Ocean Carbon Capture and Storage (OCCS)- The concept and its implications as a geoengineering option.

Richard Sanders and Richard Lampitt

National Oceanography Centre

Southampton

UK

Fate of Anthropogenic CO_2 Emissions (2010)

9.1 GT C y^{-1}

+

0.9 GT C y^{-1}

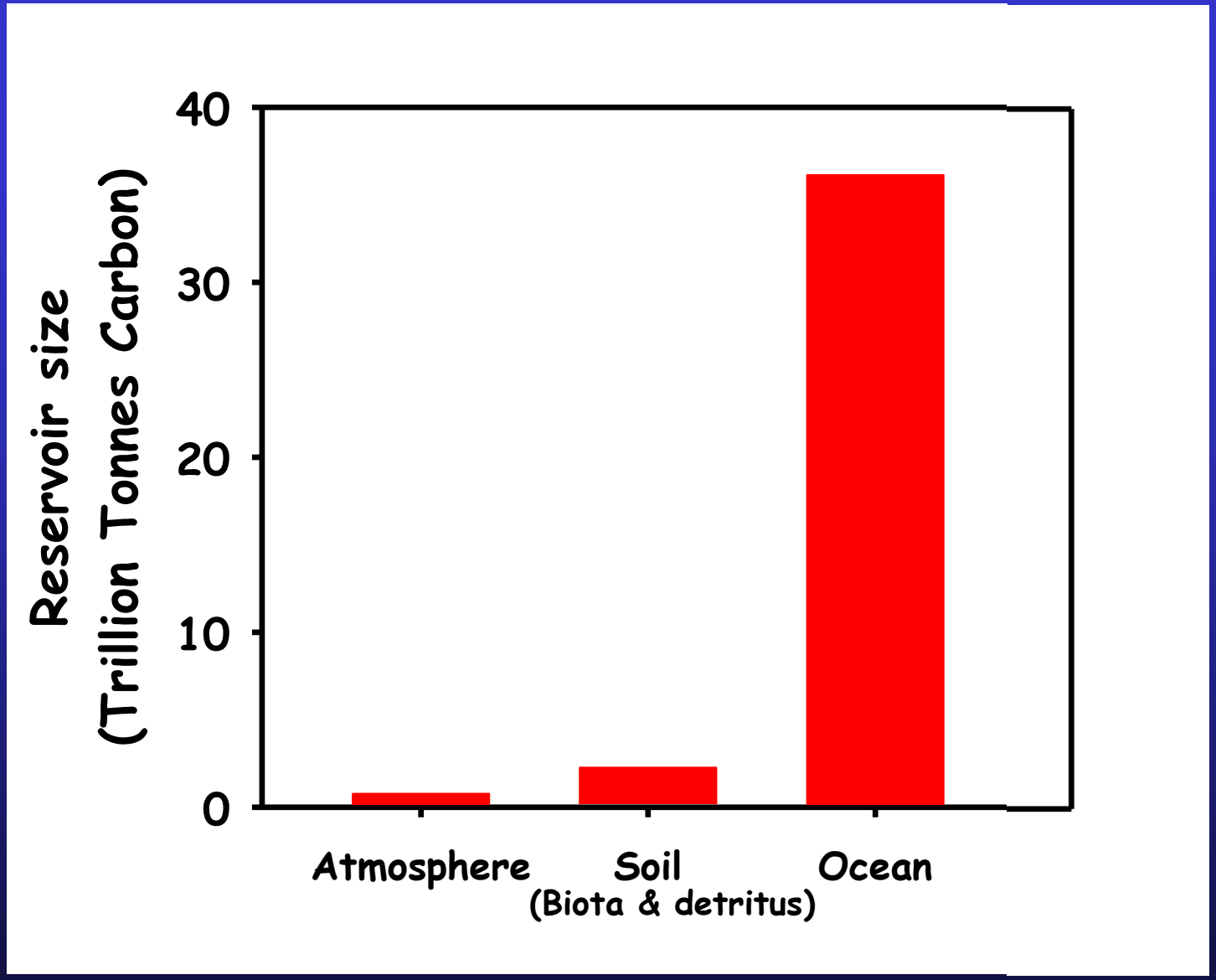
50%

26%

24%

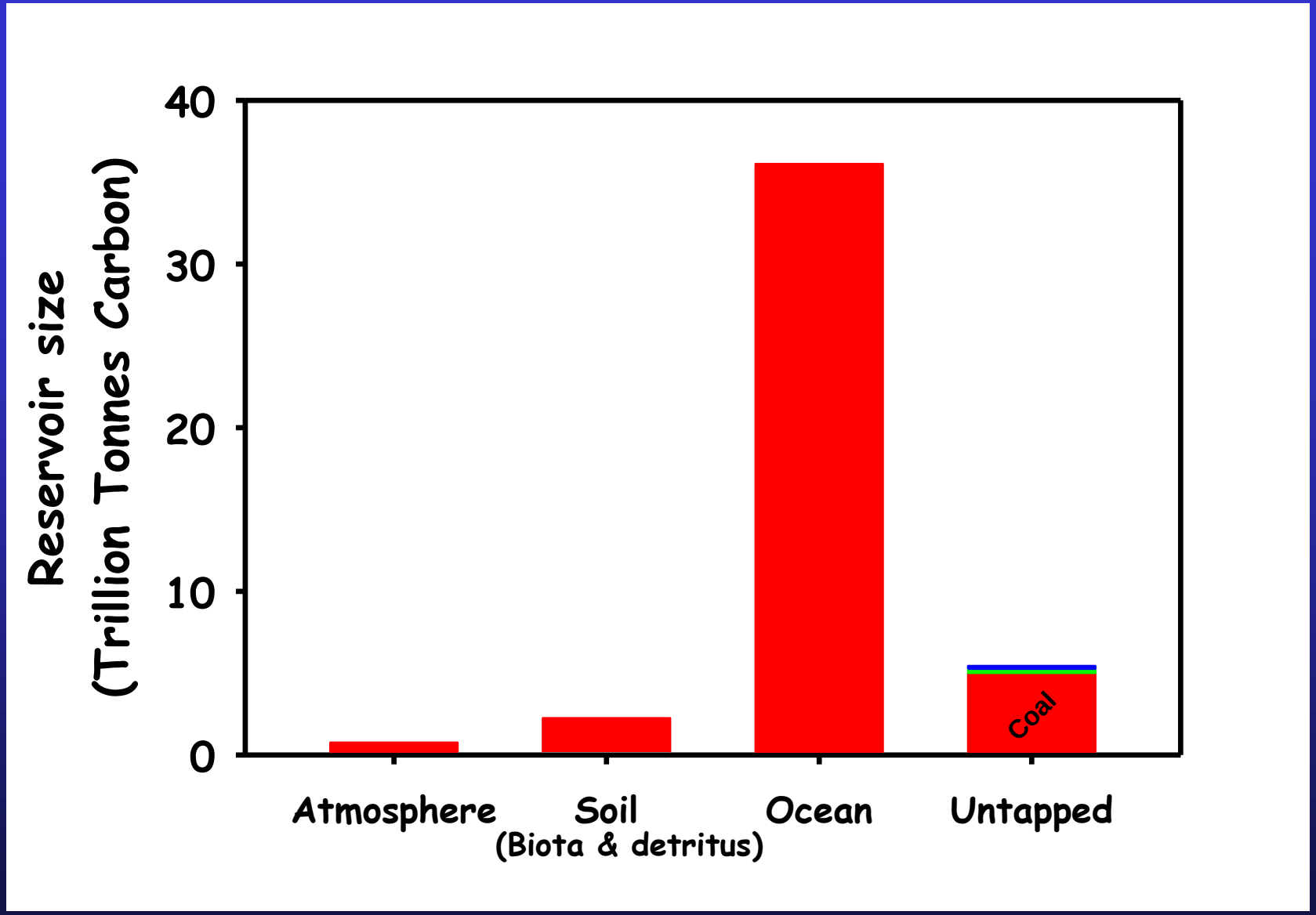
2.4 GT C y^{-1}

From Le Quéré et al. 2009, ; Canadell et al. 2007,



Global reservoirs of carbon

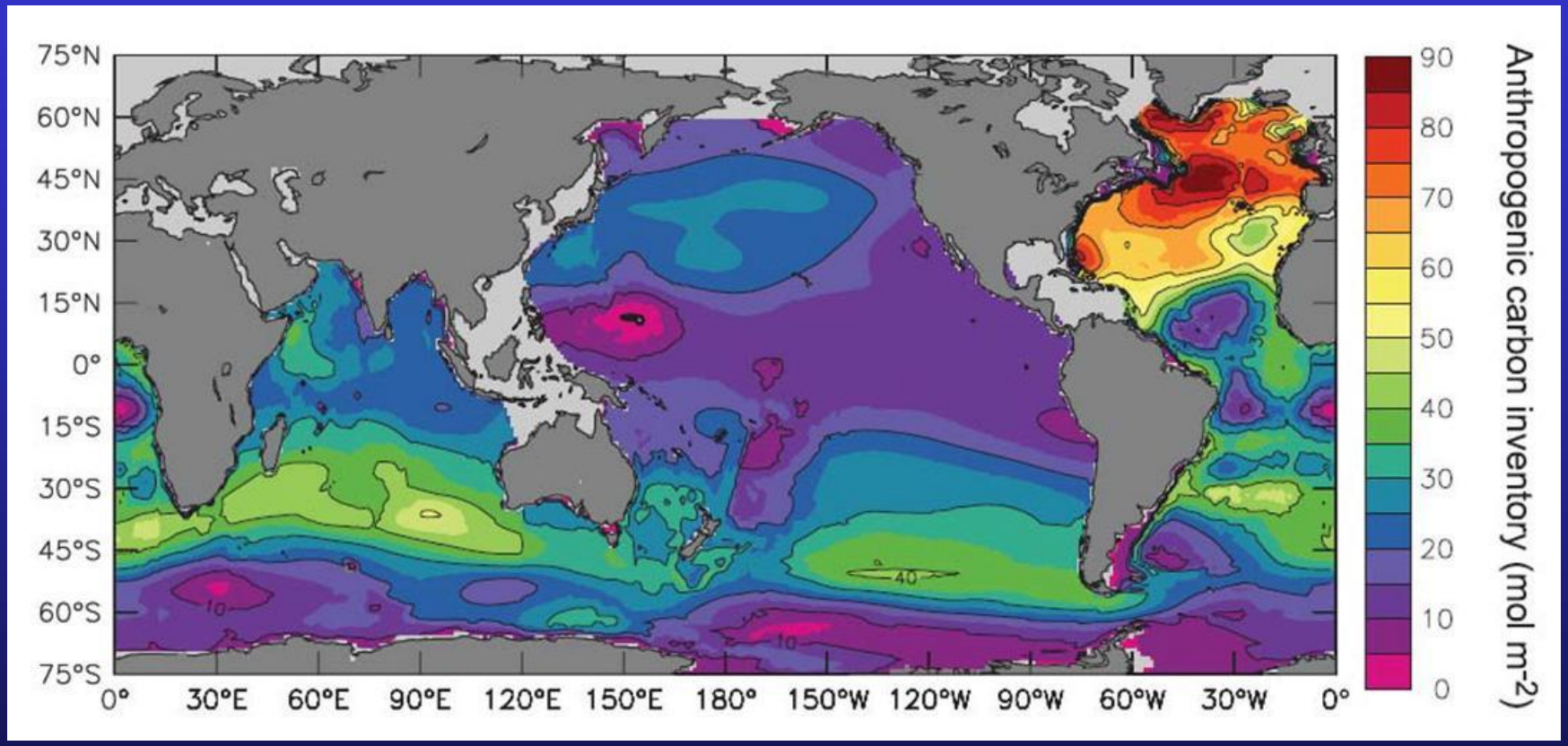
From: Sarmiento and Gruber (2002), Archer (2005)



Global reservoirs of carbon

From: Sarmiento and Gruber (2002), Archer (2005)

Anthropogenic CO_2 in the ocean (mol m^{-2})

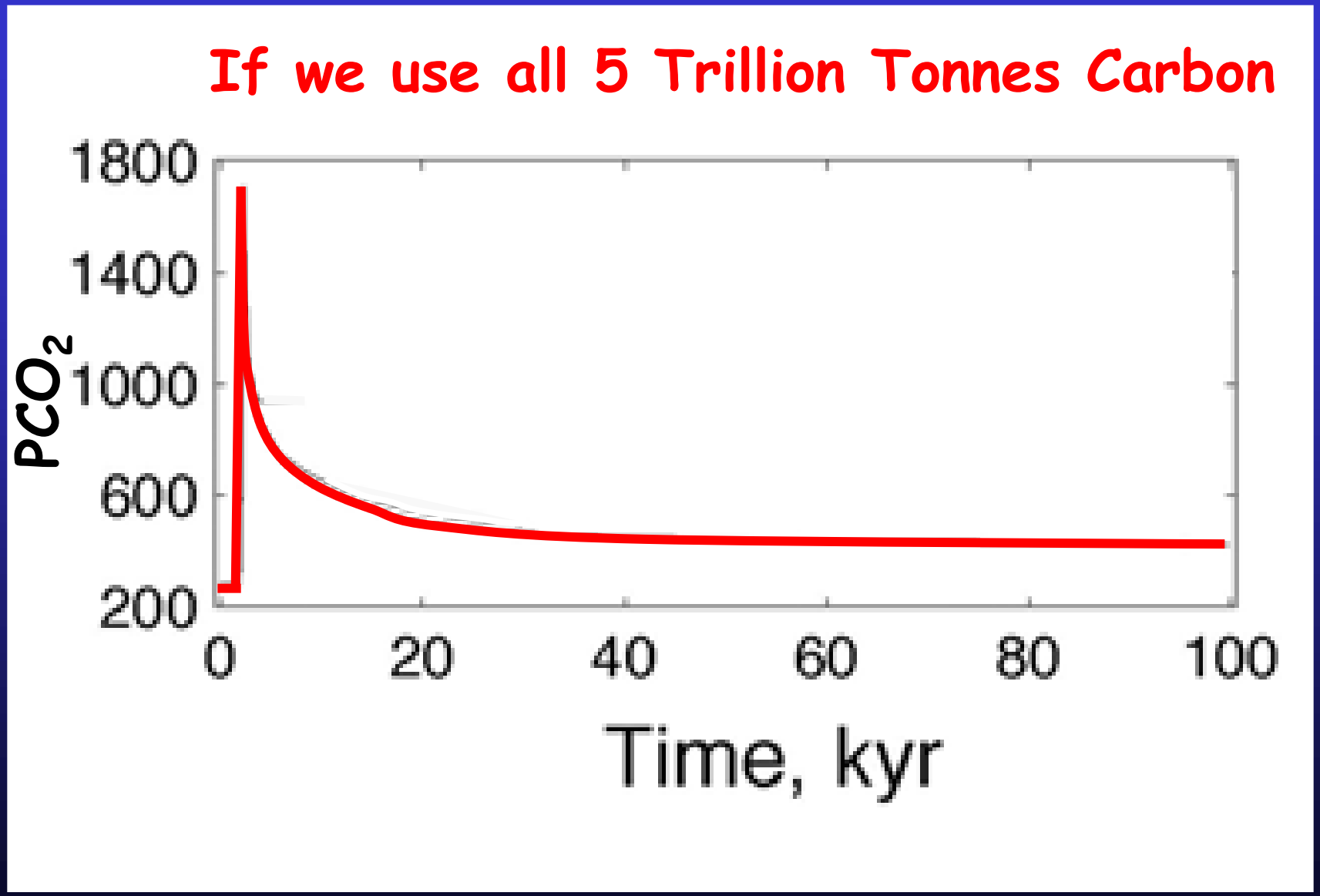


Storage of anthropogenic CO_2 (1800-1994) = 48% of the emissions

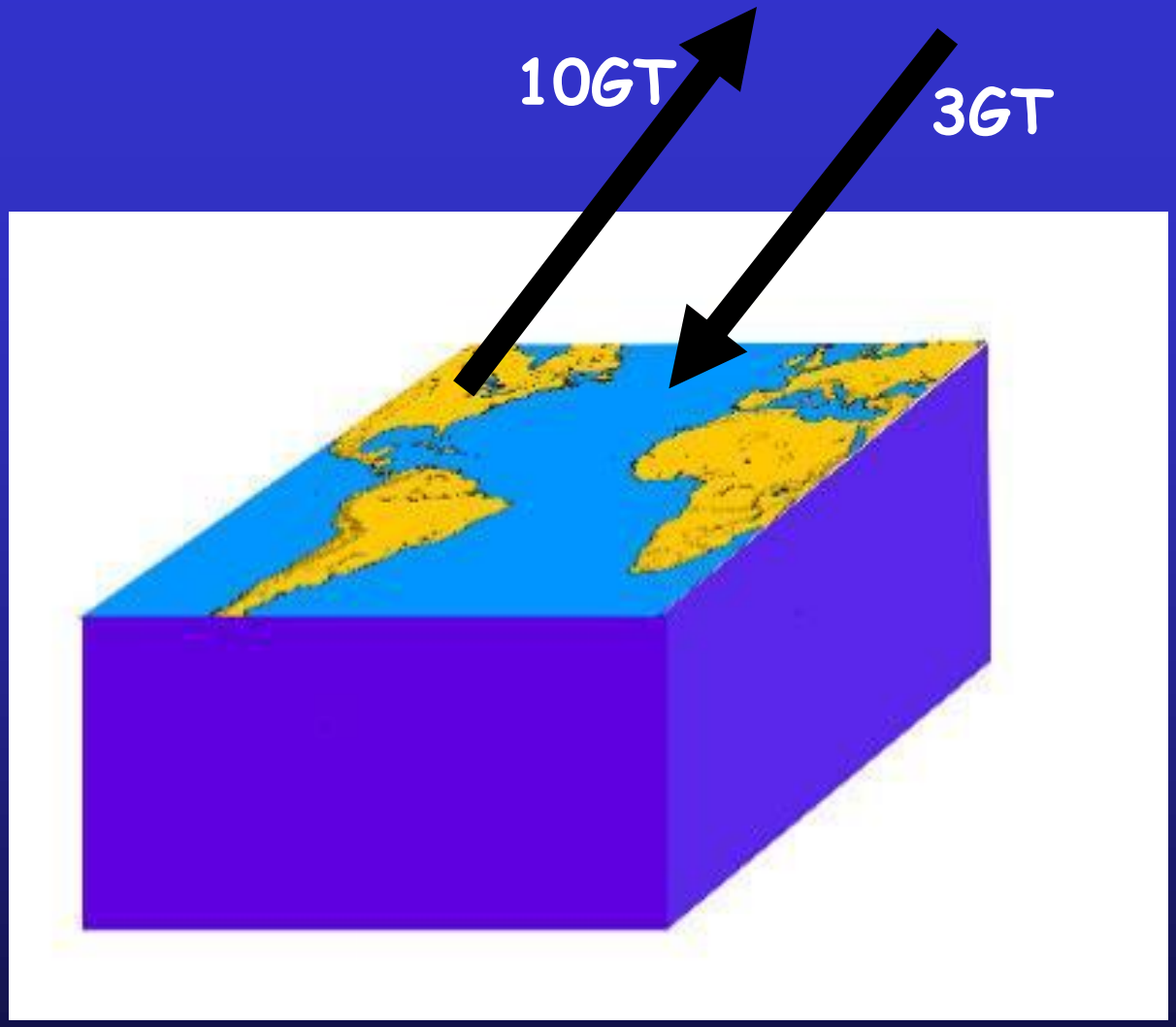
Sabine et al 2004

Almost all of the released carbon will end up in the ocean eventually ..... but before that happens:

Atmospheric CO_2 concentration



Archer (2005)

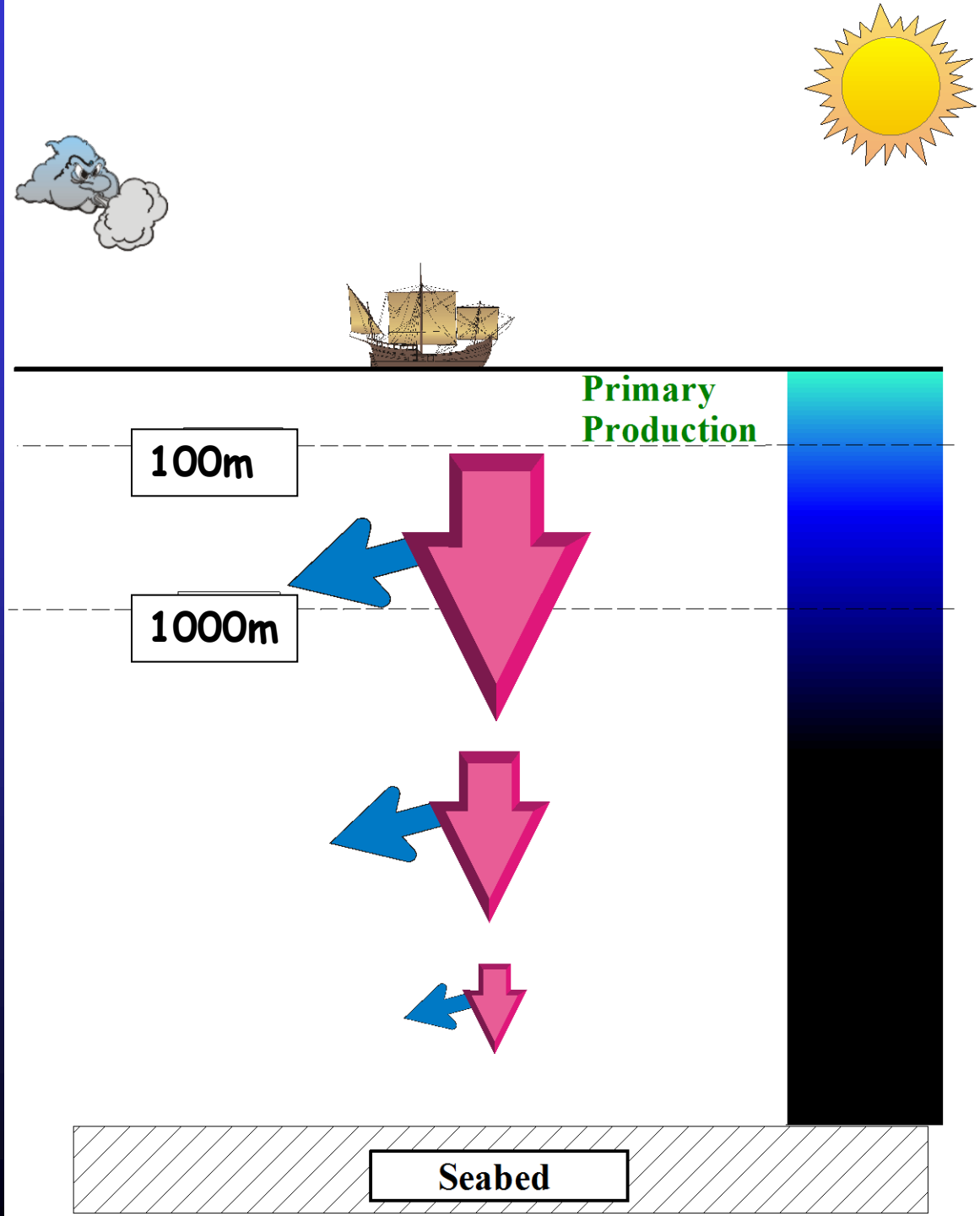


Global carbon fluxes

Carbon pumps

Solubility pump

Biological pump



The Biological Carbon Pump (BCP)

Export

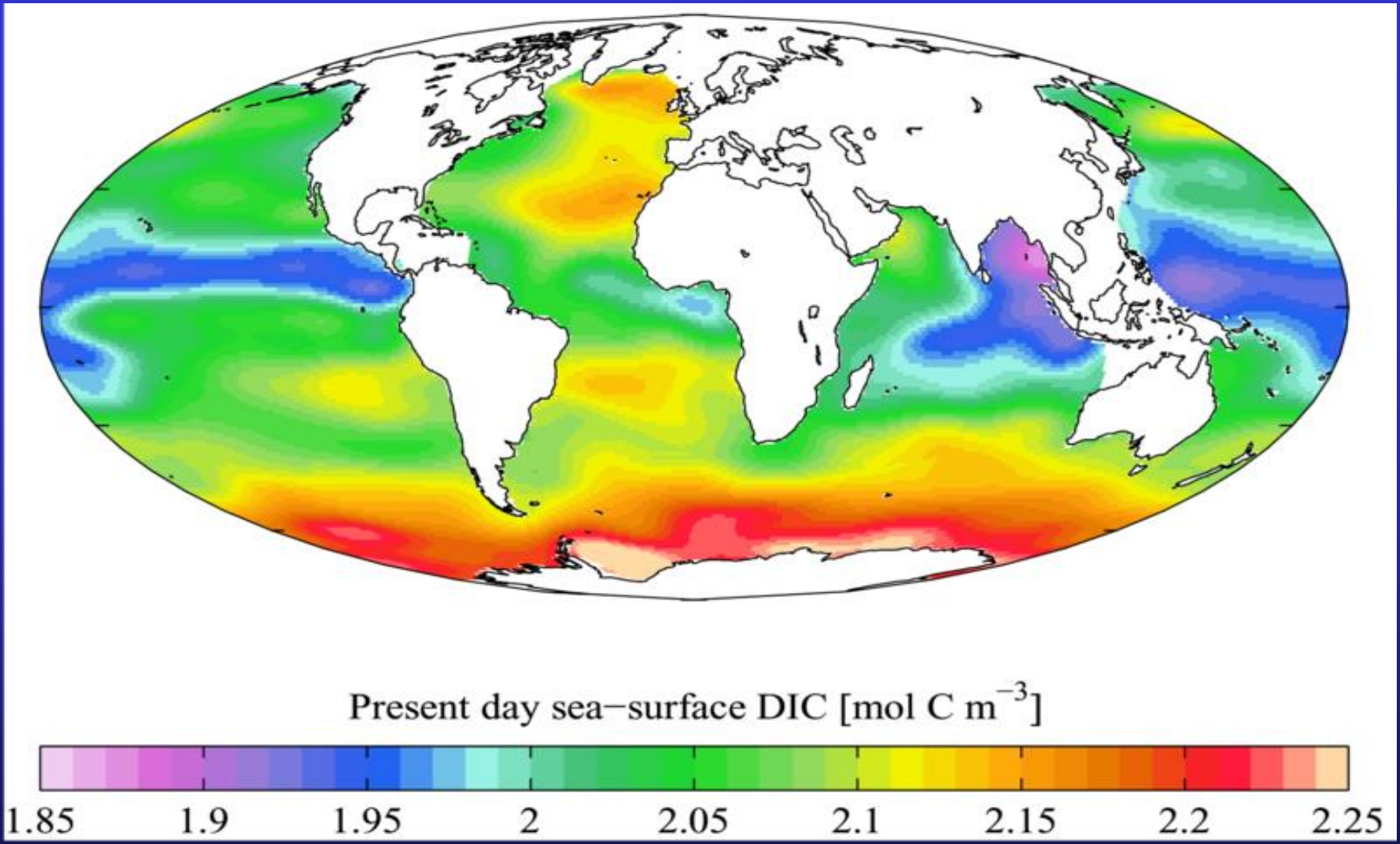
Sequestration

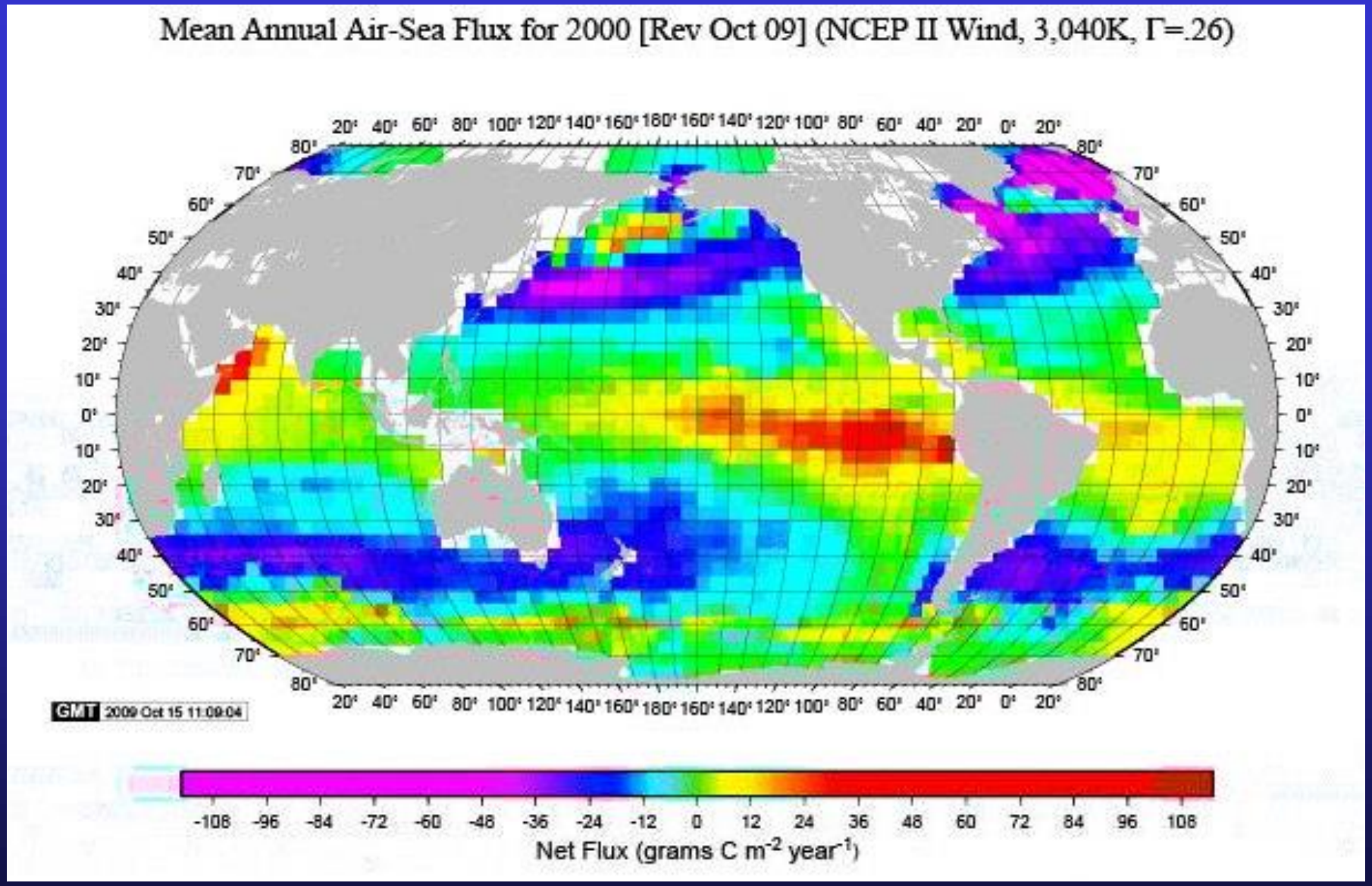
For all geoengineering schemes proposed:

1: Will it work?

2: Is it safe / legal / ethical?

Ocean Carbon Capture and Storage (OCCS)


Present day sea−surface DIC [mol C m^{-3}]
1.85
1.9
1.95
2
2.05
2.1
2.15
2.2
2.25



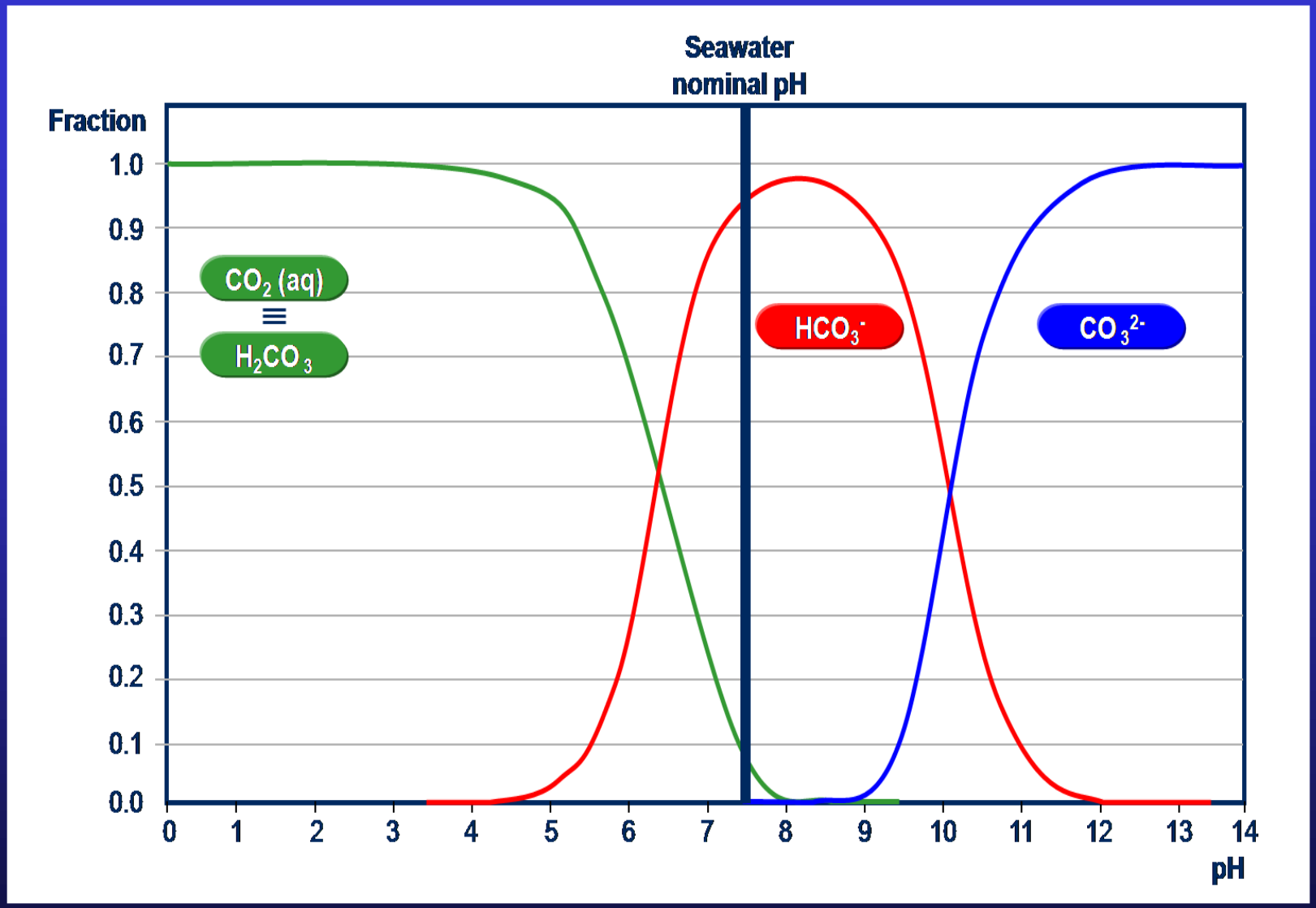
Transfer of CO_2 in and out of the ocean

Takahashi (2009)

Ocean Carbon Capture and Storage (OCCS)

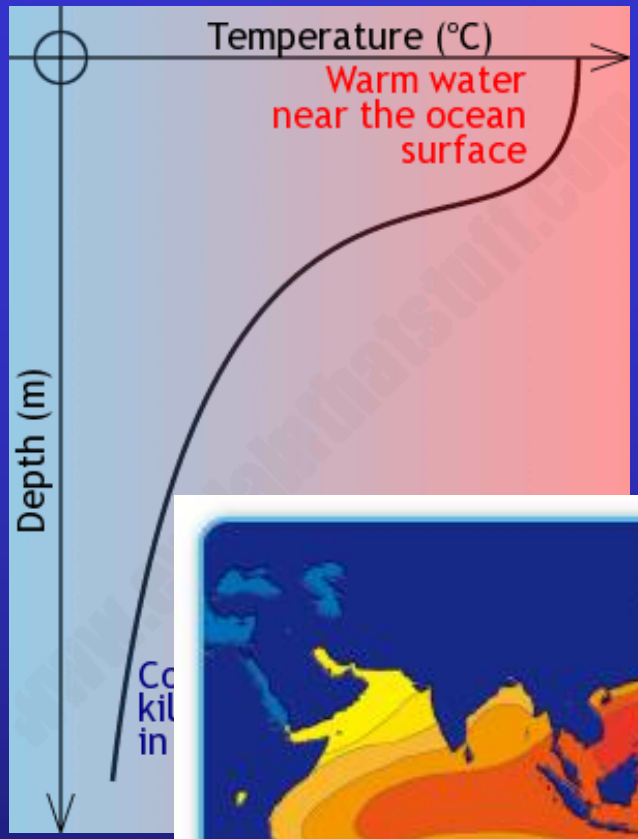
The principle is to remove CO_2 from the ocean so that either outgassing is reduced or uptake is enhanced.

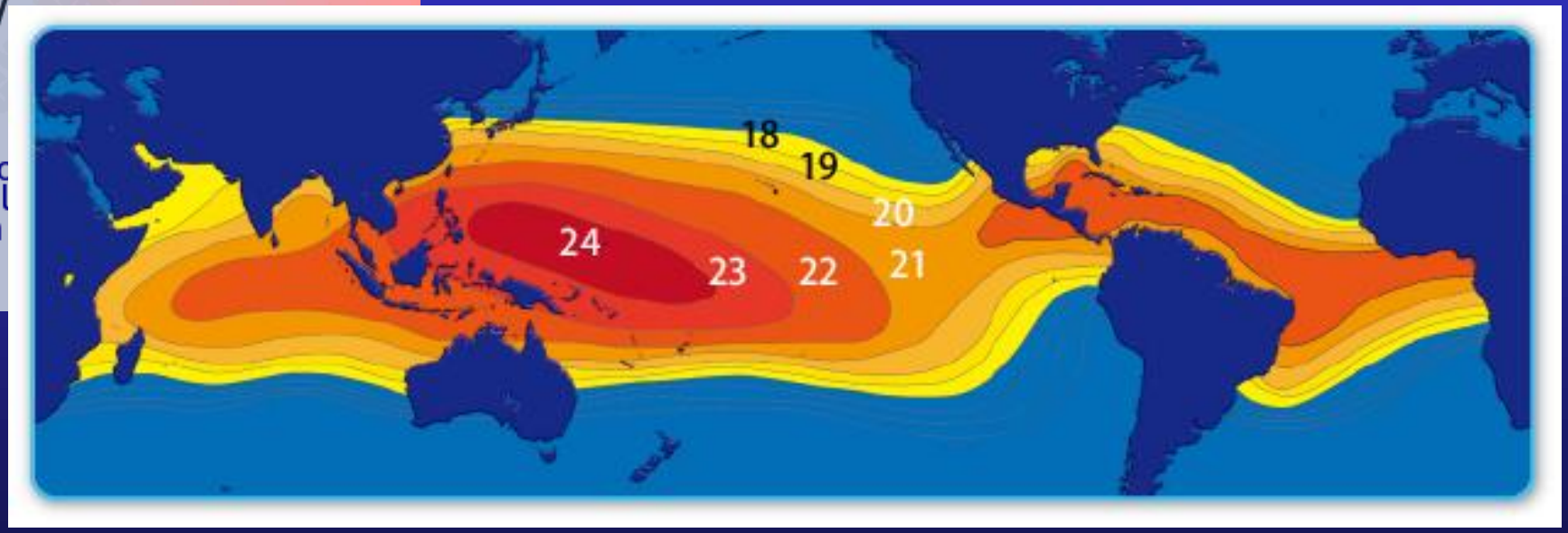
Removal of CO_2 on an industrial scale is hard.



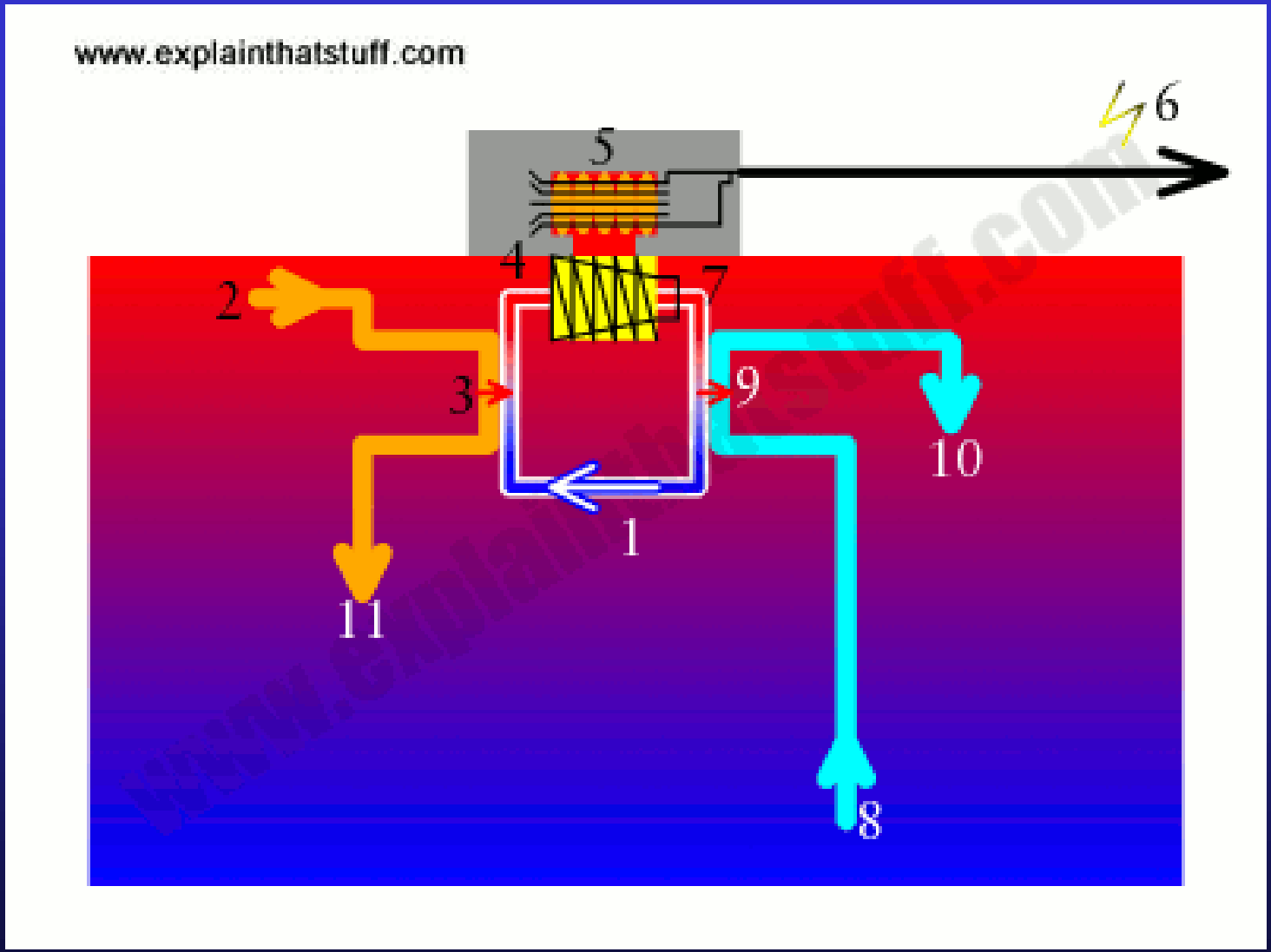
Bjerrum plot

Ocean Thermal Energy Conversion (OTEC)





Temperature difference between surface and 1000m depth



Closed circuit OTEC system

Generic 100 MW Closed-Cycle OTEC Facility Characteristics

	Range of Parameters
Location	3 – 4 miles offshore Hawaii
Warm Water Intake Depth	20 m
Warm Water Intake Temperature	25°C
Warm Water Intake Flow	460 m^3/s
Warm Water Intake Velocity	0.15 m/s
Warm Water Intake Antifouling	Intermittent Chlorination (50 – 70 µg/L for 1 hr)
Cold Water Intake Depth	1000 m
Cold Water Intake Temperature	5°C
Cold Water Pipe Diameter	10 m
Cold Water Intake Flow	370 m^3/s
Cold Water Intake Velocity	2.5 m/s
Cold Water Intake Antifouling	None
Discharge	Combined or Separate Depth TBD

830 tonnes/second for 100MW

Cf

Thanet Offshore Wind Project, UK: 300 MW.

Three Mile Island Nuclear plant, USA: 800 MW

Three Gorges hydro-elec. plant, China: 22.5 GW

Geoengineering

<u>OCCS could:</u>

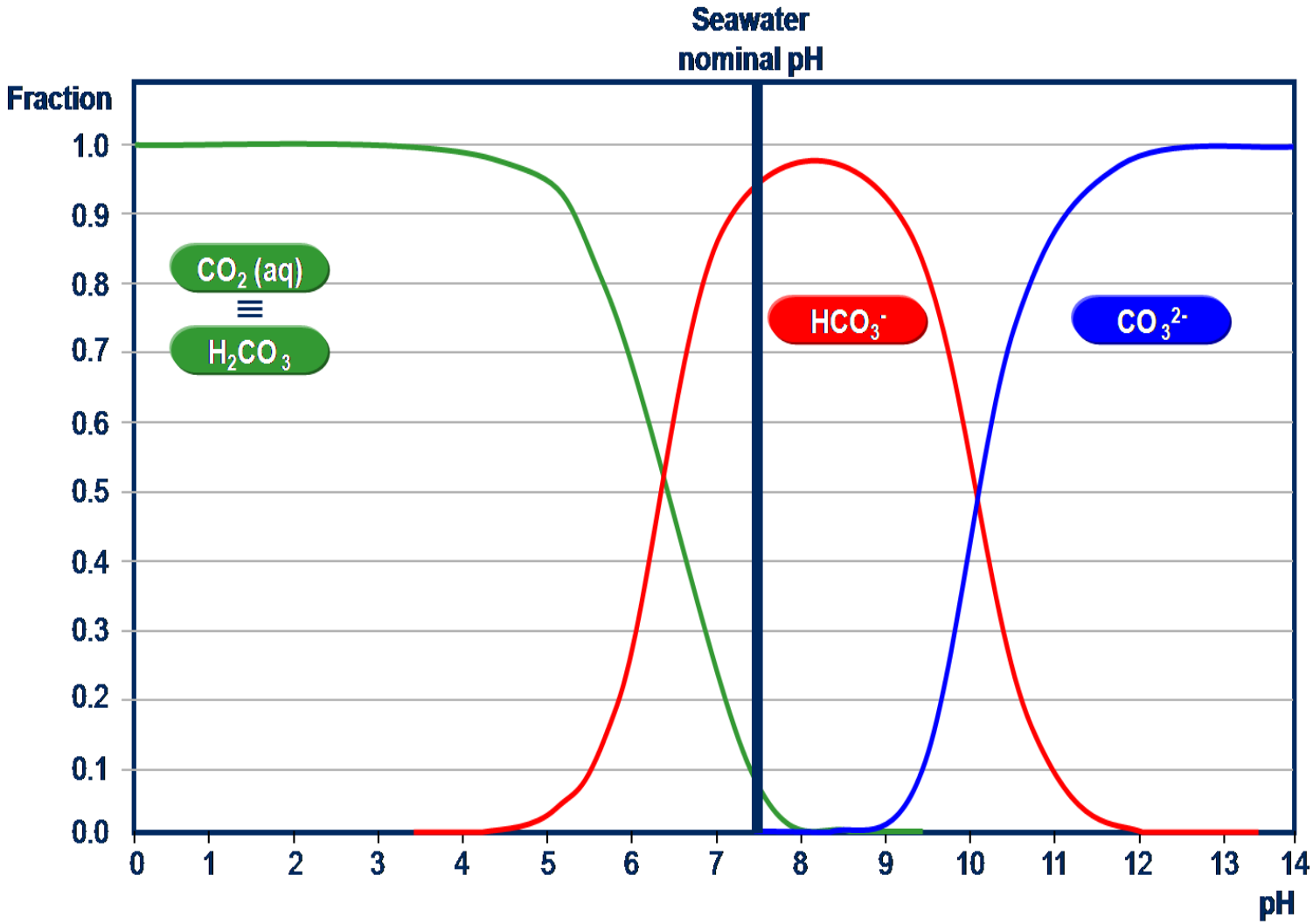
1: Reduce CO_2 outgassing/enhance uptake

And if with OTEC

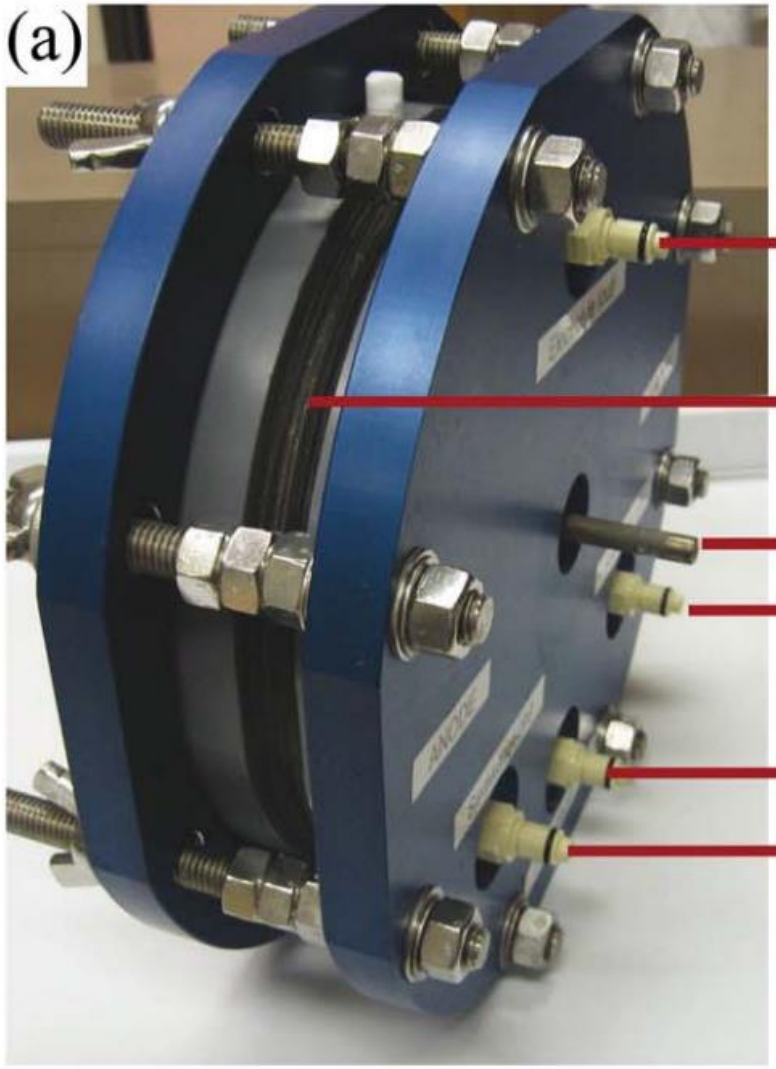
2: Enhance surface productivity
3: Enhance the BCP

Chemical engineering developments required

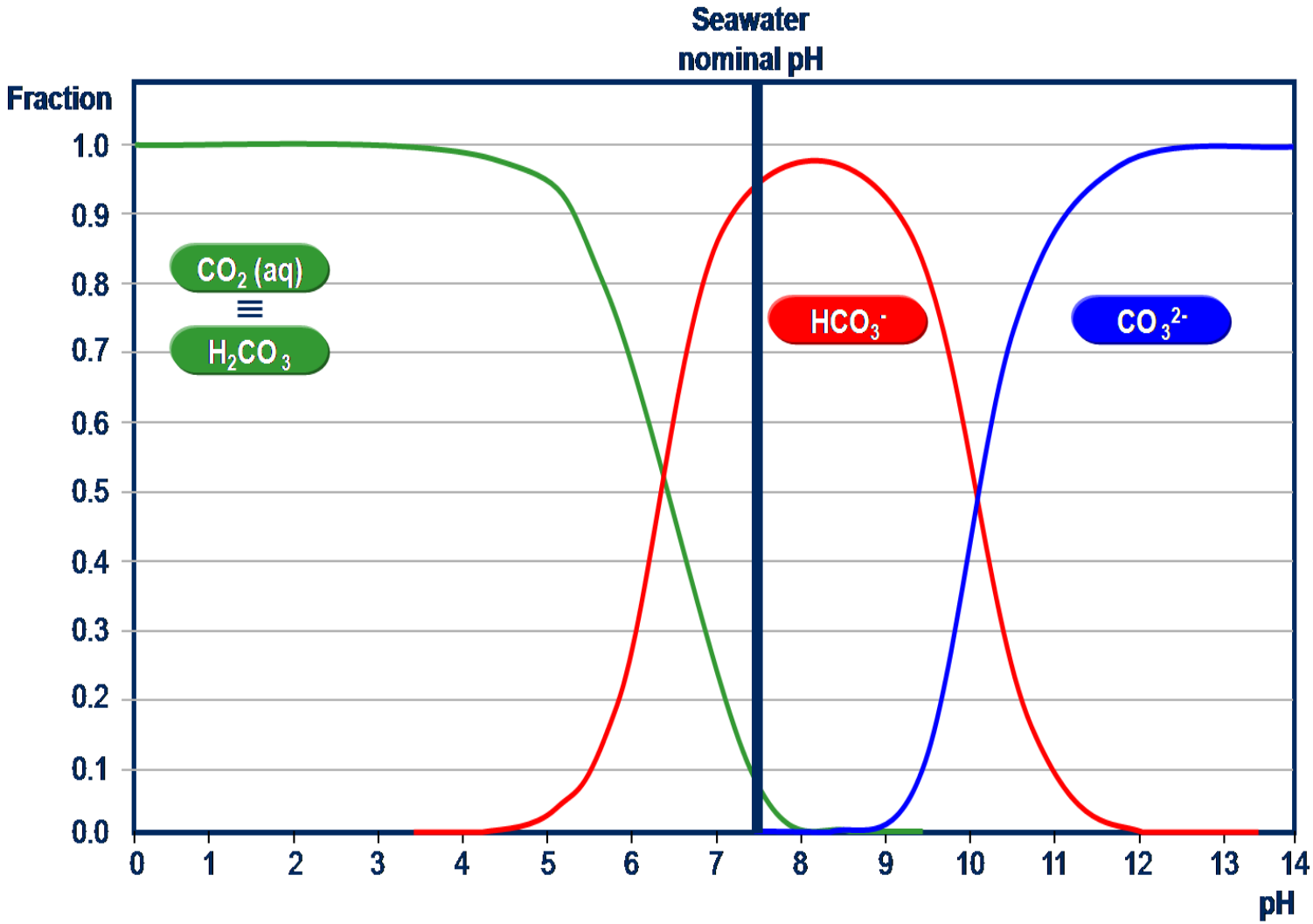
How to extract CO_2 from seawater

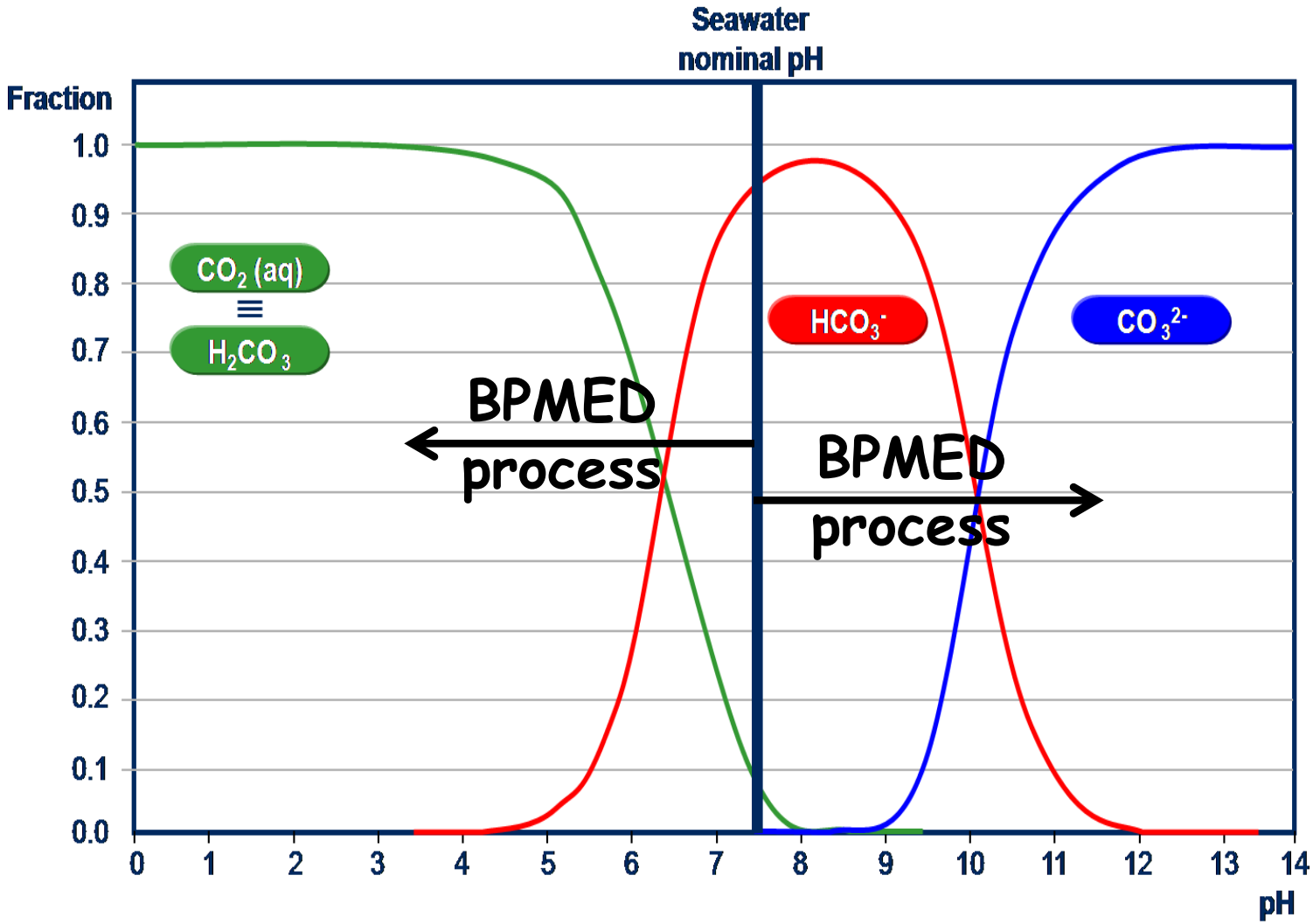

Seawater
nominal pH
Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CO2 (aq)
≡
H2CO3
HCO3-
CO3 2-
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
pH

Bipolar Membrane Electrodialysis (BPMED)



Eisaman et al 2012


Seawater
nominal pH
Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CO2 (aq)
≡
H2CO3
HCO3-
CO3 2-
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
pH


Seawater
nominal pH
Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
pH
CO_2 (aq)
≡
H_2CO_3
HCO_3^-
CO_3^{2-}
BPMED
process
BPMED
process

Seawater pumped through BPMED system giving two output streams:
acidified and basified seawater.

Acidified stream: HCO_3^- and CO_3^{2-} ions converted to dissolved CO_2, which is then vacuum stripped.

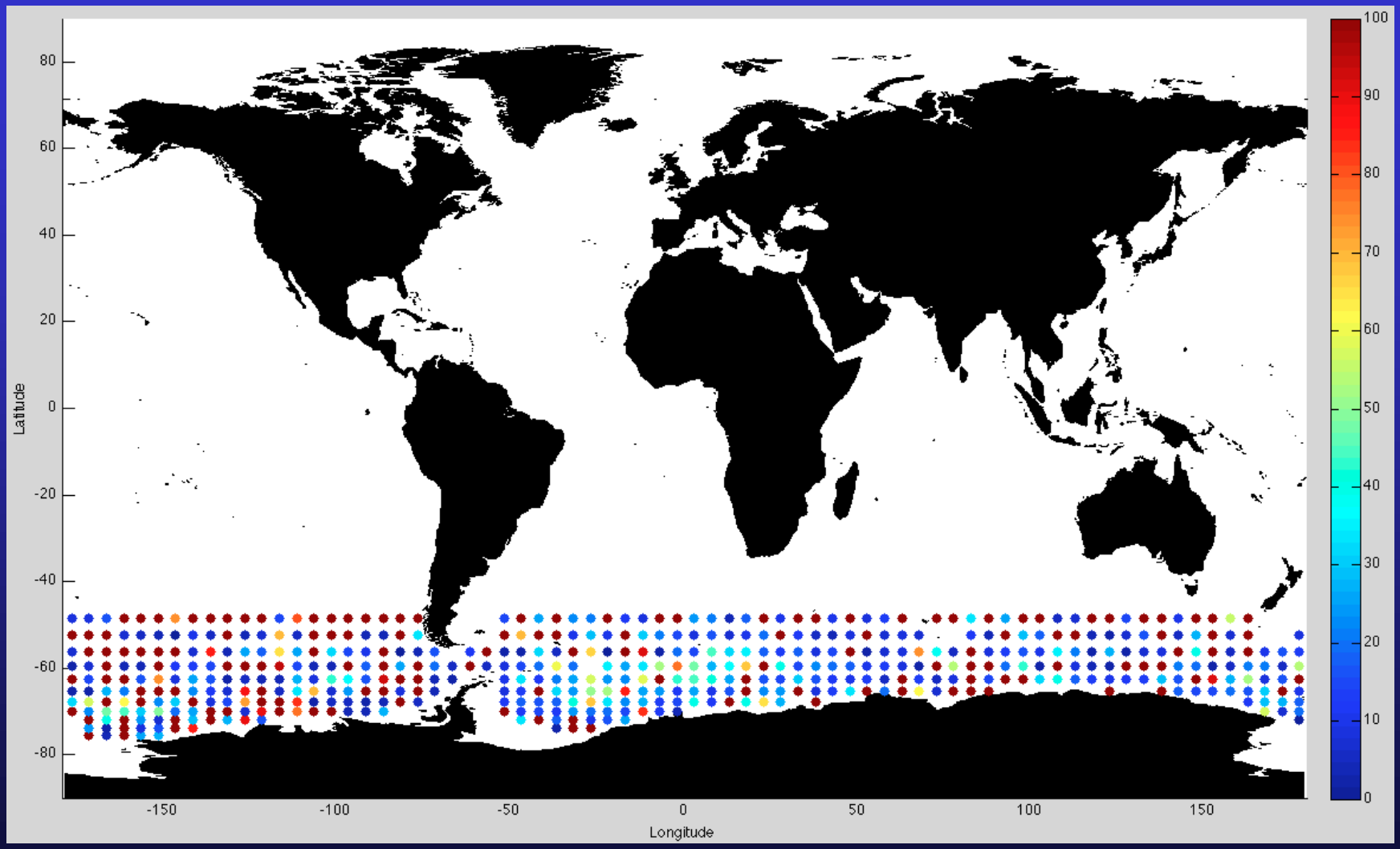
The CO_2-depleted acidified solution then combined with the basified solution for return to ocean.

59% extraction of DIC as CO_2 gas with energy consumption of 242 KJ/mol (CO2)

Type of physical modeling study required

(This was for OIF)

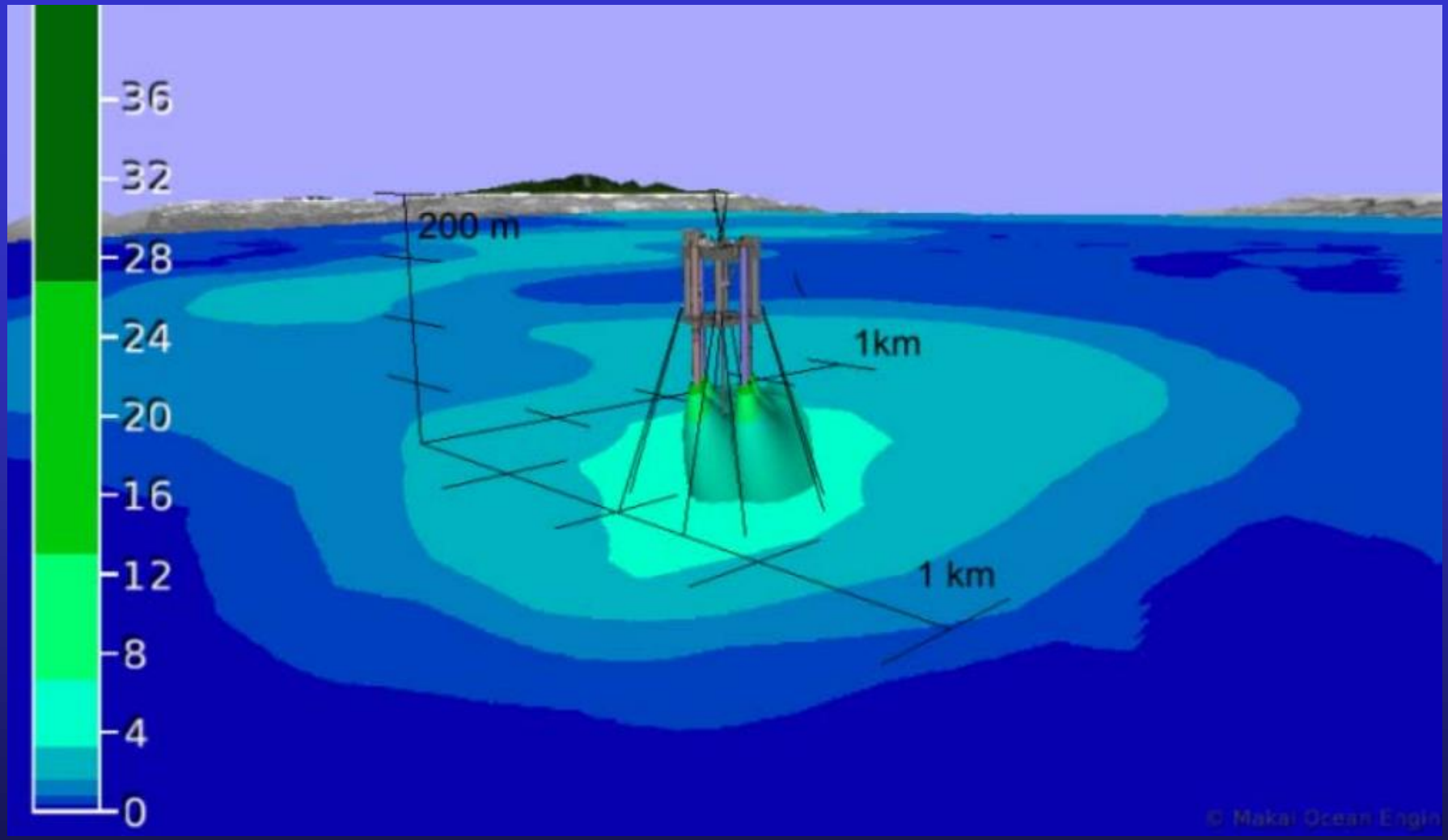
The Global Conveyor Belt



Robinson et al 2013

Type of environmental assessment required

- Lab experiments
- Field experiments
- Models



Model output of nitrate concentration from 100MW OTEC plant

Grandelli et al 2012

Type of environmental assessment required

1: Phytoplankton response to such perturbation
2: Effect on the BCP

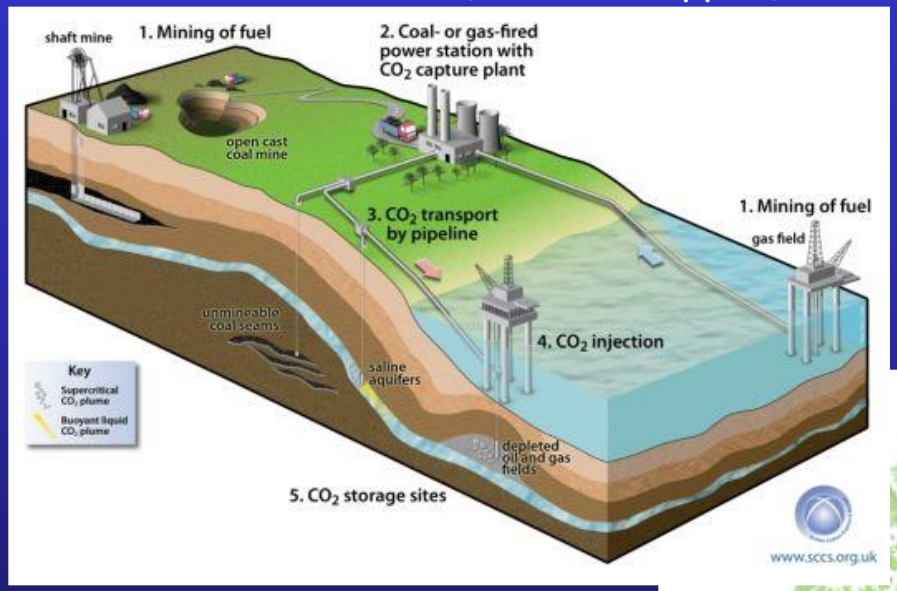
Research into carbon storage required

Carbon Storage technologies

1. Unmineable coal seams
2. Saline aquifers
3. Depleted oil and gas fields

CCS Projects

on shore <-> off shore

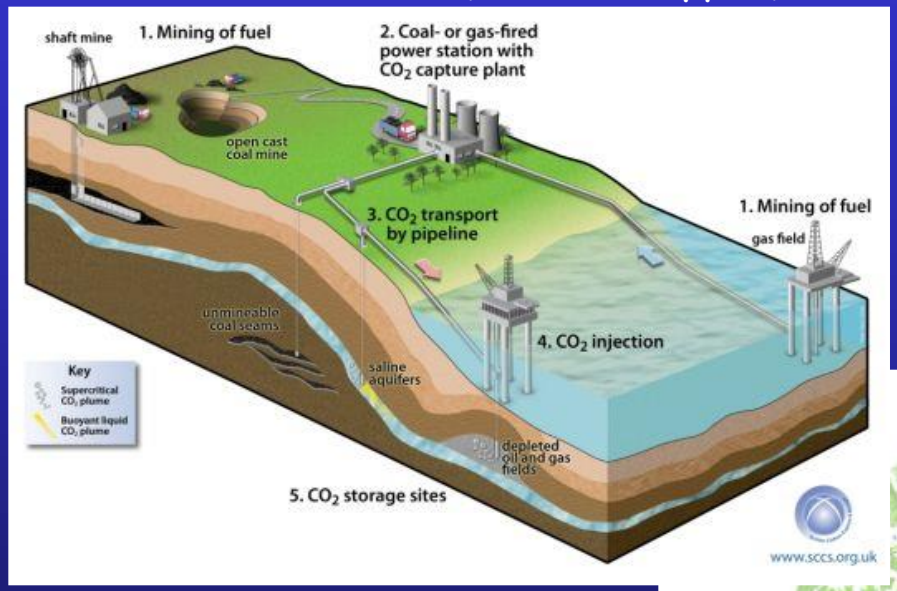


worldwide > 60 CCS projects identified

Courtesy Rachael James

CCS Projects

on shore <-> off shore

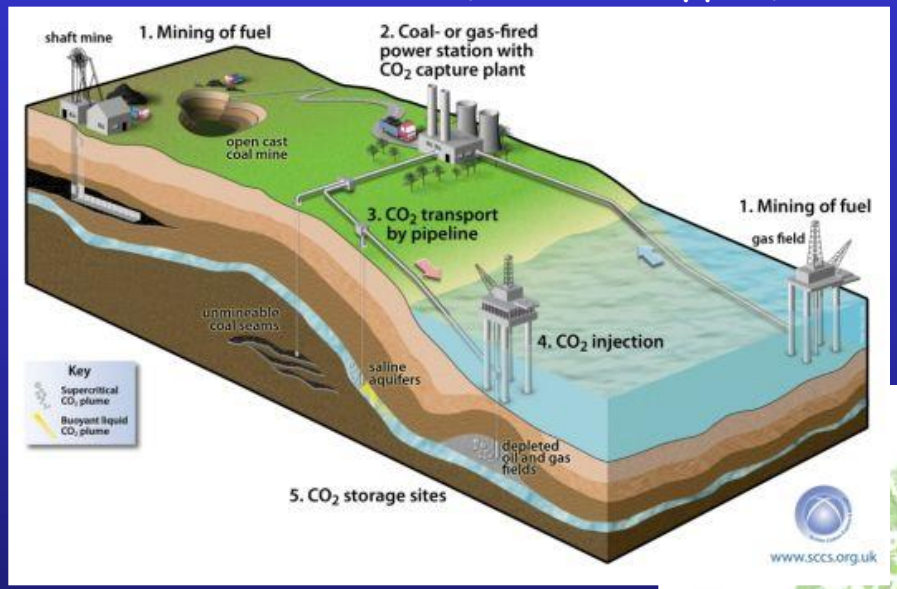


worldwide > 60 CCS projects identified
17 active projects

Courtesy Rachael James

CCS Projects

on shore <-> off shore



worldwide > 60 CCS projects identified
17 active projects
Europe:-> offshore storage

Longest operated site (since 1996)
1 Mt CO_2 a^{-1}

Courtesy Rachael James

Intended biogeochemical consequences:

1: Reduced outgassing/ enhanced uptake
2: Enhanced productivity
3: Enhanced biological carbon pump

Unintended consequences:

1: Harmful algal blooms
2: Reduced O_2 in lower water column

Other issues:

1. Verification
2. Links with the commercial sector.