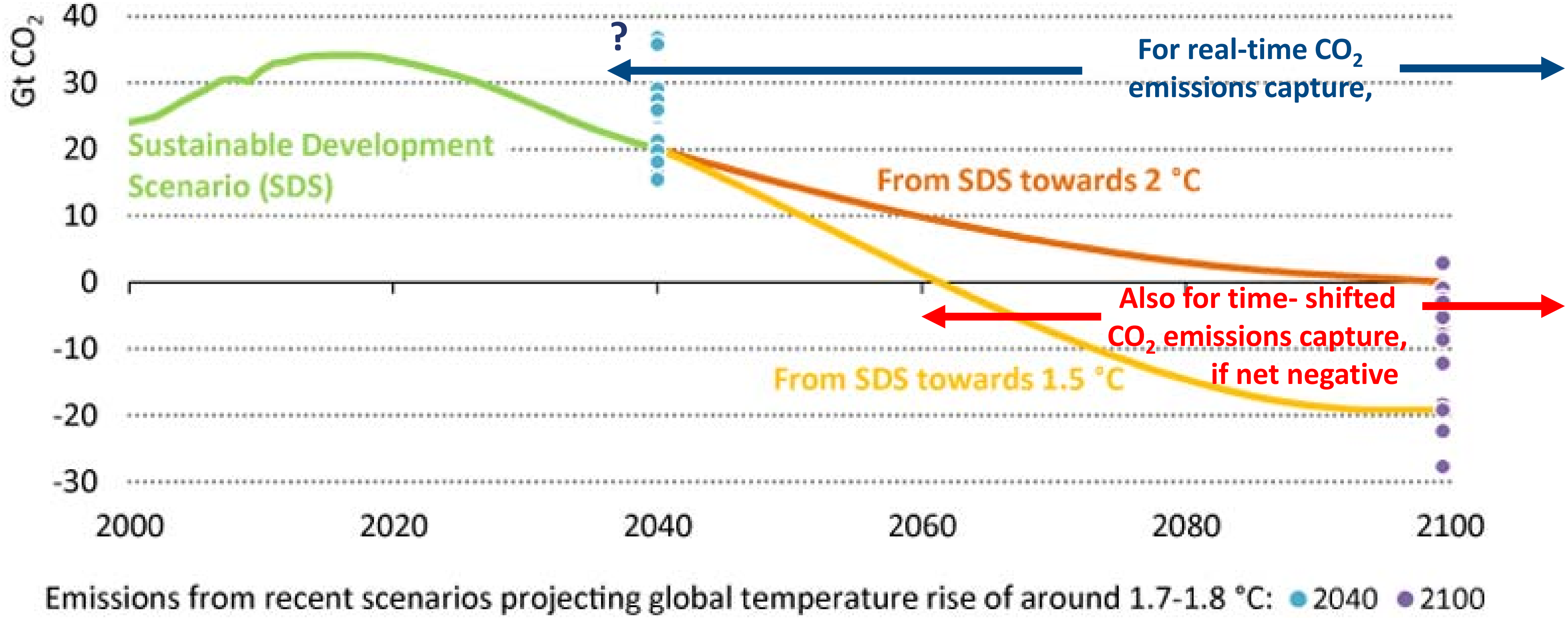
Direct Air Capture with CO_2 Storage - a backstop technology for achieving net-zero

Jon Gibbins

Director, UK CCS Research Centre

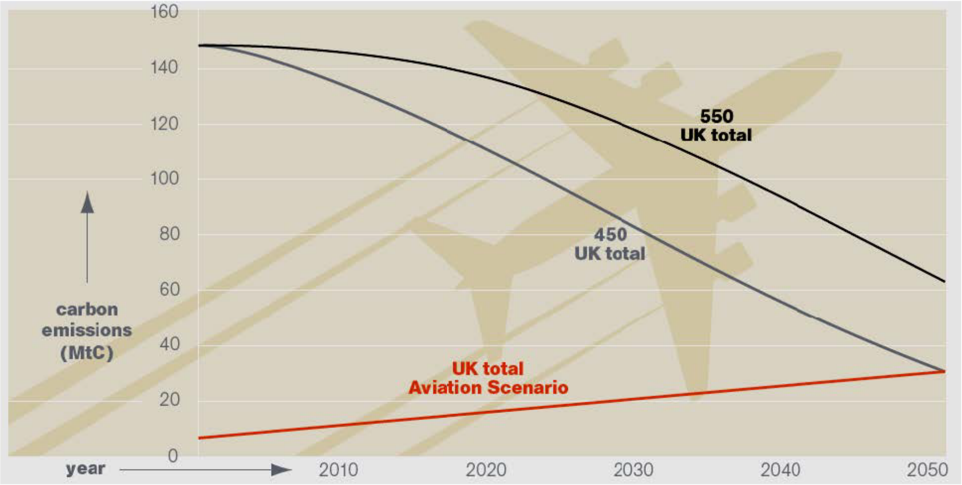
Professor of Power Plant Engineering & Carbon Capture, University of Sheffield

IEA World Energy Outlook 2017 Scenarios
What do negative emissions technologies get used for?



LONGER TERM POTENTIAL FOR BIOMASS WITH CCS?

Tyndall Centre
'Decarbonising the UK'
http://www.tyndall.ac.uk



Cambridge Energy Forum
Carbon Capture & Storage: the impact on UK Nuclear Policy?
26 October 2005

Carbon capture and storage

Dr Jon Gibbins
Energy Technology for Sustainable Development Group
Mechanical Engineering Department, Imperial College London
j.gibbins@imperial.ac.uk

Principal Investigator, TSEC programme, UK CCS Consortium
www.ukccsc.co.uk

Tyndall UK aviation emissions projections for 2050	~ 30 MtC
RCEP estimates for max UK biomass production by 2050	~ 60 Mt
Carbon content of biomass	~ 24 MtC
Carbon captured using biomass with CCS	~ 90%
Energy recovered compared to use without CCS	~ 75%
Oil price equivalent of $50/tonne CO2	$22/barrel

Transport Atmosphere carries CO2 from plane to plant for free!
But need to supply biomass to CCS plants

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BECCS Overview

- Doable technically, Drax is examining possibilities in UK
- Not the same as coal CCS, biomass has unique properties
- Carbon capture probably more important than energy
- Need a baseload way to convert biomass to CO_2 – combustion is easiest, gasification still not demonstrated at necessary scale
- MUST leave space in the energy system for BECCS
- Just as bad not to capture CO_2 from biomass as from fossil – and biomass generates a lot more CO_2 than natural gas when used
- So better to use biomass with CCS and replace unabated biomass by gas without CCS – generally wasteful to use biomass to decarbonise heat (or transport)
- **But always limited biomass, especially when climate change adds water and food stresses.**
- **BECCS is good to use for biomass but cannot be a backstop.**

* http://www.aps.org/policy/reports/assessments/upload/dac2011.pdf

Klaus Lackner, Gordon Research Conference 2015

Air capture is the capture of last resort

- can handle emissions from any and all sources
- sets upper limit on cost of carbon management
- assures feasibility of zero carbon scenarios
- provides a solution to the risk of leaky storage
- encourages point source capture

37

Wikipedia picture

Jon Gibbins,
Two Alternative Negative Emissions Technologies to BECCS: Direct Air Capture and Enhanced Weathering
Our Common Future Under Climate Change, Paris.
Conference Session 3307: Negative emissions for climate change stabilization & the role of CO_2 geological storage, Thursday 9 July 2015 17:30-19:00 at Université Pierre et Marie Curie, Amphi 34

https://www.slideshare.net/CFCC15/gibbins-j-201507091730upmcjussieuamphi34

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Direct Air Capture can capture CO_2 for storage to offset fossil fuel emissions or for synthesis of hydrocarbon fuels using non-fossil energy sources

http://nas-sites.org/americasclimatechoices/

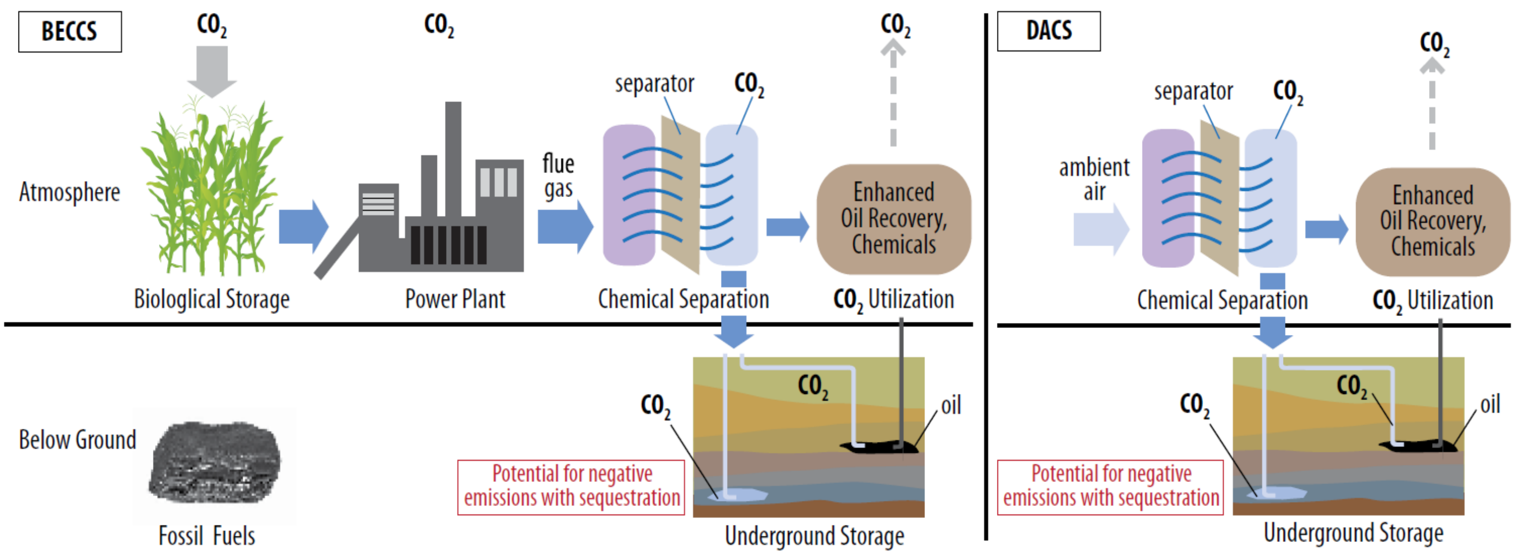
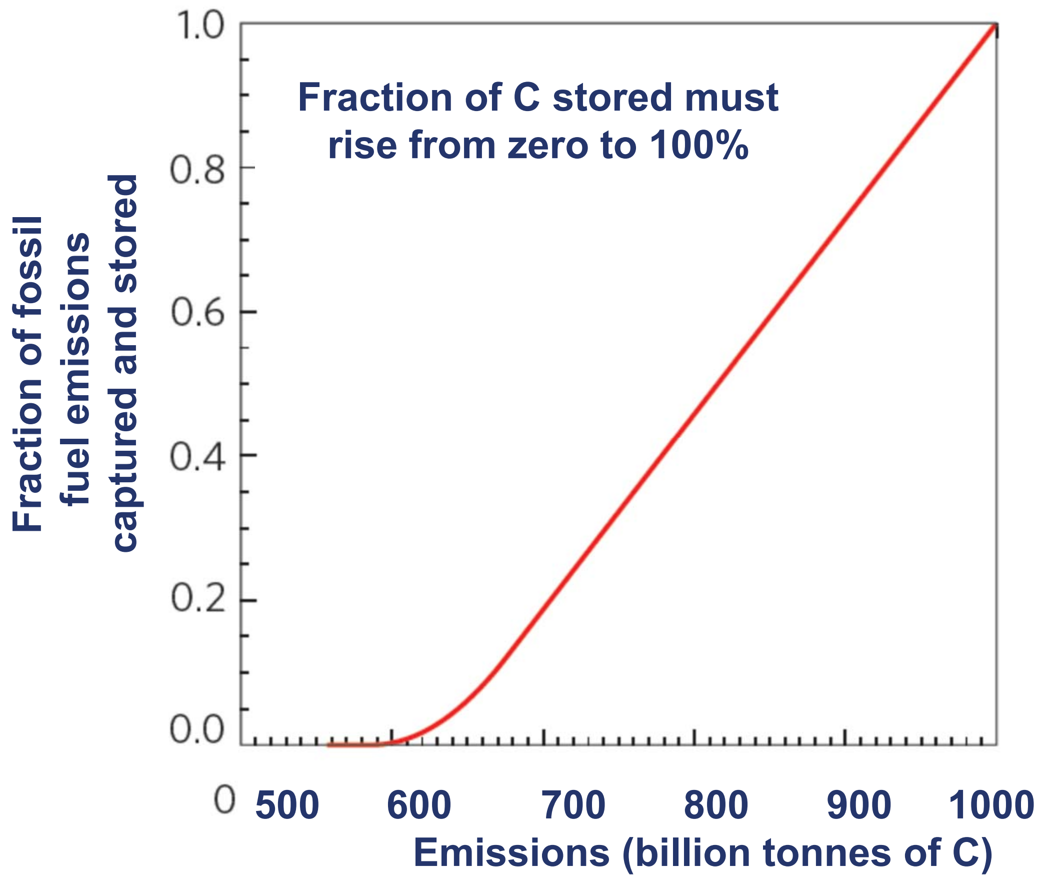


Figure 1. *In Bioenergy with Carbon Capture and Sequestration (BECCS, shown on left), crops such as corn or switchgrass take up carbon dioxide from the atmosphere as they grow. The crops can be burned in power plants to produce electricity, and the carbon dioxide generated is captured and sequestered underground. In Direct Air Capture and Sequestration (DACS, shown on right), carbon dioxide can be removed from the atmosphere as air passes through air filtering structures and is sequestered underground. Block arrows represent fluxes of carbon (as fuel or as carbon dioxide); dashed arrows indicate residual carbon dioxide emissions.*

What does the whole world have to do?

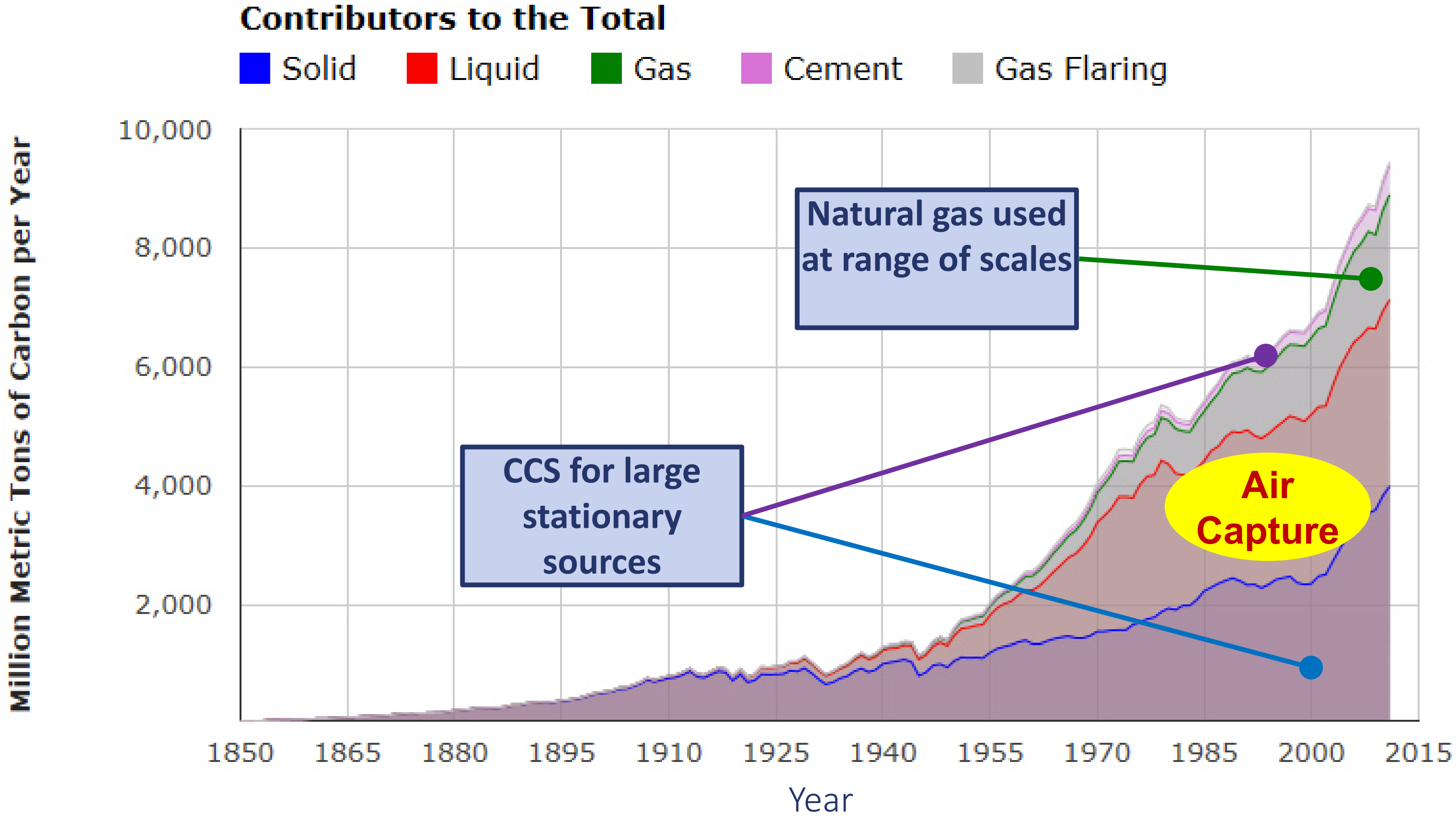
Deploying 100% CCS on fossil fuel use to limit cumulative emissions of CO_2 at a level where climate consequences are manageable is a sufficient measure to avoid dangerous climate change.

It is also in fact a necessary measure.



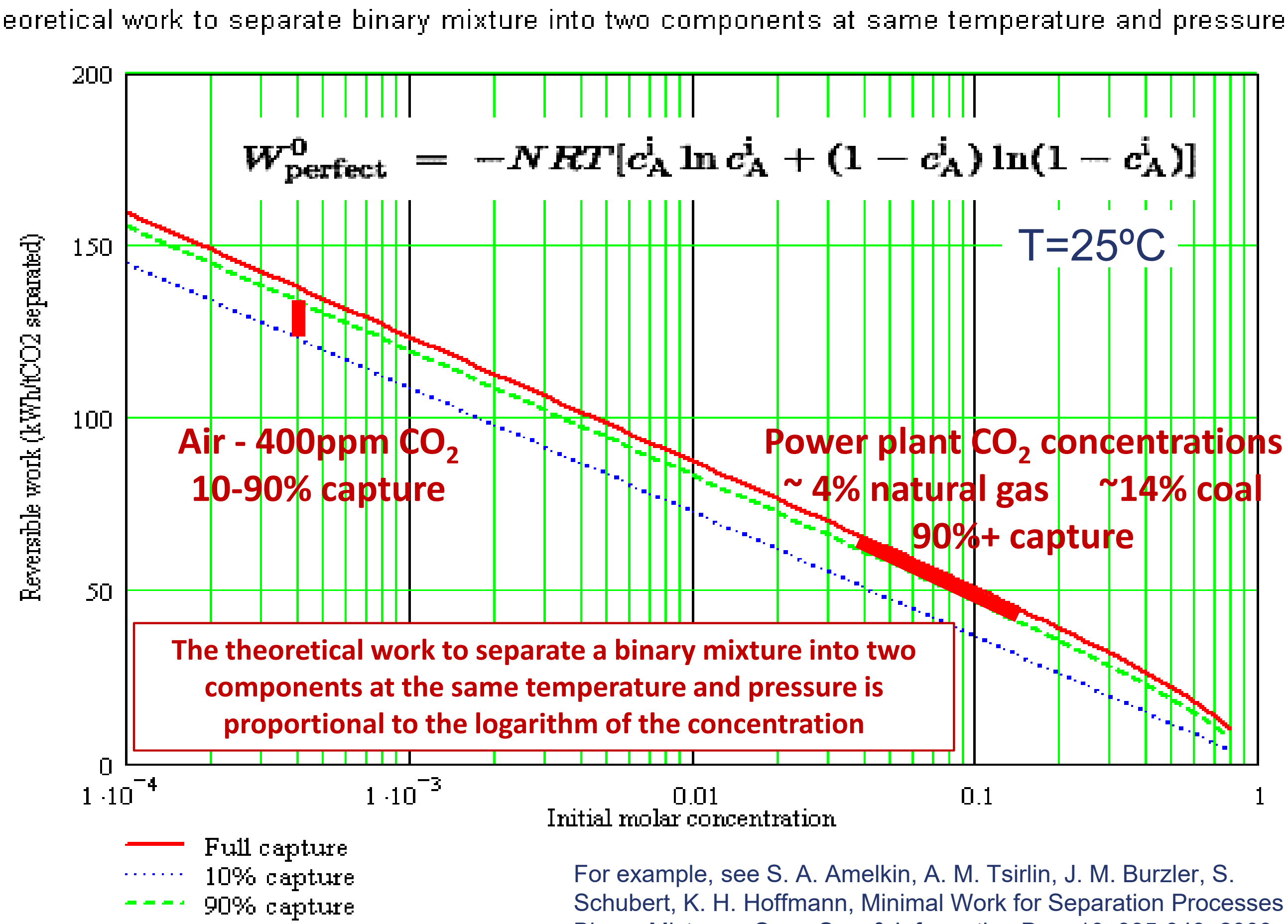
Myles R. Allen, David J. Frame & Charles F. Mason, The case for mandatory sequestration, Nature Geoscience 2, 813 - 814 (2009), doi:10.1038/ngeo709

Significant fraction of fossil fuel use requires air capture



Source: Boden, T.A., G. Marland, and R. J. Andres. 2015. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/00001_V2015. http://cdiac.ess-dive.lbl.gov/trends/emis/glo_2014.html

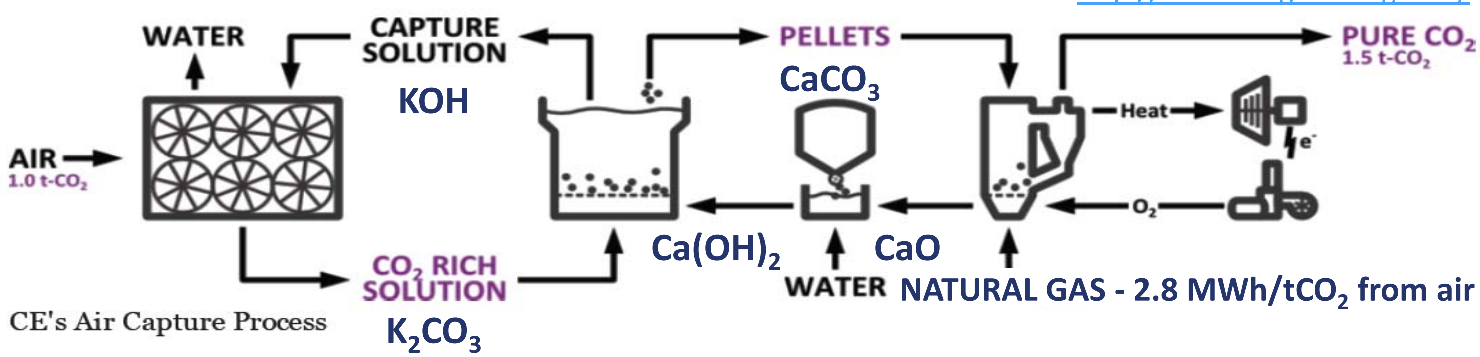
Direct air capture requires only about twice the theoretical energy input of conventional CO_2 capture from power plants



For example, see S. A. Amelkin, A. M. Tsirlin, J. M. Burzler, S. Schubert, K. H. Hoffmann, Minimal Work for Separation Processes of Binary Mixtures, Open Sys. & Information Dyn. 10: 335-349, 2003.

Example 1: Carbon Engineering air capture process

http://carbonengineering.com/



Squamish demo plant site construction

Running 2015, ~500 tCO_2/yr scale

Design for 'slab' air contactor

100,000tCO_2/yr scale

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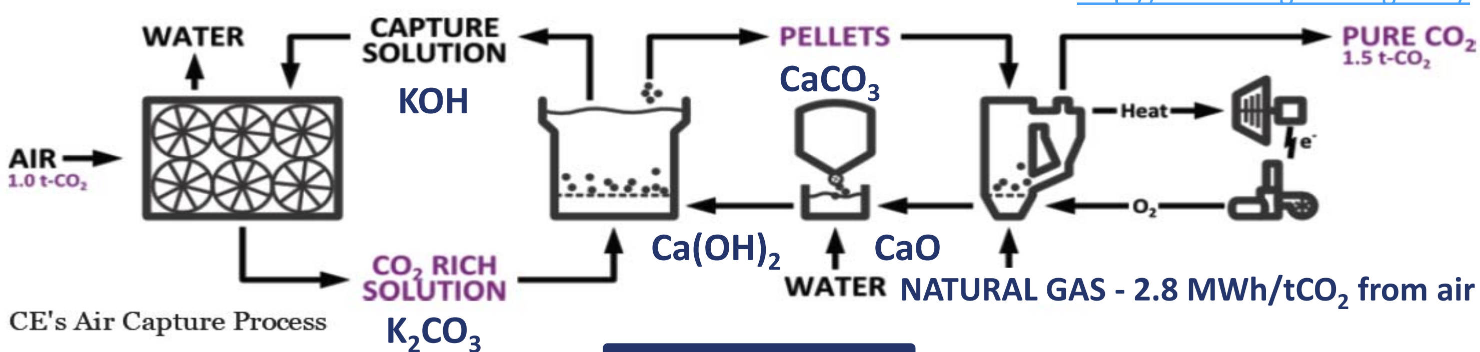

CE's Air Capture Process

Squamish demo plant site construction

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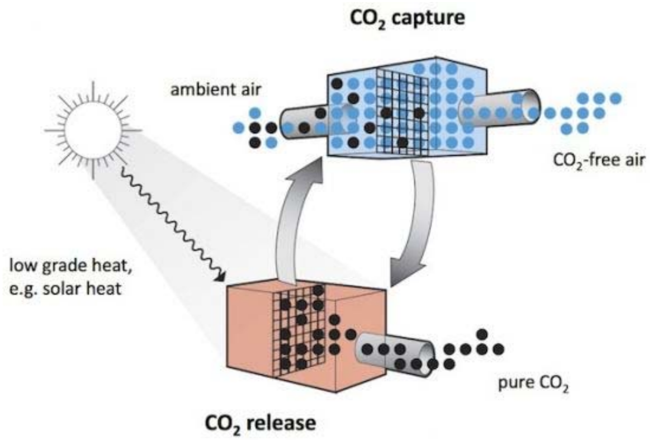
Design for 'slab' air contactor

100,000tCO_2/yr scale

Example 2: Climeworks air capture process

http://www.climeworks.com



Based on a cyclic adsorption / desorption process on a novel filter material ("sorbent"). Scalable in multiples of 300 tCO_2/yr, in shipping container sized units.

Energy demand per ton of CO_2 :

1.5 – 2.0 MWh heat at 100 °C

0.2 – 0.3 MWh electricity

Climeworks CO_2 Kollektor

Design for Climeworks CO_2 Capture Plant

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Climeworks has raised a total of SFr50m ($50.1m) and has 14 plants, operating around the world.

The University Of Sheffield.

CLIMEWORKS

http://www.climeworks.com

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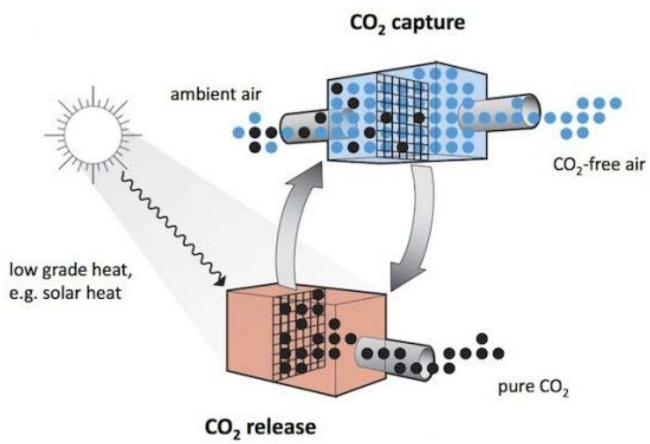

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Climeworks CO_2 Kollektor

Design for Climeworks CO_2 Capture Plant

1000 tCO_2/yr demo plant

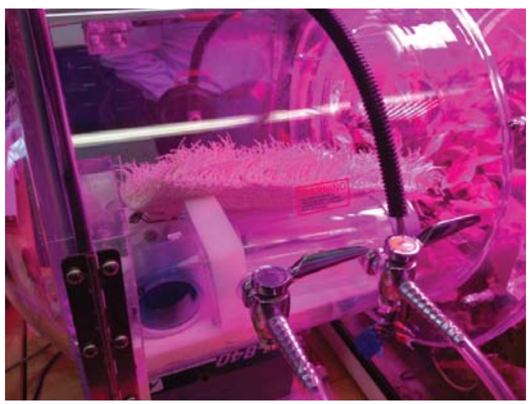
Example 3: Global Thermostat air capture process

http://globalthermostat.com

GT uses custom equipment and proprietary (dry) amine-based chemical "sorbents" bonded to porous honeycomb ceramic "monoliths" that together act as carbon sponges, efficiently adsorbing CO_2 directly from the atmosphere, from smokestacks, or from a combination of both. The captured CO_2 is stripped off and collected using low-temperature steam (85-100° C)

Example 4: Center for Negative Carbon Emissions

http://engineering.asu.edu/cnce/



A moisture swing sorbent cycle for capturing carbon dioxide (CO_2) from air. The sorbent, an anionic exchange resin, absorbs CO_2 when it is dry, and releases it again when exposed to moisture.

1000 tCO_2/yr demo plant

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ExxonMobil

globalthermostat

http://globalthermostat.com

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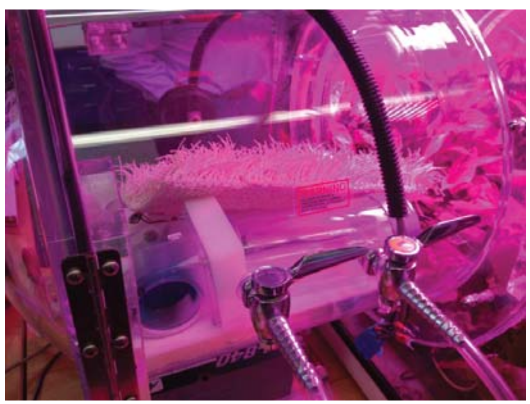

SILICON KINGDOM HOLDINGS LIMITED

A moisture swing sorbent cycle for capturing carbon dioxide (CO_2) from air. The sorbent, an anionic exchange resin, absorbs CO_2 when it is dry, and releases it again when exposed to moisture.

http://www.hoovers.com/company-information/cs/company-profile.silicon_kingdom_holdings_limited.014096ffce48b082.html?aka_re=1

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Direct Air Capture Overview

- Examples of working DAC technologies now being developed
- Initial independent* cost estimate in 2011 was ~ $\$600/tCO_2$
- Detailed 2018 engineering and cost analysis** for a 1 Mt-CO_2/year direct air capture plant by Carbon Engineering reported levelized costs of $94 to $232 per ton CO_2 from the atmosphere
- High marginal costs of abatement have been paid via Feed in Tariffs etc. for renewables, with the expectation of reducing costs as a result of experience.
- But even $\$600/tCO_2$ would add ~ $1.50 per litre of gasoline (i.e. less than doubling pump price in Europe).
- And for any stationary source operating at low load factors (e.g. natural gas plant filling in around wind) the point source CCS cost per tonne of CO_2 has to be a LOT lower to beat a DAC unit that is operating 24/7.
- DAC technologies can be developed and proven relatively cheaply as individual units that are then mass-produced to reduce costs for deployment.
- **VERY important for countries to commit within ~ 10 years to finite future emission budgets and hence, eventually, to net zero emissions – proof of viable DAC options as a back-stop could be a deal-maker.**

* http://www.aps.org/policy/reports/assessments/upload/dac2011.pdf

** https://www.cell.com/joule/fulltext/S2542-4351(18)30225-3

Technology development for global policy reasons

John F. Kennedy speaking at Rice University, September 12, 1962

There is no strife, no prejudice, no national conflict in outer space as yet. Its hazards are hostile to us all. Its conquest deserves the best of all mankind, and its opportunity for peaceful cooperation may never come again. But why, some say, the moon? Why choose this as our goal? And they may well ask why climb the highest mountain? Why, 35 years ago, fly the Atlantic? Why does Rice play Texas?

We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too.

https://er.jsc.nasa.gov/seh/ricetalk.htm

NEED TO UNDERSTAND WHY DACCS CAN MAKE SOME PEOPLE, ESPECIALLY YOUNG PEOPLE, VERY ANGRY

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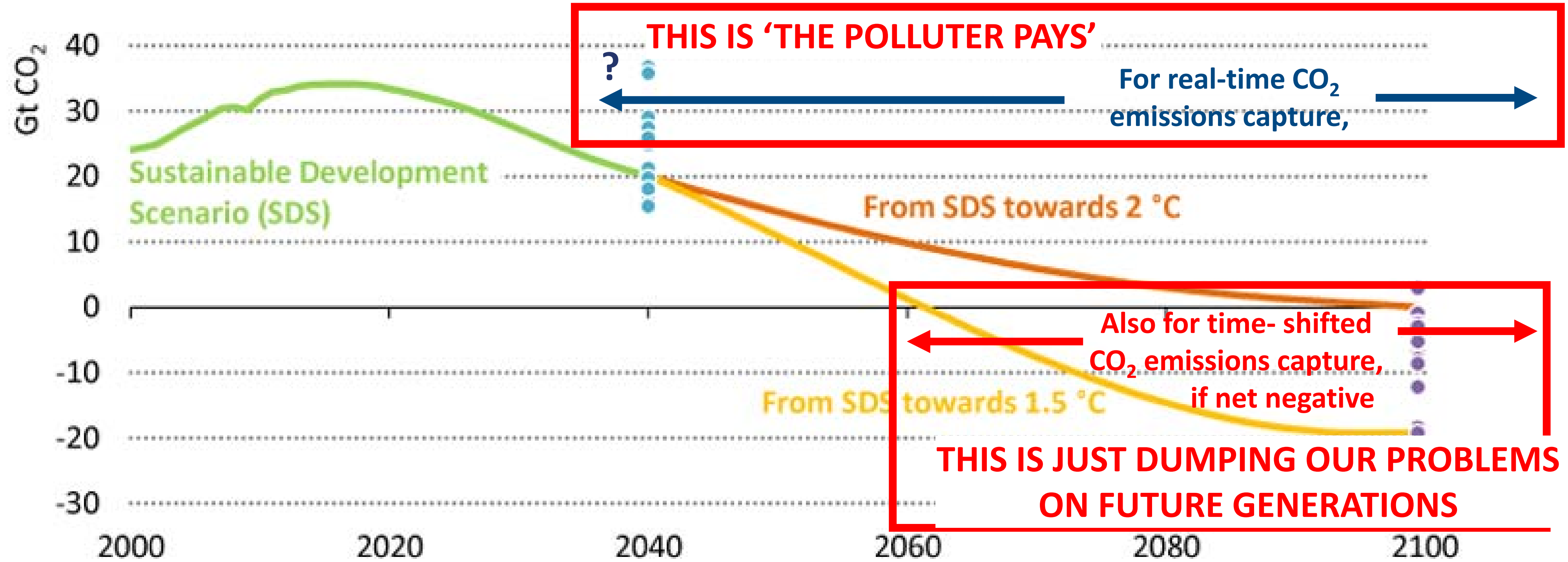

Emissions from recent scenarios projecting global temperature rise of around 1.7-1.8 °C: ● 2040 ● 2100

https://en.wikipedia.org/wiki/Rice%E2%80%93Texas_football_rivalry

Rice–Texas football rivalry

Rice Owls | Texas Longhorns

First meeting	October 17, 1914 Texas 41, Rice 0
Latest meeting	September 12, 2015 Texas 42, Rice 28
Next meeting	September 14, 2019
Statistics	
Meetings total	94
All-time series	Texas leads, 72–21–1
Largest victory	Texas, 59–0 (1915)
Longest win streak	Texas, 28 (1966–1993)
Current win streak	Texas, 13 (1995–present)

Locations in Texas

Rice victories | Texas victories | Tie games

No.	Date	Location	Winner	Score
1	1914	Austin, TX	Texas	41–0
2	1915	Austin, TX	Texas	59–0
3	1916	Austin, TX	Texas	16–2
4	1917	Austin, TX	Rice	13–0
5	1918	Houston, TX	Texas	14–0
6	1919	Austin, TX	Texas	32–7
7	1920	Houston, TX	Texas	21–0
8	1921	Austin, TX	Texas	56–0
9	1922	Houston, TX	Texas	29–0
10	1923	Austin, TX	Texas	27–0
11	1924	Houston, TX	Rice	19–6
12	1925	Austin, TX	Texas	27–6
13	1926	Houston, TX	Texas	20–0
14	1927	Austin, TX	Texas	27–0
15	1928	Houston, TX	Texas	13–6
16	1929	Austin, TX	Texas	29–0
17	1930	Houston, TX	Rice	6–0
18	1931	Austin, TX	Rice	7–0
19	1932	Houston, TX	Texas	18–6
20	1933	Austin, TX	Texas	18–0
21	1934	Houston, TX	Rice	20–9
22	1935	Austin, TX	Rice	28–19
23	1936	Houston, TX	Rice	7–0
24	1937	Austin, TX	Rice	14–7
25	1938	Houston, TX	Rice	13–6
26	1939	Austin, TX	Texas	26–12
27	1940	Houston, TX	Rice	13–0
28	1941	Austin, TX	Texas	40–0
29	1942	Houston, TX	Texas	12–7
30	1943	Austin, TX	Texas	58–0
31	1944	Houston, TX	Rice	7–0
32	1945	Austin, TX	Rice	7–6
33	1946	Houston, TX	Rice	18–13
34	1947	Austin, TX	Texas	12–0
35	1948	Houston, TX	Texas	20–7
36	1949	Austin, TX	Rice	17–15
37	1950	Houston, TX	Texas	35–7
38	1951	Austin, TX	Texas	14–6
39	1952	Houston, TX	Texas	20–7
40	1953	Austin, TX	Rice	18–13
41	1954	Houston, TX	Rice	13–7
42	1955	Austin, TX	Texas	32–14
43	1956	Houston, TX	Rice	28–7
44	1957	Austin, TX	Texas	19–14
45	1958	Houston, TX	Rice	34–7
46	1959	Austin, TX	Texas	28–6
47	1960	Houston, TX	Rice	7–0
48	1961	Austin, TX	Texas	34–7

No.	Date	Location	Winner	Score
49	1962	Houston, TX	Tie	14–14
50	1963	Austin, TX	Texas	10–6
51	1964	Houston, TX	Texas	6–3
52	1965	Austin, TX	Rice	20–17
53	1966	Houston, TX	Texas	14–6
54	1967	Austin, TX	Texas	28–6
55	1968	Houston, TX	Texas	38–14
56	1969	Austin, TX	Texas	31–0
57	1970	Houston, TX	Texas	45–21
58	1971	Austin, TX	Texas	39–10
59	1972	Houston, TX	Texas	45–9
60	1973	Austin, TX	Texas	55–13
61	1974	Houston, TX	Texas	27–6
62	1975	Austin, TX	Texas	41–9
63	1976	Houston, TX	Texas	42–15
64	1977	Austin, TX	Texas	72–15
65	1978	Houston, TX	Texas	34–0
66	1979	Austin, TX	Texas	26–9
67	1980	Houston, TX	Texas	41–28
68	1981	Austin, TX	Texas	31–3
69	1982	Houston, TX	Texas	34–7
70	1983	Austin, TX	Texas	42–6
71	1984	Houston, TX	Texas	38–13
72	1985	Austin, TX	Texas	44–16
73	1986	Houston, TX	Texas	17–14
74	1987	Austin, TX	Texas	45–26
75	1988	Houston, TX	Texas	20–13
76	1989	Austin, TX	Texas	31–30
77	1990	Houston, TX	Texas	26–10
78	1991	Austin, TX	Texas	28–7
79	1992	Houston, TX	Texas	23–21
80	1993	Austin, TX	Texas	55–38
81	1994	Houston, TX	Rice	19–17
82	1995	Austin, TX	Texas	37–13
83	1997	Houston, TX	Texas	38–31
84	1998	Austin, TX	Texas	59–21
85	1999	Austin, TX	Texas	18–13
86	2003	Houston, TX	Texas	48–7
87	2004	Austin, TX	Texas	35–13
88	2005	Austin, TX	Texas	51–10
89	2006	Houston, TX	Texas	52–7
90	2007	Austin, TX	Texas	58–14
91	2008	Austin, TX	Texas	52–10
92	2010	Houston, TX	Texas	34–17
93	2011	Austin, TX	Texas	34–9
94	2015	Austin, TX	Texas	42–28
Series: Texas leads 72–21–1				