

[4] Global CCS Institute (2019). Facilities Database, available at: https://co2re.co/FacilityData (accessed 19 September 2019).

[5] Calculation based on figures provided on by Global CCS Institute (2019). Facilities Database, available at: https://co2re.co/FacilityData (accessed 19 September 2019).

[6] Boundary Dam and Patra Nova, located in Canada and the US, respectively. Both projects involve EOR.

[7] IEA's Sustainable Development Scenario holds temperature rise to below 1.8 °C with a 66% probability without reliance on global net-negative CO_2 emissions; this is equivalent to limiting the temperature rise to 1.65 °C with a 50% probability. Global CO_2 emissions fall from 33 billion tonnes in 2018 to less than 10 billion tonnes by 2050 and are on track to net zero emissions by 2070. *See* International Energy Agency (2020a). CCUS in power, available at: https://www.iea.org/reports/tracking-power-2019/ccus-in-power#abstract (accessed 1 February 2020); *see also* International Energy Agency (2020b). World Energy Model, available at: https://www.iea.org/reports/world-energy-model/sustainable-development-scenario (accessed 1 February 2020).

BECCS still remains in the very early stages of development and has yet to be demonstrated at a commercial scale: Globally, there is one large scale BECCS facility currently capturing and storing 1MtCO_2 p.a., and four small scale plants (all combined with EOR) in operation – all ethanol plants. A single pilot project in the UK has been demonstrating capturing of about a ton of CO_2 (but not storing) per day from 100% biomass feedstock combustion, starting in 2019 at the Drax Power Station.[8]

DACCS

Very few DACCS projects are operating globally at any scale although several companies are working to commercialise the technology.[9]

CCU

CCU covers a range of technologies at differing levels of maturity, cost, and market size, with many applications still in the research and development (R&D) phase.[10]

Technological maturity aside, CCS applications face myriad deployment barriers and raise a number of environmental, economic, and social concerns. As summarised in Appendix 1, the CCS applications discussed in this paper are currently expensive to deploy, may not result in substantially lower or negative emissions, and/or raise significant sustainability and environmental justice concerns in light of their potential energy, water, land use, and other resource demands. CAN therefore remains unconvinced of the many aspects and value of CCS applications and their value as climate mitigation tools.

Conclusions on CCS

Based on current global trends and an analysis of existing literature and reports, as discussed in Appendix 1, CAN concludes about CCS and its potential to serve as a climate mitigation tool as follow:

1. **CCS at scale remains largely unproven and its potential to deliver significant emission reductions by mid-century is currently limited.** Current evidence supporting CCS as an effective and scalable climate mitigation tool is largely theoretical, and still under debate. Furthermore, for CCS to play a significant role in achieving the Paris Agreement goal, gigatonnes (Gt) of CO_2 would need to be captured and permanently stored. This would require the financing and construction of CO_2 transport infrastructure roughly equivalent in scale to today's oil and gas pipeline and marine transport networks. The political, social, economic, and technical barriers to achieving this cannot be understated. Equity, cost-effectiveness, and abatement potential are all important factors in determining whether CCS should be considered a technology solution.
2. **Safe, permanent, and verifiable storage of CO_2 is difficult to guarantee.**[11] Well-selected, fully characterised, properly designed, and appropriately managed CO_2 storage sites are likely to have

---

[8] Drax Group plc (2019). Carbon dioxide now being captured in first of its kind BECCS pilot. Press Release issued 7 February 2019. Available at: https://www.drax.com/press_release/world-first-co2-beccs-ccus/.

[9] Fasihi, M., et al (2019). Techno-economic assessment of CO2 direct air capture plants. Journal of Cleaner Production, Vol. 224: 957-980. 1 July 2019. Available at: https://doi.org/10.1016/j.jclepro.2019.03.086

[10] IOGP (2019). The potential for CCS and CCU in Europe. Report to the 32nd meeting of the European Gas Regulatory Forum 5-6 June 2019. Available at: https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf.

[11] *See* Appendix 1.

a low risk of leakage.[12] Such storage sites, however, are expected to be a limited resource and will not be evenly distributed across the globe.[13] It is therefore likely that some CO_2 storage will occur in lower quality sites, and it is reasonable to assume not all sites will be properly managed, thereby increasing leakage risk.[14] At the same time, it is very difficult to detect CO_2 leaks, which can occur in different timescales.[15] The implications for climate mitigation as well as other environmental and public health risks makes governance and the risk of leakage, even at very low rates, a serious concern.

3. **The climate impact of CCS should consider all emissions and costs from concomitant processes**. The costs and emission of greenhouse gases and some pollutants from processes associated with CCS need to be carefully factored in. Power plants and industries intended to sequester CO_2 will use additional energy to compress, transport to suitable reservoir and pump into the ground the captured CO_2. Studies calculate that 15-25% more energy would be required, depending on particular CCS technology used.[16]
4. **CCS is not needed in the power sector.** Faster, cleaner, safer, more efficient, and cheaper means exist to reduce CO_2 emissions, such as phasing out fossil fuels and replacing them with renewable energy, energy efficiency, and energy conservation.
5. **EOR/EGR is dangerously at odds with any climate action,[17]** and will not lower emissions in comparison to renewable energy and energy efficiency. To meet the Paris Agreement target, the majority of fossil fuel reserves must be left in the ground.
6. **A suite of strategies and technologies already exist to cut emissions in the industrial sector, without CCS .[18]** Emissions in the industrial sector can be significantly reduced by increasing process efficiency, but there is a need also to increase the speed of development and/or deployment of low or zero carbon processes and materials, replacing fossil fuels with renewable energy, increasing recycling rates, and designing alternative materials with lower emission footprints than steel, conventional cements, plastics and aluminum. CAN strongly supports further and internationally coordinated research, development and deployment into CO_2-free processes and alternative materials with the objective that these can ensure that energy-intensive industries eliminate all emissions by mid-century at the latest.

---

[12] Anderson, S. (2017). Risk, Liability, and Economic Issues with Long-Term CO2 Storage—A Review. Natural Resources Research 26, 2017, pp. 89-112. https://doi.org/10.1007/s11053-016-9303-6; In such reservoirs, the IPCC noted in 2005 that the fraction of CO_2 retained in such geological reservoirs is "very likely [above 90% certainty] to exceed 99% over 100 years and is likely [above 60% certainty] to exceed 99% over 1000 years." IPCC (2005). IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[13] Center for International Environmental Law (2019). Fuel to the Fire: How geoengineering threatens to entrench fossil fuels and accelerate the climate crisis. February 2019. Available at: https://www.ciel.org/reports/fuel-to-the-fire-how-geoengineering-threatens-to-entrench-fossil-fuels-and-accelerate-the-climate-crisis-feb-2019/.

[14] *See* Appendix 2, which discusses how mismanagement of the In Salah CO_2 storage project in Algeria led to fracturing of a storage formation's caprock.

[15] Hvidevold, H.K., Alendal, G., Johannessen, T., Ali, A., Mannseth, T., Avlesen, H. (2015). Layout of CCS monitoring infrastructure with highest probability of detecting a footprint of a CO_2 leak in varying marine environment. International Journal of Greenhouse Gas Control Vol. 3, June 2015, pp. 274-279. https://doi.org/10.1016/j.ijggc.2015.03.013.

[16] European Environment Agency, "Carbon capture and storage could also impact air pollution", last modified 10 December 2019, see: https://www.eea.europa.eu/highlights/carbon-capture-and-storage-could

[17] *See* Appendix 1.

[18] *See* Appendix 1.

7. **Large-scale deployment of BECCS would result in unacceptable negative impacts on food security, land use rights, and biodiversity given its land use, water, and resource requirements.**[19] CAN also concludes there is no definitive evidence that large scale BECCS will deliver on its negative emissions promise. It should also be emphasized that CAN has already agreed to focus the need for negative emissions primarily, and as much as possible, on increased carbon sequestration in the biosphere, including primarily the protection and restoration of forests and other carbon- and biodiverse rich natural ecosystems, and sustainable agricultural practices. Whilst bioenergy is already playing a role in the energy transition in some countries, its use must be strictly limited and regulated to avoid social and environmental harm. Displacement of communities due to land grabs for massive cultivation of bioenergy crops is a key concern for many developing countries. There are also serious concerns on permanence and food security around afforestation in many countries, as well as on the overall net benefits of carbon sequestration when converting unutilized grasslands/savannahs and other lands for energy crops.
8. **DACCS is in its infancy and is very costly and energy intensive, with serious doubts about its effectiveness.** DACCS poses significant challenges for energy use and there is currently insufficient evidence that it provides a feasible climate mitigation solution. Recent research revealed that for DAC removal in the US of about 850 Mt CO_2, (2% of global energy-related CO_2 emissions annually), the equivalent of almost all global present wind power would be needed,[20] or about 1000 TWh electricity representing *4% of all global electricity produced.* That approximates about 550 Mt CO_2 in the global electricity mix.[21]Using present global power mix, DACCS would require about two third of a ton of CO_2 emissions to sequester one ton of CO2. Or if using only renewables, it would significantly undermine renewable-based power sector decarbonization. Therefore, the potential larger expansion of DACCS in the near term runs counter to CAN`s climate vision and would significantly delay efforts to achieve and maintain a 100% renewable energy system. DACCS is also not immune to the same CO_2 storage problems and concerns as other CCS applications. Any future consideration of DACCS as a potential means to reduce CO_2 emissions must address energy requirement concerns and alignment with the UN's Sustainable Development Goals.
9. **Long-term CO_2 storage creates financial, liability, and climate risks that are highly likely to be transferred from the private sector to the public sector.** Liability questions for CO_2 storage have yet to be answered in many places, and most countries lack a governance structure to maintain and ensure the long-term fiscal integrity of CO_2 storage sites. Some proponents of CCS have sought to relieve private sector parties engaged in CCS of financial and legal liability by transferring risk to governments and/or incorporating liability limits into law. Even with strong financial security mechanisms in place, there is a risk that governments will ultimately be responsible for the long-term monitoring, management, and remediation of CO_2 storage sites.
10. **Continued pursuit of CCS, for example in the power sector, risks diverting attention and resources from proven, cost effective solutions.**[22] CCS is expensive, resources are limited, and

---

[19] *See* Appendix 1.

[20] Larsen, J et al., Rhodium Group (2019). "Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology", p. 45. Available at: https://rhg.com/research/capturing-leadership-policies-for-the-us-to-advance-direct-air-capture-technology/

[21] International Energy Agency *(2019). World Energy Outlook 2019*, p. 680.

[22] *See, e.g.,* Center for International Environmental Law (2019). Fuel to the Fire: How geoengineering threatens to entrench fossil fuels and accelerate the climate crisis. February 2019. Available at: https://www.ciel.org/reports/fuel-to-the-fire-how-geoengineering-threatens-to-entrench-fossil-fuels-and-accelerate-the-climate-crisis-feb-2019/; *see also* Ash, K. (2015). Carbon

time is of the essence. There is a risk that public and private monies spent supporting CCS may decrease funding available for solutions that can deliver safe and permanent emission reductions. This means the fossil fuel industry may adopt CCS as a strategy to maintain business as usual or expand operations, and potentially access climate subsidies.

11. **CCS raises significant intergenerational equity concerns as well as environmental and social justice concerns.** CCS deployment would result in resource allocation decisions likely to undermine efforts to secure a just, equitable, and sustainable future. CCS also passes the responsibility for today's climate pollution onto future generations by requiring them to maintain and ensure the long-term integrity of CO_2 storage sites.

Climate Action Network position statement

CAN fully endorses a transition to 100% renewable energy for all energy use by mid-century at the latest[23] and adopts the following positions:

1. CAN strongly supports the Paris Agreement's goal to limit global average temperature rise to 1.5ºC above pre-industrial levels, and believes that all sustainable solutions and strategies need to be implemented to achieve this goal. **CAN does not consider currently envisioned CCS applications as proven sustainable climate solutions.** It is therefore imperative that actions to reduce emissions are maximised.
2. **CAN calls upon all governments to phase out all fossil fuel production and use, and phase in 100% renewable energy, as quickly as possible but no later than mid-century.** Achieving the 1.5ºC goal requires transformational change based on a managed phase-out of fossil fuel production, increased deployment of renewable energy, dramatic reductions in energy consumption, and greater efficiency along with substantial changes in production and consumption patterns at a much faster rate than what particularly governments of richer countries have pursued or committed to thus far.
3. **All government subsidies, loans, grants, tax credit, incentives, and financial support for fossil fuels and technologies that use or otherwise support the continued used of fossil fuels, including CCS, should be phased out as soon as possible**. CAN opposes government support to the fossil fuel industry. CAN affirms that renewable energy, energy efficiency, smart grid technologies, and electricity storage provide the best value route to reducing emissions from electricity generation. Governments should rule out new fossil fuel investments, in line with a just transition and consistent with carbon budgets identified by the IPCC, to not exceed 1.5°C average global warming by the end of this century.
4. CAN believes and reiterates that radical action needs to be taken to reduce greenhouse gas emissions as quickly as possible. In terms of negative emissions approaches, absolute priority should be given to increasing the capacity of natural carbon sequestration through the protection and restoration of forests and other natural ecosystems that maximise the co-benefits to people

---

Capture Scam: How a False Climate Solution Bolsters Big Oil. Greenpeace USA. July 2015. Available at: https://www.greenpeace.org/usa/research/carbon-capture-scam/.

[23] http://climatenetwork.org/sites/default/files/can_position_energy_ambition_in_ndcs_june2019.pdf

and biodiversity. **CAN cannot and will not support any effort to promote negative emissions or offsets as an alternative to stringent emission reductions**.

5. **CAN does not recognise BECCS as a proven large-scale mitigation option that delivers negative emissions, and does not support its deployment at any scale if it results in food insecurity, resource and land use conflicts, and detrimental biodiversity impacts.** Respect of human rights, which underpins the Paris Agreement, must not be compromised through the use of BECCS or any other climate mitigation tool.

6. **CAN supports proven sustainable strategies to address carbon emissions in the industrial sector**.[24] CAN sees no definitive evidence that CCS is the fastest, cheapest, cleanest and most durable way to decarbonise the industrial sectors, including the cement, iron ore-based steel and other metals, and chemical industries. For some of these industries, alternative technologies and solutions already exist and should be rapidly deployed. The promise of CCS must not delay necessary action in the present. Governments should start and expand R&D programs for these industries to have the solutions needed to adapt.

7. EOR/EGR combined with CCS utilises captured CO_2 to improve and enhance the exploitation of oil and gas fields. Such activities do not lower overall CO_2 emissions and contradict the need to keep the majority of remaining fossil fuel reserves in the ground. **CAN opposes such an practice.**

8. **CAN does not believe DACCS will be able to contribute to significant emission reductions in the coming years**, thus it has no place in decarbonisation scenarios focusing on early and steep CO2 emissions reductions.

9. While certain CCU applications theoretically have the potential to mitigate climate emissions at scale (e.g., carbon fibers as substitute for steel), there are concerns regarding cost-effectiveness and environmental impacts. **At present, without additional mitigation incentives, further R&D, and a comprehensive review of potential environmental impacts, CCU is a mere detour for decarbonisation and unlikely to deliver mitigation in the order of gigatons of CO_2 needed to address climate change.**

---

[24] *See* Appendix 1.

Appendix 1- Carbon Capture, Storage, and Use Applications

This appendix provides a summary overview of the carbon capture, storage, and use applications discussed in this paper based on CAN's review of existing literature and reports. It provides detail on various potential applications for CCS technology, including limitations likely to prevent their safe, efficient and cost-effective deployment as a carbon mitigation or carbon removal technology. Whilst not exhaustive, this overview summarises the main issues associated with CCS and its deployment.
The following CCS applications are the subject of this paper:

- CCS in the power sector
- CCS in industry to capture process and smokestack emissions (also known as "industrial CCS")
- Bioenergy with carbon capture and storage (BECCS)
- Direct air carbon capture and storage (DACCS)
- Carbon capture and utilisation (CCU), which is distinct to CCS due to the different end-of-life use for the captured CO_2: rather than sequestered in geological formations, captured CO_2 is converted into a new product.
- While not a type of CCS, EOR/EOG can be applied alongside CCS, having significant implications on its potential as a climate technology and is also discussed below.

CCS is an integrated process comprised of three distinct parts: carbon capture, transport, and storage (including measuring, monitoring, and verification).

- Capture technology collects CO_2 from a point source (e.g., power station smokestack) that can be compressed, transported, and stored.
- Transport of captured CO_2 is mostly likely to take place via pipelines, but could also be moved via ships, rail, and road.
- CO_2 storage is most likely to occur underground in geological sites on land or below the seabed of at least 800 meters (up to more than three kilometers) under a caprock. Whilst CO_2 disposal at the seafloor (ocean carbon sequestration) has previously been proposed by certain governments, this method has been largely discounted by UN-fora or even banned by many nations due to the significant impacts it would have on the ocean ecosystem and legal constraints that effectively prohibit it.[25]

CCS Applications

A. CCS in the Power Sector

Fossil fuel power stations, particularly those that burn coal provide a large point sources of CO_2. Some power stations emit as much as 10 $MtCO_2$ or more per year, creating an economy of scale for capture, transport, and storage. CCS has a limited commercial track record in the power sector

---

[25] For example, the United Nations Convention on the Law of the Sea (UNCLOS), the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), the Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Protocol, which will eventually replace the London Convention), and regional agreements such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention).

and associated costs for different capture technologies (e.g., amine-based post-combustion capture and oxyfuel combustion) remain high.[26]

Power sector applications of CCS have several drawbacks, including increasing overall energy demand (which means burning more fossil fuels to produce the same amount of energy) and reducing power plant efficiency. For example, the energy penalty for pulverized coal power stations fitted with carbon capture can be 25% or more, whilst the efficiency penalty can be as high as 15%.[27] Such penalties mean more fuel has to be burned to produce the same amount of power, which has a host of implications related to energy costs, non-CO_2 air pollutants, and power station resource demands. In short, using capture technology on power stations increases costs, emissions of non-CO_2 air pollutants, power station water demand, and impacts associated with the mining, extraction, and transport of fossil fuels.[28]

Even more importantly, from a climate perspective, carbon capture does not eliminate CO_2 emissions from fossil fueled power stations. Theoretically, CCS has the potential to reduce power station CO_2 emissions by as much as 90%. In practice, however, capture rates on most of the power stations fitted with capture technology have been much lower.[29] CCS also results in additional upstream or downstream emissions, including those generated upstream through the mining and transport of fossil fuels and the transport and storage of CO_2. When such emissions are accounted for, CCS results in even lower net capture rates over the life of a project.[30]
Large-scale fossil fuel CCS power stations also risk running counter to and could hinder the transition to a 100% renewable energy system. Some argue that CCS can provide a climate solution while renewable energy is deployed worldwide, while others note the risk this strategy will incentivize or justify prolonged fossil fuel use. In general, coal-fired power plants have a limited technical ability to balance variable renewable energy resources like wind and solar. Coal CCS would therefore not improve this ability and could even constrain other fossil fuel power plants' capacity to serve as a flexible resource for technical and/or economic reasons.[31]

One of the crucial environmental impacts is enhanced water consumption by carbon capture applications in power plants. Freshwater is a scarce resource, a precondition for all life on Earth, and needs to be protected much more particularly in times of enhanced global warming and

---

[26] *See, e.g.,* Lazard Ltd (2018). Lazard's Levelized Cost of Energy Analysis—Version 12.0. Lazard Ltd. November 2018. Available at: https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf, which shows the cost of CCS power stations relatives to other energy technologies. Note that the Lazard LCOE analysis does not includes costs for CO_2 transport, storage, and monitoring.

[27] Budinis, S., Krevor, S., MacDowell, N., Brandon, N., Hawkes, A. (2018). An assessment of CCS costs, barriers and potential. Energy Strategy Reviews, Vol. 22, November 2018, pp. 61-81. https://doi.org/10.1016/j.esr.2018.08.003.

[28] *See, e.g.*, Newcastle University, Institute for Sustainability, Impact of carbon capture & storage on water, available at: https://www.ncl.ac.uk/sustainability/ourresearch/excellence/water/ccs/ (accessed 1 February 2020).

[29] *See, e.g.,* Schlissel, D. (2019). IEEFA op-ed: Reality of carbon capture not even close to proponents' wishful thinking. Guest editorial in Denver Post. 8 August 2019. Available at: https://ieefa.org/reality-of-carbon-capture-not-even-close-to-proponents-wishful-thinking/.

[30] Jacobson, M. (2019). The health and climate impacts of carbon capture and direct air capture. Energy & Environmental Science, 12, 2019, pp.3567-3574. https://doi.org/10.1039/C9EE02709B.

[31] Domenichini, R., Mancuso, L., Ferrari, N., Davison, J. (2013). Operating Flexibility of Power Plants with Carbon Capture and Storage (CCS). Energy Procedia vol. 37, pp.2727-2737. https://doi.org/10.1016/j.egypro.2013.06.157.

biodiversity decline. Carbon capture in coal and gas power plants can result in increased water consumption by 20% to 60% in the absence of water recovery options.[32]

Economics is one of the primary reasons why CCS hasn't been more extensively deployed in the power sector. Outfitting new or existing fossil fuel power stations with CCS is very expensive, requires considerable space near the power plant for the capture device, and costs significantly more than zero emission renewable energy technologies per tonne of CO_2 avoided.[33] To-date, only few coal power plants capturing CO_2 emissions exist worldwide and a handful of gas power plant CCS projects are under development. Significantly, there is not a single commercial-scale power plant capturing and sequestering emissions for the purpose of climate mitigation at-scale anywhere in the world.[34]

Considering the costs, especially without CO_2 restrictions or without a considerable CO_2-price well above €50-70 per ton of CO_2 which is two to three times the present carbon price in the European Emissions Trading System, no power producer would consider building a new fossil fuel power plant with CCS or retrofit an existing power plant for CCS. The economic case for CCS in the power sector, in the absence of public support and revenue from captured carbon sales to EOR/EGR operations, therefore rests on carbon pricing or government support. Studies have suggested that even a very high carbon price (e.g., greater than US$50 MWh) would not guarantee that CCS is able to overcome current cost barriers.[35]

Based on operational experience in the past decade, it is likely that CCS will not advance substantially in the power sector in the coming decade.[36] This leaves only niche applications for the technology, which would have to carry the full R&D, deployment, and infrastructure development costs.

I. Enhanced Oil and Gas Recovery

In its application with CCS, EOR describes the process of captured CO_2 being injected underground extract otherwise unreachable of oil and gas. EOR/EGR is not a new process,

---

[32] *Magneshi et al. (2017). Available at: https://reader.elsevier.com/reader/sd/pii/S1876610217319720?token=C460FDDC1C312BAFF5F2A4D447B5C7B7FE2981C45134C3B7DC842DBFC272B610EADC2405A8E9414C2EDE03E9D266406B*

[33] Jacobson, M. (2019). The health and climate impacts of carbon capture and direct air capture. Energy & Environmental Science, 12, 2019, pp.3567-3574. https://doi.org/10.1039/C9EE02709B.

[34] The Boundary Dam project in Saskatchewan, Canada is often touted as the world's first coal-fired CCS project. The project is a post-combustion retrofit of a single coal-fired unit that cost more than US$1 billion; a large part of the project's cost was paid for with government funding. Boundary Dam has been plagued by operating difficulties and has had difficulty maintaining a high capture rate. What's more, captured CO_2 is sold to a nearby EOR operation rather than stored in a standalone geological formation. Schlissel, D. (2018). Holy Grail of Carbon Capture Continues to Elude Coal Industry. Institute for Energy Economics and Financial Analysis. November 2018. Available at: https://ieefa.org/wp-content/uploads/2018/11/Holy-Grail-of-Carbon-Capture-Continues-to-Elude-Coal-Industry_November-2018.pdf.

[35] Cost estimates for CCS often focus on the level of carbon price needed to make a power station fitted with carbon capture technology economic whilst discounting or ignoring the cost of transport, injection, storage, and storage site monitoring. *See, e.g.,* Lazard Ltd (2018). Lazard's Levelized Cost of Energy Analysis—Version 12.0. Lazard Ltd. November 2018. Available at: https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf, which shows the cost of CCS power stations relatives to other energy technologies. Note that the Lazard LCOE analysis does not includes costs for CO_2 transport, storage, and monitoring.

[36] "…as far as the power sector is concerned the overall message seems to be that for the moment it is 'game over' for CCS, in the EU especially, with renewables offering a cheaper option." Elliott, D. (2018). Whatever happened to carbon capture? PhysicsWorld. 5 September 2018. Available at: https://physicsworld.com/a/whatever-happened-to-carbon-capture/.

and has been in commercial use since the 1970s. At present, EOR/EGR is one key aspect to the economic viability for CCS projects – most notably in the United States.[37]

Estimates of the amount of CO_2 remaining underground when used in EOR/EGR operations vary widely. Nevertheless, the risk of leakage in such underground storage sites can also be significantly higher due to the existence of multiple wells that may or may not have been properly sealed.[38] Sound independent and scientific monitoring and verification activities at such sites, if they occur at all, are usually not transparent and information is rarely shared with the public. However, more than three quarters of the reportedly stored all CO_2 from CCS is based on EOR.

Lifecycle analyses of the CO_2 mitigation potential of CCS linked with EOR/EGR vary in their results primarily due to differing boundary definitions, which makes comparisons between studies difficult. Cradle-to-grave analyses that assess the net lifecycle emissions of CO_2-EOR projects from coal mining to product combustion conclude that CO_2-EOR projects have historically emitted more CO_2 than they have removed through geologic storage[39]. In this way, EOR/EGR could perhaps be described as a CO_2 capture and release strategy whereby CO_2 captured from power station smokestacks is used to recover fossil fuel resources that may have otherwise remained underground that, when burned, release CO_2 back into the atmosphere. While EOR/EGR makes business sense for the fossil fuel industry, it is not a winning strategy for the climate.

B. Industrial CCS

Energy-intensive Industries and some **with CO_2 process emissions** are a large source of CO_2 emissions in some countries and are part of global supply chains. For example, the iron and steel industries use pure carbon-rich coking coal for reduction of iron ore (oxide) to metal and emits about 2 Gt CO_2 worldwide. Graphite electrodes for the electrolysis used in the production of aluminum are transforming to CO_2. The cement industry has to heat limestone, which then as process emissions emits vast amounts of CO_2. The entire cement making emits about 2.5 Gt CO2 worldwide. Chemical and fertilizer industries produce polyethylene and Ammonia, respectively, two very energy-intensive processes from fossil fuels. - Other high-emitting industries include paper and pulp production and oil refineries.

While industrial CCS is promoted by some as a key feasible strategy to decarbonize industry, a wide range of solutions for net zero industry are emerging including increased material efficiency, material recirculation and new production processes. Different approaches, alternative materials, and R&D, particularly into new processes have the potential to eliminate the need for CCS in this

---

[37] Center for International Environmental Law (2019). Fuel to the Fire: How geoengineering threatens to entrench fossil fuels and accelerate the climate crisis. February 2019. Available at: https://www.ciel.org/reports/fuel-to-the-fire-how-geoengineering-threatens-to-entrench-fossil-fuels-and-accelerate-the-climate-crisis-feb-2019/.

[38] *See* Appendix 1.

[39] *See, e.g.,* Jaramillo, P., Griffin, W. M., McCoy, S. T. (2009). Life cycle inventory of CO_2 in an enhanced oil recovery system. Environmental Science & Technology, vol. 43, pp.8027–8032. https://doi.org/10.1021/es902006h. Other lifecycles analyses have indicated that CO_2-EOR may reduce carbon emissions, or result in net negative emissions, for all or some portion of a CO_2-EOR project's life but the boundaries for these analyses are usually not cradle-to-grave. For a gate-to-grave lifecycle analysis along these lines, see Núñez-López, V., Gil-Egui, R., Hosseini, S. A. (2019). Environmental and operational performance of CO_2-EOR as a CCUS technology: a Cranfield example with dynamic LCA considerations. Energies, vol.12(3), p 448. https://doi.org/10.3390/en12030448.

sector. Iron ore, for example, can be mined less with better recycling and recovery methods. Alternative production processes are also being trialed, which could eliminate the need for coal, such as the iron ore reduction using renewably-produced hydrogen obtained through the electrolysis of water.

Aluminum can also be produced either with renewably-produced hydrogen or with inert electrodes instead of graphite electrodes. For the cement industry, alternative binders such as geopolymers (clays), pozzolanic (volcanic ash, ash from coal combustion), slag and magnesium-based cements can be used instead of CO_2-emitting Portland cement to make concrete. A greater focus on waste prevention, alternative sustainable bio-based materials, along with reuse and recycling, can reduce or eliminate the need to incinerate household and other wastes that contain a large fraction of plastics.

Further, district heating plants, steel mills, paper mills, and industrial heating plants are far from ideal for CCS. Such facilities tend to be much smaller in size than power stations and can be widely dispersed. Capture and transport costs will therefore be proportionally higher. A typical district combined heat and power or industrial heating plant is between 1 and 100 MW; and each plant would require a separate engineering design, environmental impact assessment, permitting, and financing process.

Given that current CCS costs make the economics for a single 2 GW coal power plant producing 10 $MtCO_2$ per year challenging, CCS is even less likely to be economically feasible for 100 smaller plants located anywhere from 10 to 100 (or more) kilometers apart. Proponents of CCS clustering in Europe have asked for grants, subsidies, and loan guarantees for projects that would share infrastructure and costs to make them economically viable and financeable.[40]

C. Bioenergy with Carbon Capture and Storage

BECCS envisions the use of plants, such as trees or agricultural crops, to naturally remove CO_2 from the atmosphere; the subsequent burning of such plants to produce electricity (or heat); and the capture and storage of any emissions produced in connection with energy transformation activities. It has gained attention in recent years as a potential negative emissions strategy, and features prominently in a number of decarbonisation pathways.[41] Some studies question the carbon neutrality claim of biomass[42] as well as the negative emissions claims of BECCS.[43]

---

[40] *See* Duruset, E. (2017). Deployment of an Industrial CCS Cluster in Europe: A Funding Pathway. i24c. 7 August 2017. Available at: http://i2-4c.eu/wp-content/uploads/2017/10/Deployment-of-an-industrial-CCS-cluster-in-Europe_v2.2_final_web.pdf.

[41] As noted by Carbon Brief, "[i]n little more than a decade, BECCS had gone from being a highly theoretical proposal for Sweden's paper mills to earn carbon credits to being a key negative emissions technology underpinning the modelling, promoted by the IPCC, showing how the world could avoid dangerous climate change this century." CarbonBrief (2016). Timeline: How BECCS became climate change's 'saviour' technology. Carbon Brief. 13 April 2016. Available at: https://www.carbonbrief.org/beccs-the-story-of-climate-changes-saviour-technology.

[42] *See, e.g.,* Southern Environmental Law Center (2019). Fact Sheet: New Report Shows Wood Pellets from Drax's U.S. Mills Increase Carbon Emissions During the Timeframe Necessary to Address Climate Change. Southern Environmental Law Center. 8 August 2019. Available at: https://www.southernenvironment.org/uploads/publications/2019-08-08_FINAL_Biomass_Factsheet_Drax_SIG_Report_Updated1.PDF.

[43] Harper, A.B., Powell, T., Cox, P.M. et al. Land-use emissions play a critical role in land-based mitigation for Paris climate targets. Nature Communications 9, 2938 (2018). https://doi.org/10.1038/s41467-018-05340-z.

Furthermore, many experts and scientists have highlighted ecological, water and resource constraints and competition with food production which would limit its deployment.[44]

A single BECCS pilot project which is burning 100% biomass feedstock exists globally and has been capturing about a tonne of CO_2 (but not storing) per day since 2019 at the Drax Power Station in the UK.[45] The Drax Power Station is a coal- and biomass-fired power station, and the UK's largest source of CO_2 emissions. The power station is also the world's single biggest burner of biomass (burning more wood than the UK produces annually).[46] The company that owns the Drax Power Station receives more than >£2.1 million in public subsidies per day to support its wood burning activities.[47] Whilst the company has signaled its intent to expand its use of BECCS at the power station, such plans are contingent on the continuation of public subsidies as well as "an effective negative emissions policy and investment framework."[48]

Whilst biomass is an abundant resource, its use in the energy section should be limited given concerns about potential climate benefits as well as competing demands on land and water, especially for food production and the protection of forests and natural ecosystems. In many parts of the world, biomass production often involves land use conflict between many different interests from food to biodiversity, transport fuels, industry, as building material, power, and heat.[49] Combining biomass with CCS at a large scale is likely to exacerbate existing issues.[50]
Studies on deploying BECCS at scale envisioned raises significant concerns related to land use, food security, water use, and biodiversity impacts:

- ***Land use***. Estimates vary, but models have estimated millions to a billion (or more) hectares would be needed to produce sufficient biomass to achieve BECCS's share of emission reductions in many climate pathways.[51]

---

[44] *See, e.g.*, Smith, P., Davis, S., Creutzig, F. et al. Biophysical and economic limits to negative CO_2 emissions. Nature Clim Change 6, pp.42–50 (2016). https://doi.org/10.1038/nclimate2870; *see also* Smith, L.J., Torn, M.S. Ecological limits to terrestrial biological carbon dioxide removal. Climatic Change 118, pp.89–103 (2013). https://doi.org/10.1007/s10584-012-0682-3.

[45] Drax Group plc (2019). Carbon dioxide now being captured in first of its kind BECCS pilot. Press Release issued 7 February 2019. Available at: https://www.drax.com/press_release/world-first-co2-beccs-ccus/.

[46] Biofuelwatch (2019a). Drax Plc: Harming Forests, Climate and Communities. April 2019. Available at: https://reclaimthepower.org.uk/uncategorized/drax-power-station-burning-all-the-things/.

[47] Biofuelwatch (2019b). Campaigners Call on Government to Stop Drax from Fuelling Environmental Injustice, Forest Destruction and Climate Breakdown. Press Release issued 9 October 2019. Available at: https://www.biofuelwatch.org.uk/2019/drax-protest-pr-2/.

[48] Fawthrop, A. (2019). Drax to deploy BECCS technology to become carbon-negative by 2030. NS Energy. 10 December 2019. Available at: https://www.nsenergybusiness.com/news/company-news/drax-carbon-negative/.

[49] *See, e.g.,* European Environment Agency (2016). Land use conflicts necessitate integrated policy, available at: https://www.eea.europa.eu/highlights/land-use-conflicts-necessitate-integrated-policy (accessed 1 February 2020).

[50] The Illinois Industrial Carbon Capture and Storage Project in Decatur, Illinois which involves capture of CO_2 from ethanol production and storage in Mount Simon Sandstone Reservoir, for example, involves massive industrial monocropping that could compete with food production and add pressure on land and water resources when adopted at scale globally as a mitigation approach. *See* Greenberg, S. (2018). Illinois Basin Decatur Project - Sharing practical lessons learned about moving from pilot to large-scale demonstration. Presentation, available at: http://conference2018.co2geonet.com/media/28835/10-greenberg.pdf.

[51] For example, "[i]n the Integrated Assessment Model scenarios consistent with a 2 °C target, a median of 3.3 GtC yr^{-1} was removed from the atmosphere through BECCS by 2100, equivalent to one-third of present-day emissions from fossil fuel and industry. This median amount of BECCS would result in cumulative negative emissions of 166 GtC by 2100 and would supply ~170 EJ yr^{-1} of primary energy. The bioenergy crops to deliver such a scale of CO_2 removal could occupy an estimated 380–700 Mha of land, equivalent to up to ~50% of the present-day cropland area." Harper, A.B., Powell, T., Cox, P.M. et al. Land-use emissions play a critical role in land-based mitigation for Paris climate targets. Nature Communications 9, 2938 (2018). https://doi.org/10.1038/s41467-018-05340-z.

- ***Food security.*** The demand for land area for BECCS deployment at scale corresponds to globally converting approximately 50% of arable land and permanent crops for biomass.[52] Some studies have shown that as a result of decreasing land availability, BECCS could increase food prices and increase conflict for land, biomass, and water by putting pressure on limited natural resources.[53]
- ***Water use.*** If implemented at scale, BECCS could more than double the amount of water currently used for irrigation in food production to support the growth of biomass for combustion.[54]
- **Biodiversity.** If implemented at scale, BECCS has the potential to reduce biodiversity, especially if land areas are converted to monoculture plantations and/or use non-native plant species.[55]

Like CCS as applied to fossil fuel power stations, BECCS also has to grapple with the same energy demand associated with CO_2 capture technology, transport issues, and identifying appropriate and permanent storage sites within reasonable proximity to the bioenergy facility.

D. Direct Air Carbon Capture and Storage

DACCS involves filtering CO_2 from ambient air which represents 0.04% of air by volume. This approach, whilst technically feasible, is in its infancy. As with BECCS, DAC is promoted by some for its potential to delivery negative emissions. Several companies are currently working to advance the technology, including Climeworks, Carbon Engineering, Skytree, and Antecy. Climeworks has advanced the farthest with a small-scale demonstration including in Switzerland, where captured CO_2 is used for various applications rather than stored.[56] In 2019, Carbon Engineering and Occidental Petroleum announced plans to build the world's first large-scale direct air capture plant, where captured CO_2 would be used for EOR.[57]

Two key barriers to DACCS commercialisation are cost and energy demand. DACCS is currently very energy intensive and expensive because massive volumes of air must be filtered to capture any reasonable amount of CO_2. One study examining the potential of DACCS to help meet the Paris Agreement goal found that widescale deployment of DACCS would account for a full one-quarter of global energy demand for heat and power by the end of this century.[58] Cost estimates

---

[52] *Ibid.*

[53] Stokstad, E. (2019). Bioenergy plantations could fight climate change—but threaten food crops, U.N. Panel warns. Science. 8 August 2019. Available at: https://www.sciencemag.org/news/2019/08/bioenergy-plantations-could-fight-climate-change-threaten-food-crops-un-panel-warns.

[54] Yamagata, Y., Hanasaki, N., Ito, A. et al. Estimating water–food–ecosystem trade-offs for the global negative emission scenario (IPCC-RCP2.6). Sustainability Science 13, pp.301–313 (2018). https://doi.org/10.1007/s11625-017-0522-5.

[55] Smith, P., Price, J., Molotoks, A., Warren, R., and Malhi, Y. (2018). Impacts on terrestrial biodiversity of moving from a 2°C to a 1.5°C target. 376. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. https://doi.org/10.1098/rsta.2016.0456.

[56] National Academies of Sciences, Engineering, and Medicine (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda, Chapter 5 Direct Air Capture. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

[57] Rathi, A. (2019). Carbon Engineering is doubling its CO_2-capturing machine even before it's built. Quartz. 21 September 2019, available at: https://qz.com/1713529/carbon-engineering-and-occidental-will-capture-1-million-tonnes-of-carbon-dioxide/.

[58] Realmonte, G., Drouet, L., Gambhir, A. et al. An inter-model assessment of the role of direct air capture in deep mitigation pathways. Nature Communications10, 3277 (2019). https://doi.org/10.1038/s41467-019-10842-5.

vary widely and span an order of magnitude, from US$100 to US$1,000 per ton of CO_2, not including associated transport and storage costs.[59]Critically, these estimates represent the cost of CO_2 captured rather than the cost of net CO_2 removed from the atmosphere. Factoring in this cost tends to make DACCS the most expensive atmospheric CO_2 removal approach.[60]

Overall, there are serious doubts about the effectiveness of DACCS given the tension between the need for high capture rates and the very low concentration of CO_2 in the atmosphere. Another potential barrier to widescale DACCS deployment is pollution concerns associated with the chemical sorbent manufacture at "vast scales" to capture CO_2 from the atmosphere.[61] Also a point of concern is the fact that DACCS has attracted attention and investment from the oil and gas sector, which views the technology as a potential source of CO_2 for EOR/EGR operations.[62]

E. Carbon Capture and Utilisation

CCU covers a variety of processes which involve the absorption or conversion of CO_2 during the manufacture of usable product. For example, CO_2 can be utilised as a chemical feedstock or input to produce products, like synthetic fuels. CO_2 could be also used to fertilise algae or increase CO_2 levels in greenhouses to boost plant growth. It is also possible to use CO_2 to produce carbon fibers as a substitute for many materials and applications containing other mineral fiber components[63].

Theoretically, CCU is a promising technology which, depending on its application, may support achieving the 1.5°C target. However, many CCU applications are in the early research phase and very far from commercialisation. Costs and market size are also difficult to assess at this stage.[64] However, it is clear that the volume of CO_2 that would need to be captured far outpaces potential uses in industrial and other applications, including EOR/EGR operations.[65]

Because CCU typically results in the re-release of captured GHG emissions, its potential is limited to a carbon neutral technology. Further, some processes that use CO_2 as a chemical intermediary, such as the production of synthetic fuels have limited or no value from a climate mitigation perspective. Only CCU processes that integrate and permanently store CO_2 would have the

---

[59] Ishimoto, Y., M. Sugiyama, E. Kato, R. Moriyama, K. Kazuhiro Tsuzuki, and A. Kurosawa (2017). Putting costs of direct air capture in context. Forum for Climate Engineering Assessment Working Paper Series: 002. Washington, DC: American University School of International Service.

[60] National Academies of Sciences, Engineering, and Medicine (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda, Chapter 5 Direct Air Capture. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

[61] Realmonte, G., Drouet, L., Gambhir, A. et al. An inter-model assessment of the role of direct air capture in deep mitigation pathways. Nature Communications 10, 3277 (2019). https://doi.org/10.1038/s41467-019-10842-5.

[62] Center for International Environmental Law (2019). Fuel to the Fire: How geoengineering threatens to entrench fossil fuels and accelerate the climate crisis. February 2019. Available at: https://www.ciel.org/reports/fuel-to-the-fire-how-geoengineering-threatens-to-entrench-fossil-fuels-and-accelerate-the-climate-crisis-feb-2019/.

[63] The problem with light weight carbon fibers is their very high energy need when produced from virgin materials but they presently have very low re-cyclability. Since they hardly decompose because of their physio-chemical inertness, products with carbon fibers end mostly in landfills. The opportunity for carbon fibers lies in the reusability of the product in case the physical shape does not change, like plane and car envelopes.

[64] IOGP (2019). The potential for CCS and CCU in Europe at 3. Report to the 32nd meeting of the European Gas Regulatory Forum 5-6 June 2019. Available at: https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf.

[65] Group of Chief Scientific Advisors (2018). Novel carbon capture and utilization technologies. European Commission Directorate-General for Research and Innovation. May 2018. Available at: https://ec.europa.eu/research/sam/pdf/sam_ccu_report.pdf.

potential to mitigate and or remove CO_2 emissions albeit with varying concerns associated in specific applications.[66]

Carbon Dioxide Storage

Globally, experience with the long-term underground/sub-seabed storage of CO_2 though CCS applications is limited. The longest running CO_2 storage project in the world, the marine Sleipner oil field in Norway, has only been operational since 1996 and is still actively injecting CO_2.[67] The IPCC noted in 2005 that the fraction of CO_2 retained in such geological reservoirs is "very likely [above 90% certainty] to exceed 99% over 100 years and is likely [above 60% certainty] to exceed 99% over 1000 years."[68] Whilst the existence of naturally occurring carbon dioxide deposits provides an indication on the permeance of storage through CCS, issues concerning CO2 leakage risks, governance and storage capacity inform on the challenges of CCS technologies. While a 2005 special report from the IPCC[69] assessed the CO2 storage as safe, some scientists[70] and some NGOs (footnote) seeing large risk with storage facilities like Sleipner and in the North Atlantic in general.

A. CO_2 Leakage

For CCS to serve as a safe, effective mitigation tool, captured carbon must be injected and stay underground permanently.[71] The IPCC had shown in its Fifth Assessment Report in 2013 that up to 40% of atmospheric CO2 stays there for at least 1000 years. Therefore, even very low leakage rates over long periods of time could negate the climate benefits of CCS. For example, a leakage rate of 0.1% per year would release 73% of stored CO_2 from a storage site over 1,000 years.

As long as CO_2 is present in geological formations, there is a risk of leakage. In contact with water, CO_2 becomes a weak but permanent acid and therefore corrosive and can compromise the integrity of caprocks, well casings, and cement plugs. Undetected fractures and abandoned, improperly, or unsealed wells (in the case of depleted oil and gas fields) can also provide an avenue for CO_2 to escape. Remediation for CO_2 leaks may be possible but there is no track record or cost estimate for such measures.

Whilst leakage rates in appropriately selected and maintained storage sites particularly in the sub-seabed[72] are likely to be limited, such sites are a limited resource and will not be distributed evenly

---

[66] For example, CO_2 can be used to "cure" cement, or in the manufacture of aggregates. Doing so stores some CO_2 for the long term and could displace emissions-intensive conventional cement but does not offset all emissions from the cement production process.

[67] *See* Appendix 2 for a discussion of potential leakage risk in the Sleipner formation.

[68] IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[69] The IPCC noted in 2005 that the fraction of CO_2 retained in such geological reservoirs is "very likely [above 90% certainty] to exceed 99% over 100 years and is likely [above 60% certainty] to exceed 99% over 1000 years; IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[70] https://www.airclim.org/acidnews/myths-about-carbon-storage-%E2%80%93-sleipner-case

[71] Therefore, national CCS laws (e.g., Germany) assume zero leakage. If leakage occurs - in contrary to this assumption - the operator of the storage site has to start measures to stop this.

[72] Vielstädte, L. et al, "Footprint and detectability of a well leaking CO2 in Central North Sea: Implications from a field experiment and numerical modeling", International Journal of Greenhouse Gas Control, Vol 84, May 29, pp. 190-203 https://doi.org/10.1016/j.ijggc.2019.03.012, available in: https://www.sciencedirect.com/science/article/pii/S1750583618304857

across the globe.[73] Moreover, significant uncertainty remains in estimates of potential leakage risk.[74] Depleted oil and gas fields, including those used in EOR/EGR operations, are one type of storage site used by CCS applications. These storage sites tend to be very well characterised but the multiple bore holes and wells drilled in them to find and extract oil and gas increase the risk of leakage.

The increased risk is due, in part, to what may be labeled as a lack of diligence on the part of the oil and gas industry to clean up after itself. Many wells in oil and gas fields are improperly sealed or not sealed at all. For example, an investigation conducted by the Associated Press (AP) in the wake of the British Petroleum Deepwater Horizon disaster found that oil companies "routinely circumvented" regulations for temporarily abandoned wells. More than 1,000 temporarily abandoned wells in Gulf of Mexico "lingered in an unfinished condition for more than a decade."[75] In that same AP investigation, whilst an oil company representative insisted that it was in everyone's interest to seal wells and to do so properly, state officials estimated that "tens of thousands [were] badly sealed, either because they predate[d] strict regulation or because the operating companies violated the rules.[76]

Aside from compromising climate mitigation efforts, depending on volume and concentration, CO_2 leakage also has the potential to contaminate ground and surface waters, impact soil ecology and the marine environment, and harm human health. A natural example of the danger of CO_2 leakage occurred in a volcanically active area at Lake Nyos in Cameroon in 1986. Large quantities of CO_2 that had accumulated at the bottom of the lake were suddenly released, killing 1,700 people and thousands of cattle over a range of 25 kilometres.[77]

B. Liability for CO_2 Storage

Another barrier to CCS deployment is the question of who is liable for CO_2 once it is stored underground. The answer to this question determines who is likely responsible for monitoring a CO_2 storage site, remediating CO_2 leaks to the extent possible, providing financial security, and paying for any "harm" to the climate, private property, environment, human health, etc. in the event something goes wrong. It is for these reasons that public opposition to onshore CO_2 storage further limits opportunities to deploy CCS. Due to concerns regarding leakage and seismic events,[78]communities have mobilised to stop CO_2 storage projects from going forward. Public acceptance for onshore CO_2 storage, in particular, is limited in Europe, with storage projects

---

[73] IPCC (2005). IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[74] Anderson, S.T. (2017). Risk, Liability, and Economic Issues with Long-Term CO2 Storage—A Review. Natural Resources Research 26, pp.89–112 (2017). https://doi.org/10.1007/s11053-016-9303-6.

[75] Donn, J. and Weiss, M. (2010). Gulf awash in 27,000 abandoned wells. Associated Press. 7 July 2010. Available at: https://www.cbsnews.com/news/27000-abandoned-gulf-oil-wells-may-be-leaking/.

[76] *Ibid.* The article also mentions a 2006 report from the US Environmental Protection Agency regarding wells on land. The report notes that, "[h]istorically, well abandonment and plugging have generally not been properly planned, designed and executed."

[77] Diesendorf, M. (2006). Can geosequestration save the coal industry?, in J Byrne, L Glvoer & N Toly (eds), Transforming power: Energy as a social project, Energy and Environmental Policy Series vol. 9, 2006, pp. 223-248.

[78] Under pressure, CO_2 is an extremely efficient lubricant and may create earthquakes. According to the US National Academy of Sciences, "[l]arge-scale CCS may have the potential for causing significant induced seismicity." National Research Council (2013). Induced Seismicity Potential in Energy Technologies at 12. Washington, DC: The National Academies Press. https://doi.org/10.17226/13355.

scrapped in the Netherlands and Denmark as companies have failed to persuade residents that the benefits outweigh the risks.[79]

Industry actors are often unwilling to invest in CCS unless they are protected from the risks associated with long-term CO_2 storage. Concerns over liability are so great that utilities are often unwilling to make CO_2 available for storage unless they are relieved of ownership upon transfer of CO_2 from the power station. Others have urged that their legal liability for stored CO_2 be limited to defined periods of time, e.g. 10 years. In some countries, efforts to limit the liability of those engaged in CCS have included liability caps, federal indemnity programs, and a complete transfer of liability from the private to public sector.[80]

Long-term CO_2 storage over hundreds or even thousands of years hands over our climate responsibility to a plethora of future generations - it also raises questions about whether regulatory frameworks can appropriately manage and allocate risk throughout every phase of a CO_2 storage project. These questions remain unanswered as the world has limited experience with CO_2 storage (particularly sub-seabed) and CCS regulatory frameworks that exist are largely untested. In 2009, the European Union (EU) established "a legal framework for the environmentally safe geological storage" of CO_2.[81]

This framework creates a risk-based approach for CO_2 storage to prevent and eliminate environmental and public health risks as much as possible. This is a laudable goal but will be difficult to achieve in practice. To-date, the permitting framework for CO_2 storage has been infrequently used with a handful of permit applications submitted for review and only two storage permits issued.[82] The effectiveness of the framework's financial security mechanism, which includes provisions to ensure storage operations provide funding to maintain storage sites through their operation and post-closure phases, remains to be seen. How much funding will be needed, for example, to support long-term monitoring and mitigation is unknown. The risk of inadequate funding is significant with industry lobbying for lower funding requirements.

C. CO_2 Storage Capacity

Many CCS reports and studies assume abundant global or regional capacity to store captured CO_2. In Europe, for example, some have previously claimed the North Sea can store 1,000 years of CO_2 emissions.[83] Taking such claims at face value, is risky, as these types of top-down estimates of

---

[79] The Barendrecht onshore CO_2 storage project was cancelled by the Dutch government in 2010 due, in large part, to local opposition to the project. Carbon Capture & Sequestration Technologies @MIT (2016). Barendrecht Fact Sheet: Carbon Dioxide Capture and Storage Project. Available at: https://sequestration.mit.edu/tools/projects/barendrecht.html (accessed 1 February 2020); *see also* Acid News (2016), CCS sidelined by public oppositions, No.1, April 2016. Available at: https://www.airclim.org/acidnews/ccs-sidelined-public-opposition.

[80] Havercroft, I. and Macrory, R. (2014). Legal Liability and Carbon Capture and Storage: A Comparative Perspective. October 2014. Available at: https://sequestration.mit.edu/pdf/GHGT8_deFigueiredo.pdf.

[81] Directive 2009/31/EC.

[82] European Commission (n.d.). Implementation of the CCS Directive. European Commission. Available at: https://ec.europa.eu/clima/policies/innovation-fund/ccs/implementation_en (accessed 5 September 2019).

[83] Equinor (2019). Here's how your CO_2 emissions can be stored under the ocean, available at: https://www.equinor.com/en/magazine/carbon-capture-and-storage.html (accessed 1 February 2020).

CO_2 storage capacity (e.g. the 2,000 Gt CO_2 in IPCC SR CCS, 2005) are largely estimates of theoretical rather than effective or practical capacity.[84]

Theoretical storage capacity estimates are of limited use as they do not account for a variety of site-specific factors, including pore space availability and injectivity, which are a critical in evaluating the suitability of a geological formation for CO_2 storage. Injectivity refers to the rate at CO_2 can be injected through a well into a formation and is based on how much pressure can be increased within a formation without compromising site (e.g., caprock) integrity. Injectivity is poorly understood in most geological formations and has significant cost implications for CO_2 storage.[85] Such estimates also fail to account for the fact that potential CO_2 storage locations are not evenly distributed. Co-location of captured CO_2 and potential storage locations has economic implications for the cost of CO_2 transport and storage.

When such factors are evaluated, top-down capacity estimates are frequently revised drastically downwards. For example, the Utsira formation where the Sleipner CO_2 storage project operates had "practically unlimited" storage potential and could handle CO_2 emissions from "all power stations in Europe for the next 600 years."[86] However, after an in-depth study, the Norwegian Petroleum Directorate downgraded the storage capacity estimate for the Utsira formation from "able to store all European emissions for hundreds of years" to "not very suitable."[87]

---

[84] Bjureby, E., Rochon, E., Gulowsen, T. (2009). Reality Check on Carbon Storage. Greenpeace International. May 2019. Available at: http://www.globalislands.net/greenislands/docs/norway_reality-check-on-carbon-storage.pdf.

[85] Whiriskey, K. (2014). Scaling the CO_2 storage industry: A study and a tool. Bellona Europa. November 2014. https://bellona.org/assets/sites/4/Scaling-the-CO2-storage-industry_Bellona-Europa.pdf.

[86] Bjureby, E., Rochon, E., Gulowsen, T. (2009). Reality Check on Carbon Storage. Greenpeace International. May 2019. Available at: http://www.globalislands.net/greenislands/docs/norway_reality-check-on-carbon-storage.pdf.

[87] *Ibid.*

Appendix 2- Brief History of CCS (2001-2017): Expectations and Results

High hopes were pinned on CCS in the first decade of the 2000s after, among other things, promising results from the Sleipner storage site in Norway where roughly 1 $MtCO_2$ have been injected per year since 1996.[88] CCS garnered strong support from the US under the Bush administration, the EU, and governments in the UK, Canada, Australia, and Germany. The UN General Secretary (and Angela Merkel) appointed the Vattenfall CEO Lars G. Josefsson, a leading coal apologist and CCS champion, as climate advisor. The EU enacted legislation aimed at supporting 10-12 operating CCS demonstration projects (mostly power plants, but also for industrial process emissions) by 2015 and Norway's Prime Minister Stoltenberg claimed 2007 that CCS was that country's "moon landing" project.

Support for CCS only grew following the release of the IPCC Special Report on Carbon Dioxide Capture and Storage (IPCC Report) in 2005.[89] The IPCC Report claimed that "in /most scenarios/ in a least-cost portfolio of mitigation options, the economic potential of CCS would amount to 220–2,200 Gt CO_2 … cumulatively, which would mean that CCS could contribute 15–55% to the cumulative mitigation effort worldwide until 2100".[90] The IPCC Report also stated that it was "likely" that at least about 2,000 Gt CO_2 geological storage capacity existed. Almost every major power company believed coal was an inevitable part of the future, and the only way to make the continued use of coal consistent with efforts to lower global greenhouse gas emissions was through CCS.

The European Commission summed up the global mood on CCS in May 2008: "[i]ntroducing CCS may delay the need to reduce levels of fossil fuel use by at least half a century."[91] At the time, the conventional wisdom was that:

- Renewables were too expensive and CCS would be a bridge technology whilst alternatives to fossil fuels are further developed and deployed."
- There was a strong link between economic growth and energy growth, especially electricity consumption, so energy efficiency was a limited option.
- There was no realistic option and no major political power to stop coal growth, so the fuel shift option (from coal to gas) was limited.
- 550 ppm CO_2 and higher was considered as mitigation. The ultimate objective of UNFCCC in Art. 2 was only operationalised and adopted at COP 16 in 2010 ("2-degree limit"). At the G8-Summit in Heiligendamm (2007) there were intense discussions on the 2-degree limit but no consensus could be found as US-President Bush objected to that.

Since the early 2000s, however, a lot has changed in the energy landscape. World CO_2 emissions have decelerated to <0.5% growth per year between 2013 and 2017, compared to 2.5% the previous 10 years. Electricity consumption has more or less stabilized in major economies such as the US, EU, and Japan. Coal use in the power sector declined in the OECD from >4000 TWh to <3000 TWh between 2007 and 2017.

---

[88] The Sleipner project in Norway strips CO_2 that is co-produced with a natural gas stream from a field in the North Sea. The CO_2 is then re-injected below the seafloor in a saline aquifer in order to avoid payment of a CO_2 tax.

[89] IPCC (2005). IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[90] *Ibid.*

[91] *See, e.g.,* European Commission DG ENV (2008). News alert, Issue 105, May 2008. Available at: https://ec.europa.eu/environment/integration/research/newsalert/pdf/105na3_en.pdf.

New coal power has become a no-go in an increasing number of countries whilst a great deal of existing coal capacity has been phased out. CCS was presented as a "bridge technology" but as renewables have surged ahead, CCS has barely advanced. Renewable energy deployment is now booming across the globe thanks to significant cost declines. Wind power production, for example, has grown by a factor of more than 10 since the IPCC report was released in 2005- from 104 TWh 2005 to about 1,400 TWh in 2019. Solar power production has increased by more than a factor of 100- from 4 TWh in 2005 to more than 600 TWh in 2019[92]. Yet, wind and solar energy combined are presently responsible for only nearly 9% of global electricity and about 1.5% of global final energy demand, still far too low and much too slow than what could bring the world to an alternative path.

Meanwhile, CCS has failed to advance despite billions in public support. In the US, for example, nearly half of the US$2.6 billion spent by the US Department of Energy since 2010 to advance fossil fuel technologies was spent on CCS;[93] Australia has spent AUS$1.3 billion on CCS since 2003;[94] the provincial government in Alberta is in the process of spending CA$1.24 billion on two projects; [95] the UK spent £168 million on two failed CCS competitions and continues to allocate millions in public funds to CCS on an annual basis; [96] and despite passing the CCS Directive (2009/31/EC) and spending €424 million over 10 years, Europe has zero CCS demonstration plants to date.[97]

Notable project failures and technical flaws include:

- In Salah—Poor management at the CO_2 storage site in Algeria resulted in the cessation of injection activities in 2011 after over-pressurisation of the formation fractured the caprock;[98]
- FutureGen and Kemper—These high-profile US projects were cancelled after major cost overruns, delays, and technical issues;[99] and
- Mongstad—Norway's "moon landing" CCS project was scrapped after cost overruns and delays.[100]
- Sleipner—Discovery of fractures near the CO_2 storage site, discovered in 2012, have led to concerns that CO_2 could eventually leak;[101]

---

[92] World Energy Outlook, IEA 2020

[93] Patel, S. (2018). DOE Sank Billions of Fossil Energy R&D Dollars in CCS Projects. Most Failed. Power. 9 October 2019. Available at: https://www.powermag.com/doe-sank-billions-of-fossil-energy-rd-dollars-in-ccs-projects-most-failed/.

[94] Brown, B., Swann, T. (2017). Money for Nothing. The Australia Institute. 30 May 2017. Available at: https://www.tai.org.au/content/money-nothing.

[95] Alberta (2020). Carbon capture and storage, available at: https://www.alberta.ca/carbon-capture-and-storage.aspx.

[96] Rathi, A. (2017). The UK could have changed the way the world fights global warming. Instead it blew $200 million. Quartz. 2 May 2017. Available at: https://qz.com/972939/the-uk-could-have-changed-the-way-the-world-fights-global-warming-instead-it-blew-200-million/.

[97] Rathi, A. (2018). The EU has spent nearly $500 million on technology to fight climate change—with little to show for it. Quartz. 23 October 2018. Available at: https://qz.com/1431655/the-eu-spent-e424-million-on-carbon-capture-with-little-to-show-for-it/.

[98] Spotts, P. (2014). Can we hide carbon dioxide underground? Algeria site offers note of caution. Christian Science Monitor. 27 May 2014. Available at: https://www.csmonitor.com/Environment/2014/0527/Can-we-hide-carbon-dioxide-underground-Algeria-site-offers-note-of-caution.

[99] Mississippi ratepayers are responsible for US$1 billion of the cost of the failed Kemper project. Wilson, S. (2019). Two Years Since Kemper Clean Coal Project Ended. Mississippi Center For Public Policy. 17 July 2019. Available at: https://www.mspolicy.org/two-years-since-kemper-clean-coal-project-ended/.

[100] Holter, M. (2013). Norway Drops 'Moon Landing' as Mongstad Carbon Capture Scrapped. Bloomberg. 20 September 2013. Available at: https://www.bloomberg.com/news/articles/2013-09-20/norway-drops-moon-landing-as-mongstad-carbon-capture-scrapped.

[101] Acid News (2018). Myths about carbon storage—the Sleipner case, No.2, June 2018. Available at: https://airclim.org/acidnews/myths-about-carbon-storage-%E2%80%93-sleipner-case. However, leaks have not yet been detected. Cavanagh, A. (2015). Statoil CO_2 storage experience: 20 years and 20 million tonnes; http://conference.co2geonet.com/. Presentation in Session 5 from the second day (12 May 2015).

CLIMATE ACTION NETWORK
International

CLIMATE ACTION NETWORK

Position on Solar Radiation Modification (SRM)

September 2019

Climate Action Network (CAN) is the world's largest network of civil society organizations working together to promote government action to address the climate crisis, with more than 1500 members in over 130 countries.
www.climatenetwork.org

1. **Robust adaptation and mitigation actions are the first-line solutions to climate change. SRM is not a substitute for either and should not be seen as climate action.**
2. **Recognize the inherent transboundary nature of SRM and significant and unknown risks (geopolitical, social, environmental, ethical) involved.**
3. **Strongly opposes deployment of SRM.**
4. **Strongly opposes real-world experiments.**[i]

There is unanimous alignment among CAN membership that **robust adaptation and mitigation actions are the first line solutions to climate change. SRM is not a substitute for either and should not be seen as climate action.**

CAN believes that SRM does not address the root causes of global warming and does not bring about the fundamentally needed transformational change in our societies to address the global crisis of resource consumption, equity and fairness to combat climate change and to achieve the Sustainable Development Goals by 2030. CAN supports the many recent scientific findings that averting dangerous climate change is possible without SRM. There is now clearer evidence that temperatures can be limited to 1.5^0 C degrees and can be reached through deep cuts on greenhouse gas emissions from different sources, transformation of energy systems and "Natural Land Solutions". CAN assesses that compared and opposed to SRM, deep GHG and CO_2 emission cuts in various sectors and by various policies have a multitude of permanent environmental, sustainable development, economic and social benefits that reach far beyond limiting temperature increase alone.

CAN recognizes the transboundary risks associated with SRM.

CAN heeds the assessment of the IPCC that SRM "faces large uncertainties and knowledge gaps as well as substantial risks, institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development." If deployed, SRM poses substantial environmental and social risks with intergenerational justice implications. CAN believes that some SRM technologies would have to be perpetually deployed to be effective and to avoid "termination shock" that could result to catastrophic sudden rapid warming or sudden change in rain patterns and consequences would be mostly irreversible. Some modelling indicates that SRM could increase international and regional tensions due to changes in precipitation patterns which could unequally affect countries and regions. It could even be "weaponized", and thus could undermine the 1977 Environment Modification Convention (ENMOD).

For these reasons, CAN is strongly opposed to the deployment of SRM.

CAN also strongly opposes outdoor experiments on SRM.

CAN acknowledges that in order for outdoor experiments on SRM to yield useful information on its impacts on climate change, they need to be large scale and conducted over a long period which would be equivalent to deployment. Large-scale SRM experiments contradict the *de facto* moratorium on geoengineering agreed by the UN Convention on Biological Diversity. CAN notes that existing planned real-world experiments focus on technology development, not on testing the environmental or social impacts of large-scale geoengineering deployment – thus will not give useful information for evaluating the effectiveness of risks and impacts of deploying SRM at scale.

CAN believes that real world experiments are founded on the assumption that experiments are as much political as they are technical – thus dragging the world to a “slippery slope” where larger experiments will be required to validate previous ones that may have failed or not deployed at sufficient scale. Unforeseen consequences of human intervention into the climate and weather systems are to be expected.

---

[i] EDF and NRDC do not support an unequivocal ban on outdoor/real-world experiments on SRM. They believe, based on their best understanding of the current science, that engaging in transparent small-scale field research to further understanding of the climate system and the implications of any solar geoengineering proposals is prudent, and governance regimes should be established in parallel with the very first experiments. UCS believes that a precautionary approach to climate risks includes developing an understanding of the risks and efficacy of solar geoengineering: UCS strongly opposes large-scale tests and believes smaller-scale outdoor experiments should only go forward if legitimate independent governance mechanisms are established to ensure that proposed experiments have high scientific quality and value and that they pose negligible environmental, social and legal risks. Such governance mechanisms must be transparent and inclusive, ensuring meaningful engagement with climate vulnerable communities and other civil society stakeholders, and provide oversight over the duration of the experiments.