南方科技大学
SOUTH UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA

Oceanic Carbon Capture and Sequestration (OCCS): One of The Most Feasible Emergency Strategies Dealing With Climate Change and Global Warming.

By 谢济宇

2018.1.15

THESIS STATEMENT

The level of carbon dioxide (CO_2) released into the atmosphere has **increased significantly** since the beginning of the industrial era.

Climate catastrophe may led to the earth as a result of the climate change and global warming, where human beings are **unable to survive**.

OCCS might be one of the best emergency strategies in dealing with climate change and global warming due to the large capacity of storing CO_2 when the situation is too worse tocontrol.

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All the data is shown in billion tonnes CO_2 ($GtCO_2$)

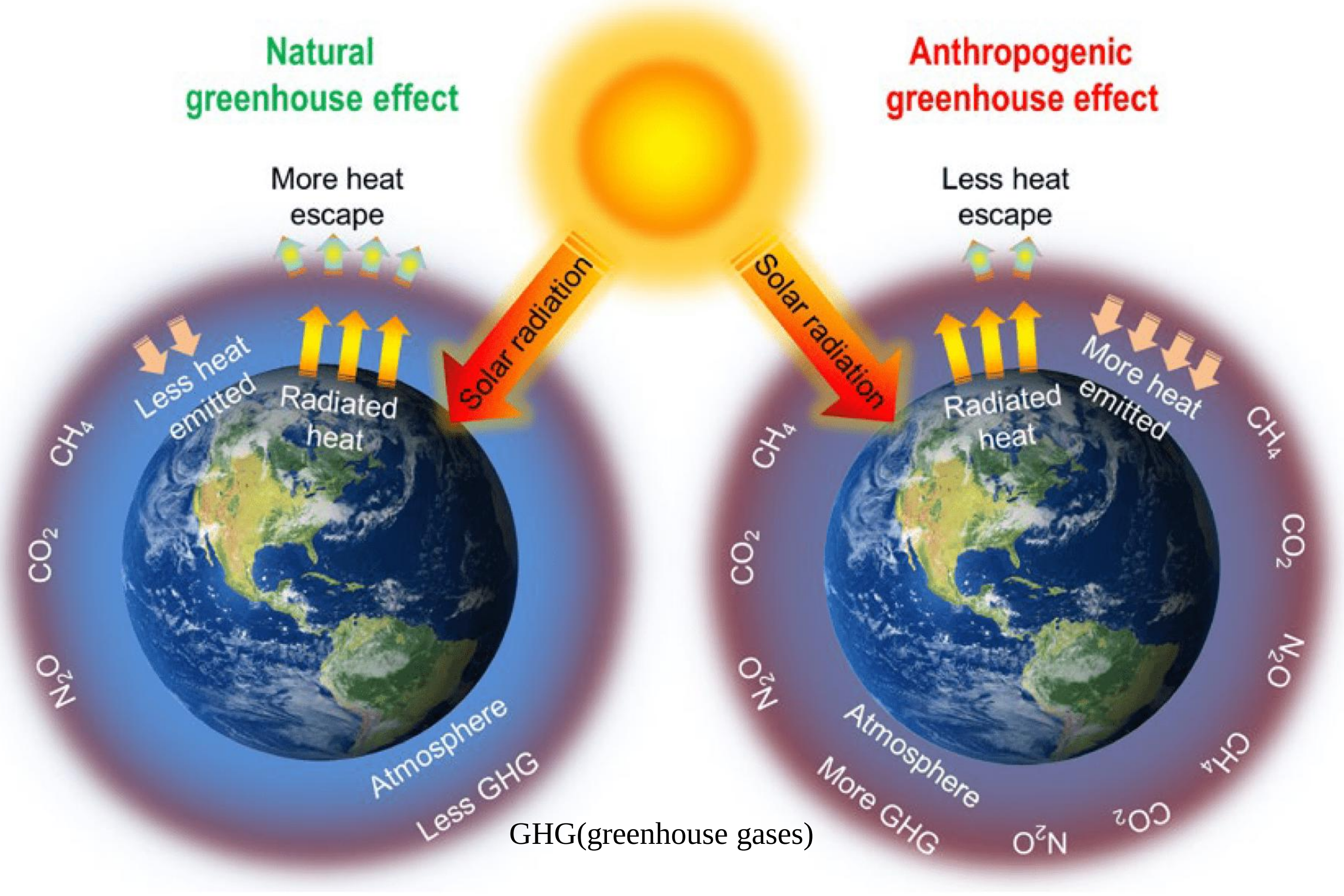
1 Gigatonne (Gt) = 1 billion tonnes = 1×10^{15}g = 1 Petagram (Pg)

1 kg carbon (C) = 3.664 kg carbon dioxide (CO_2)

1 GtC = 3.664 billion tonnes CO_2 = 3.664 $GtCO_2$

Anthropogenic Perturbation of the Global Carbon Cycle

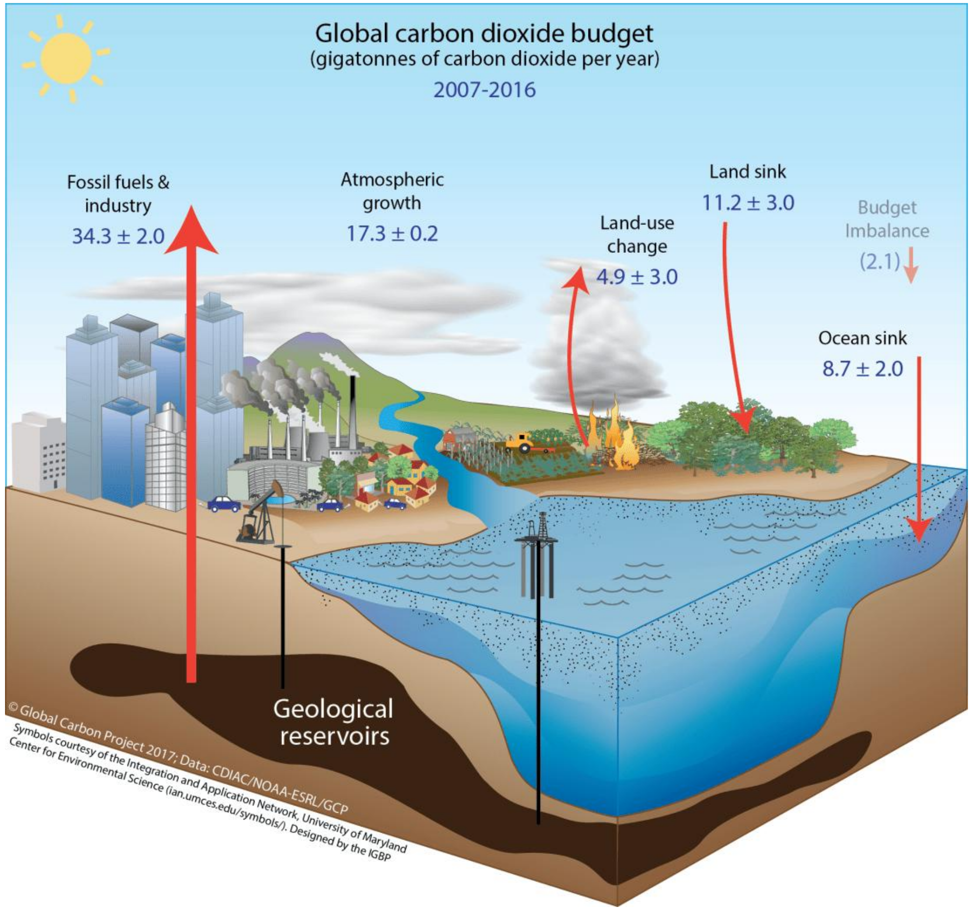
Graphical illustration of natural and anthropogenic greenhouse effects.



GHG(greenhouse gases)

Nanda, S., Reddy, S. N., Mitra, S. K., & Kozinski, J. A. (2016). The progressive routes for carbon capture and sequestration. *Energy Science and Engineering*, *4*(2), 99–122. https://doi.org/10.1002/ese3.117

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2007–2016 ($GtCO_2$/yr)

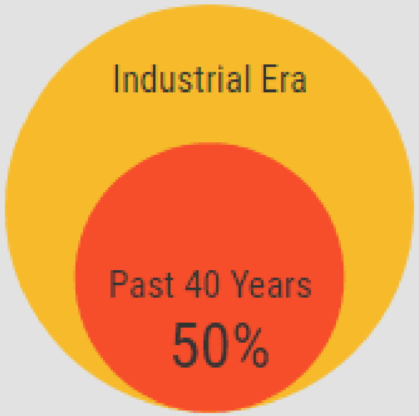


The budget imbalance is the difference between the estimated emissions and sinks.

Source: CDIAC; NOAA-ESRL; Le Quéré et al 2017; Global Carbon Budget 2017

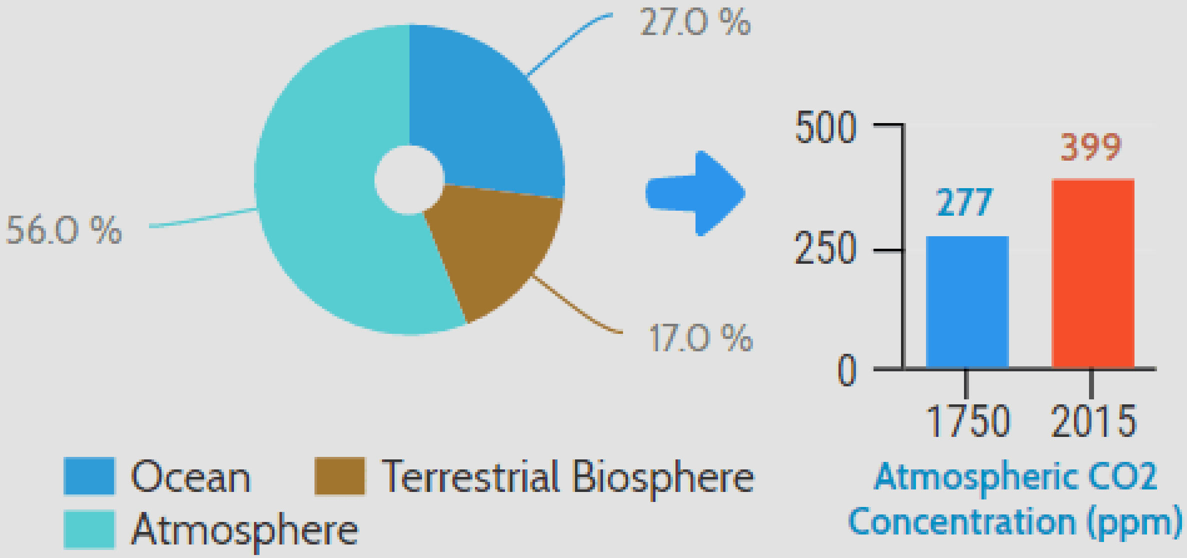
Greenhouse Gas (GHG) Emissions

The total emission of industial and anthropogenic CO2:
2,040 ± 310 GtCO2
(1750 to 2011, since the pre-industrial era).

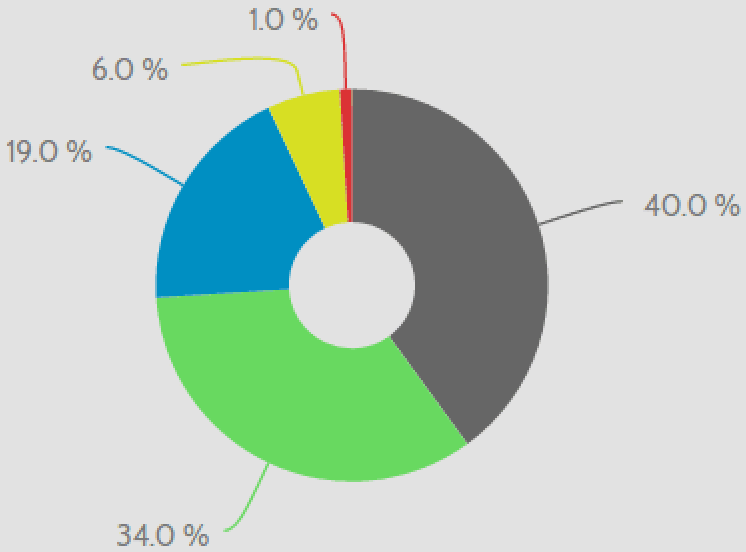


- **Nearly half of the emissions occurred during the past 40 years**

Total Global Emisssions Storage (2015, 36.4 GtCO2)



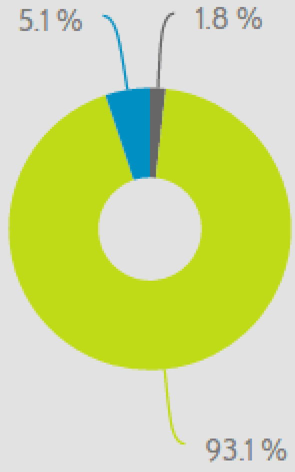
Global Emission of CO_2 (2016)



Data Source: Globyal Carbon Project

Coal | Oil | Gas | Cement | Flaring

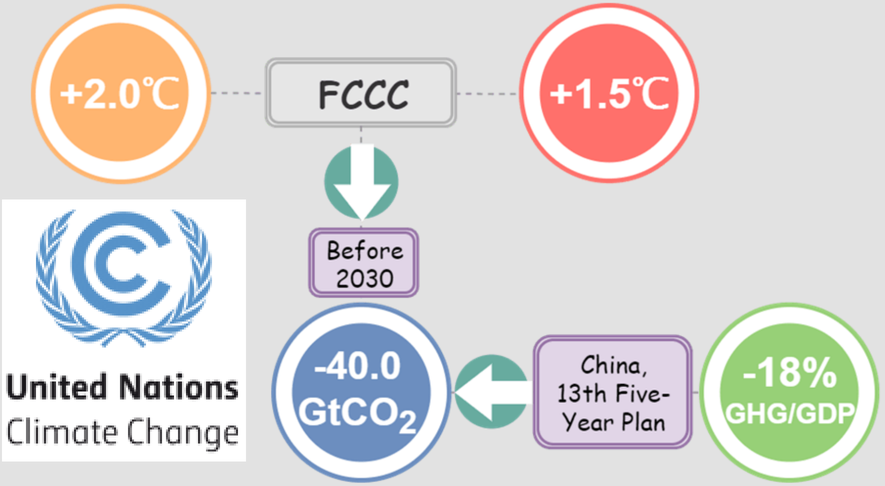
Nature Carbon Storage



- Atmosphere (750 $GtCO_2$)
- Ocean (40,000 $GtCO_2$)
- Terrestrial Biosphere (2,200 $GtCO_2$)

The Paris Agreement

In order to slow down the global warming procedure, international negotiations have produced the Framework Convention on Climate Change (FCCC) to achieve a goal of "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels". Thus, the greenhouse gases should reduce to 40.0 Gt by the year of 2030.



Less CO_2…… !!!Global Warming !!!

Aridification
Acidification
Sea Level Rising
Polar Ice Melting
Islands Disappears
Food Crisis
Financial lost
Ecological Catastrophe
Climate Refugees
Economical Impacts
……

Ocean Acidification: The Other CO_2 Problem

Scott C. Doney,[1] Victoria J. Fabry,[2] Richard A. Feely,[3] and Joan A. Kleypas[4]

【Ecology-生态】Spatial and temporal patterns of mass bleaching of corals in the Anthropocene

人类世珊瑚大量白化的时空格局

Terry P. Hughes, Kristen D. Anderson, et al.

http://science.sciencemag.org/content/359/637

图片来源：science.sciencemag.org

（导读 寒雨）珊瑚白化发生的间隔太短不足以让珊瑚完成恢复。本研究分析了 1980-2016 年间全球 100 个珊瑚礁分布点的白化现象，发现白化事件之间的恢复时间稳步减少至 6 年。日益严重的全球变暖导致热带海平面温度上升，这些变化可能导致珊瑚白化更加频繁。

nature climate change

Access provided by South University Of Science And Technology Of China

Altmetric: 731 More detail »

Letter

Keeping global warming within 1.5 °C constrains emergence of aridification

南科大环境学院郑修宗课题组在《自然气候变化》发表干旱化最新研究成果

Chang-Eui Park, Su-Jong Jeong, Manoj Joshi, Timothy J. Osborn, Chang-Hoi Ho, Shilong Piao, Deliang Chen, Junguo Liu, Hong Yang, Hoonyoung Park, Baek-Min Kim & Song Feng

Nature Climate Change **8**, 70–74 (2018)
doi:10.1038/s41558-017-0034-4
Download Citation

Received: 21 June 2017
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Published online: 01 January 2018

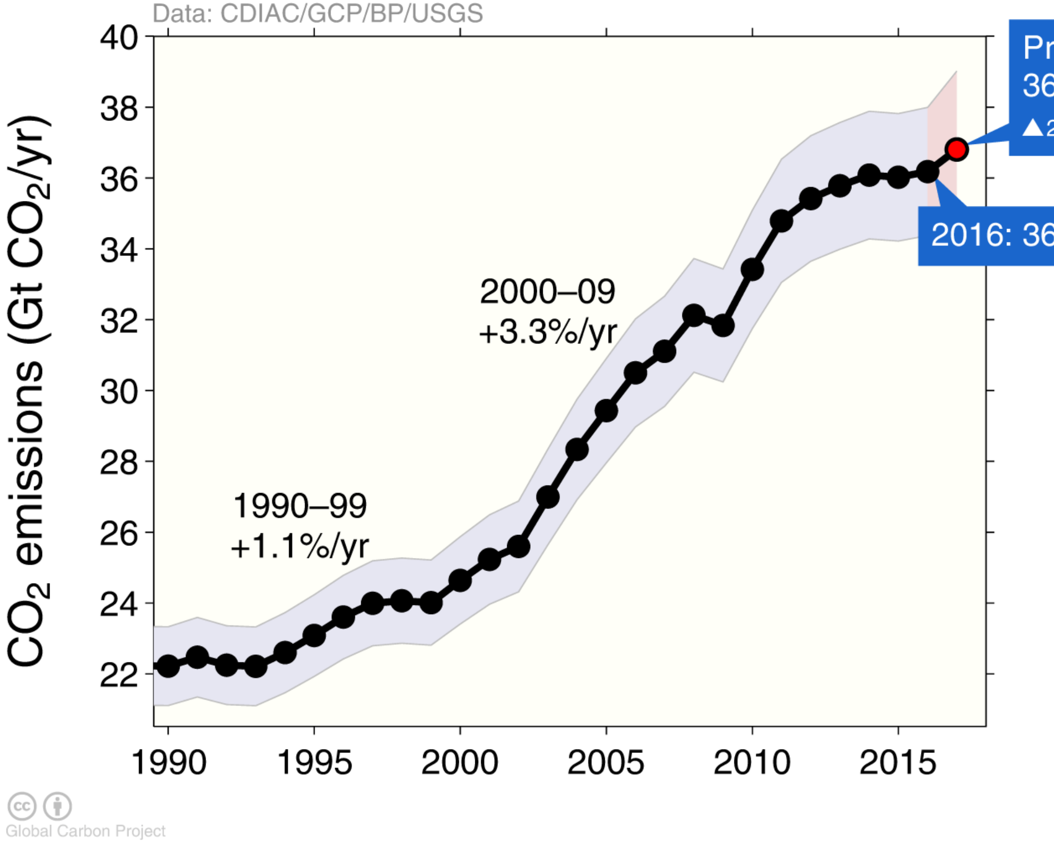
Early **action** for accomplishing the 1.5 °C temperature reduce the likelihood that large regions will face substantial ari…

–Prof. Sujong Jeong, SUSTech,

Park, C.-E., Jeong, S.-J., Joshi, M., Osborn, T. J., Ho, C.-H., Piao, S., … Feng, S. (2018). Keeping global warming within 1.5 °C constrains emergence of aridification. *Nature Climate Change*, *8*(January). https://doi.org/10.1038/s41558-017-0034-4
http://www.twwtn.com/Upload/15/10/14180113195.jpg

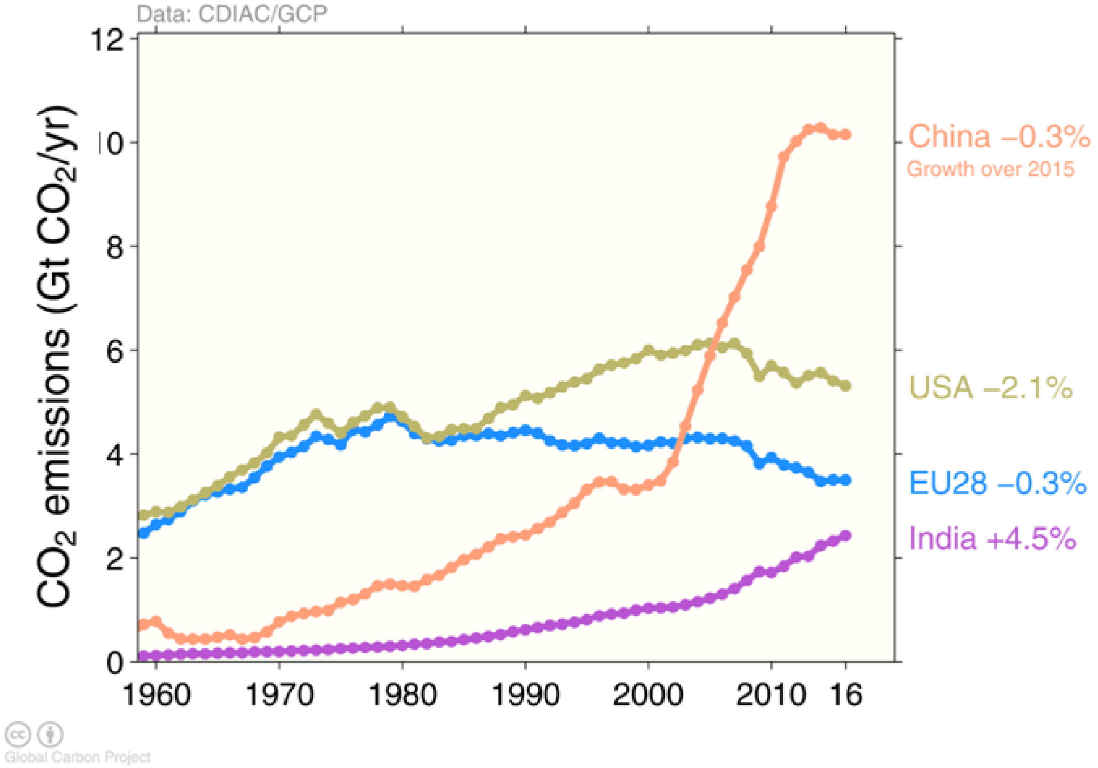
Emissions and Top Emitters from Fossil Fuel Use and Industry

Global emissions from fossil fuel and industry:
36.2 ± 2 $GtCO_2$ in 2016, 62% over 1990.
- Projection for 2017: 36.8 ± 2 $GtCO_2$, 2.0% higher than 2016.



Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

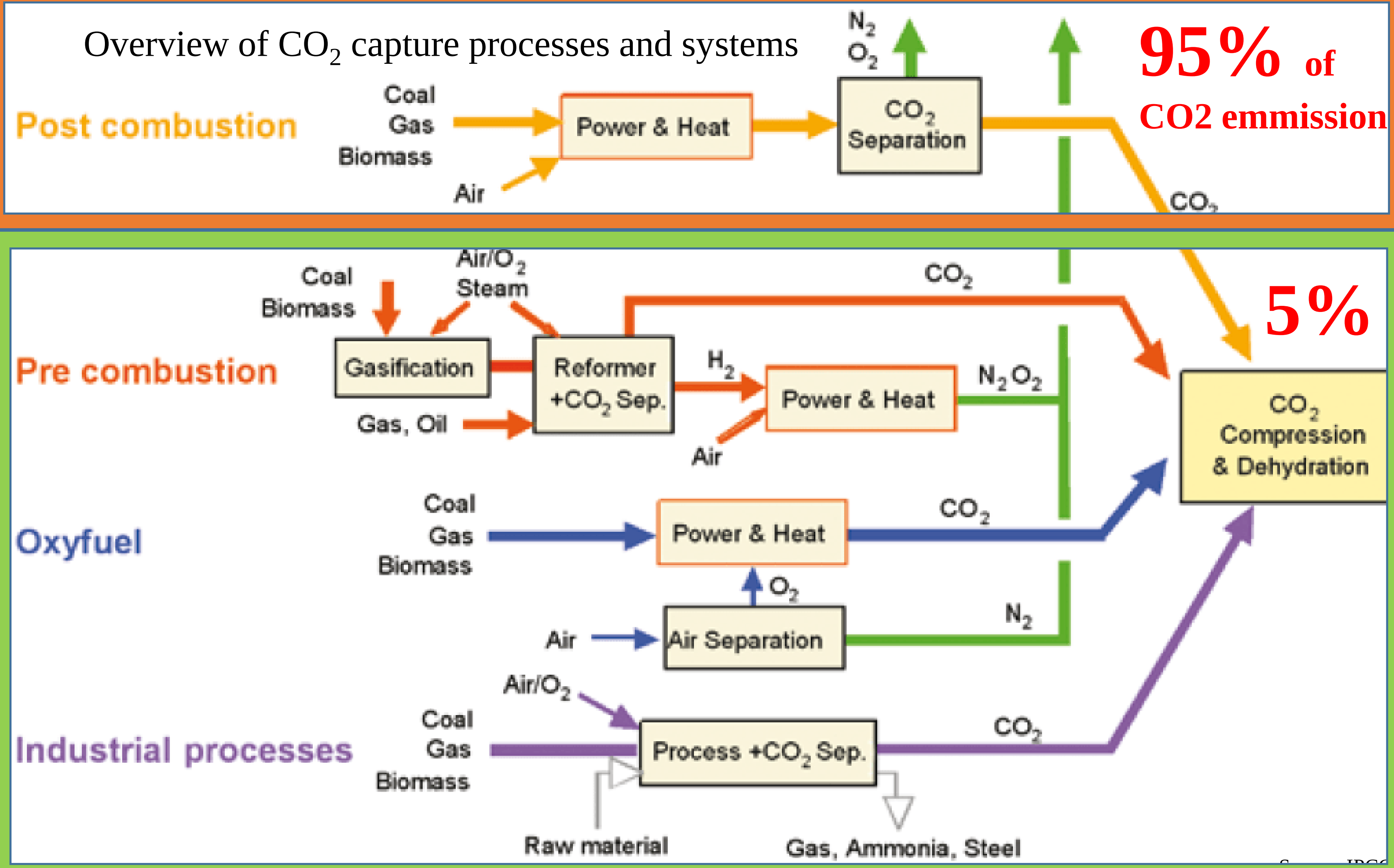
The top four emitters in 2016 covered 59% of global emissions
China (28%), United States (15%), EU28 (10%), India (7%)



LEFT SIDE: Estimates for 2015 and 2016 are preliminary. Growth rate is adjusted for the leap year in 2016.
RIGHT SIDE: Bunker fuels are used for international transport is 3.1% of global emissions.
Statistical differences between the global estimates and sum of national totals are 0.6% of global emissions.
Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017

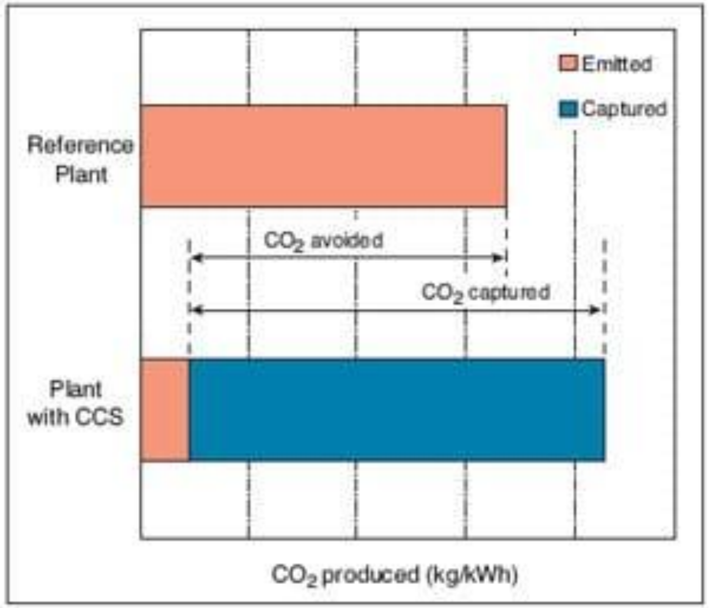
Carbon Capture and Sequestration (CCS)

Overview of CO_2 capture processes and systems



Source: IPCC,Carbon Dioxide Capture and Storage: Technical Summary (2005) Ch3. Capture of CO2, p. 25

CO_2 capture and storage from power plants.

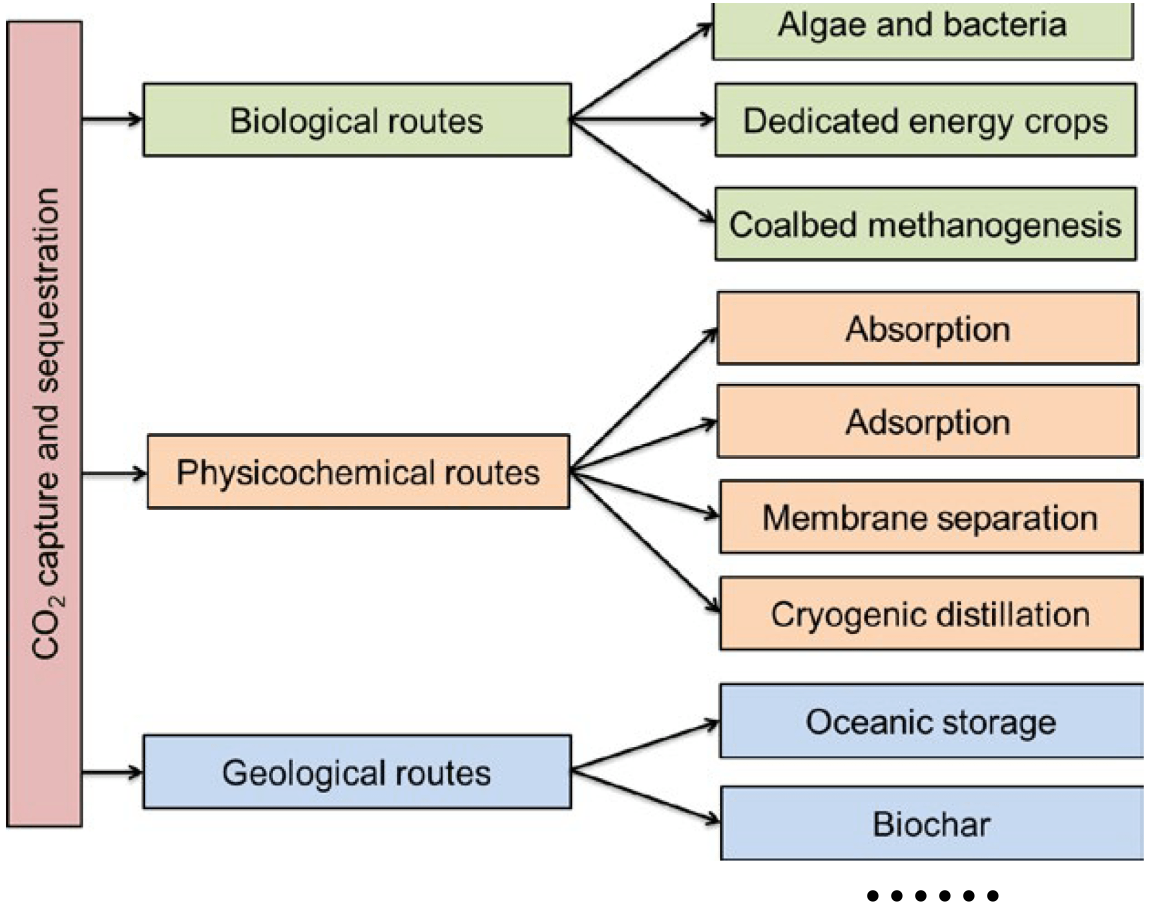


The increased CO_2 production resulting from loss in overall efficiency of power plants due to the additional energy required for capture, transport and storage, and any leakage from transport result in a larger amount of “CO_2 produced per unit of product” (lower bar) relative to the reference plant (upper bar) without capture.

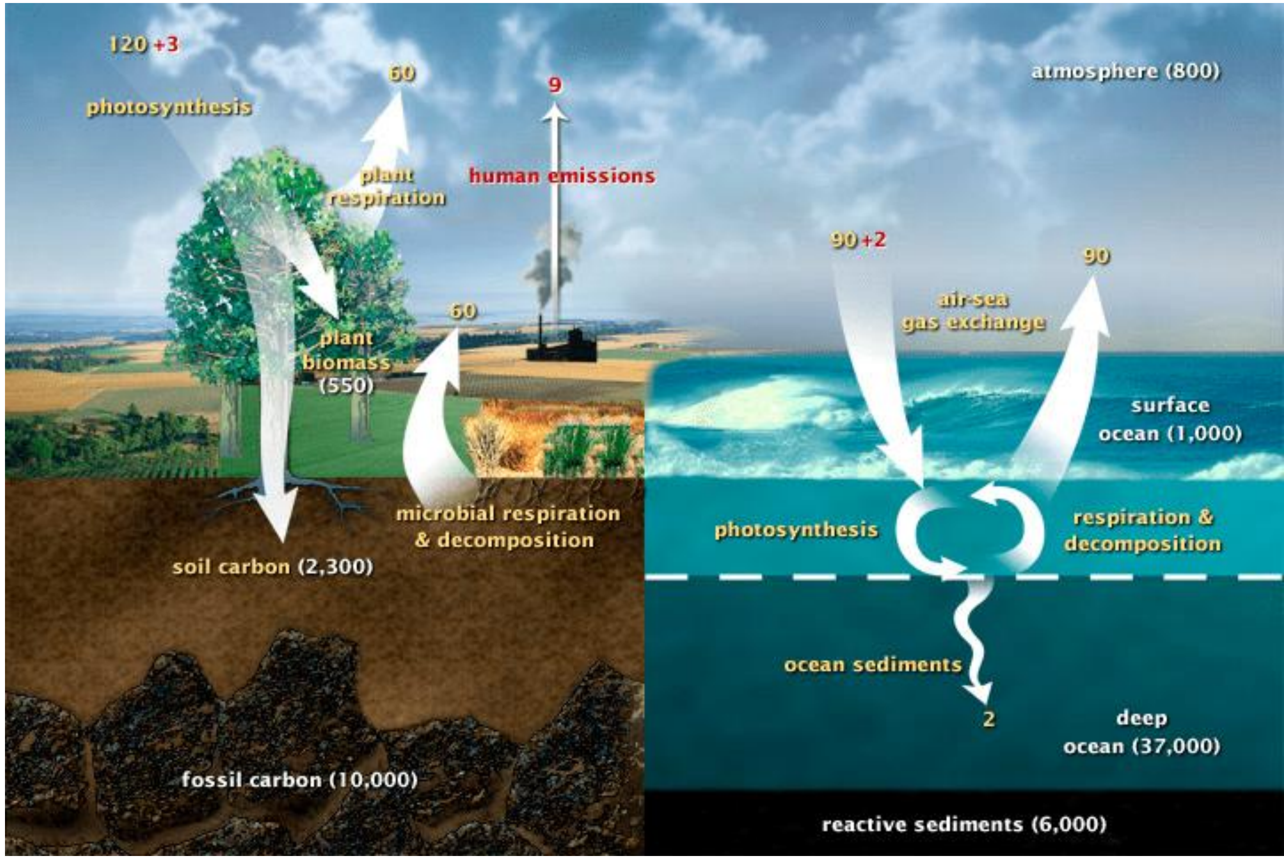
Carbon Dioxide Capture and Storage: Technical Summary (2005) Ch8. Costs and economic potential, p. 41

SUSTech Southern University of Science and Technology

Carbon Cycle (natural fluxes & human contributions)



Routes of carbon capture and sequestration.



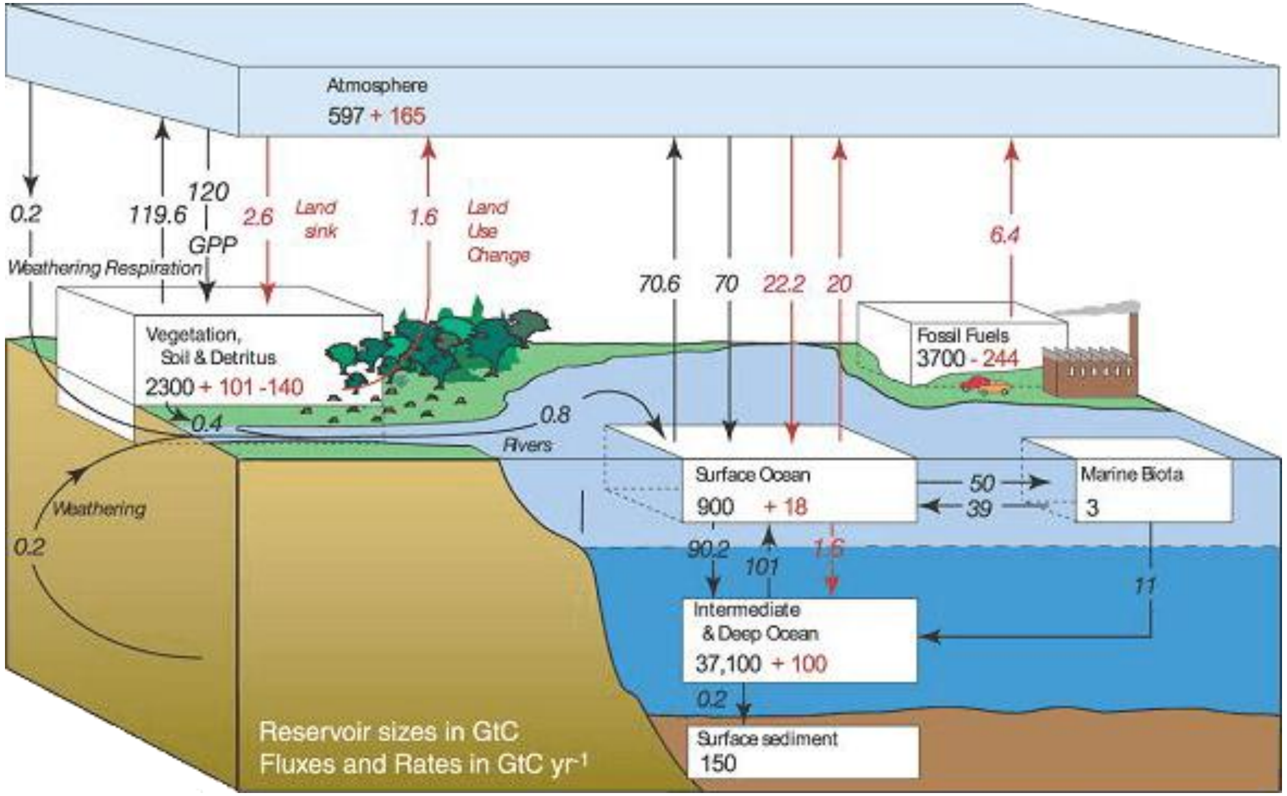
This diagram of the fast carbon cycle shows the movement of carbon between land, atmosphere, and oceans. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon ($GtCO_2$) per year. White numbers indicate stored carbon.

Nanda, S., Reddy, S. N., Mitra, S. K., & Kozinski, J. A. (2016). The progressive routes for carbon capture and sequestration. *Energy Science and Engineering*, *4*(2), 99–122. https://doi.org/10.1002/ese3.117

Source: U.S. DOE, Biological and Environmental Research Information System. http://genomicscience.energy.gov/

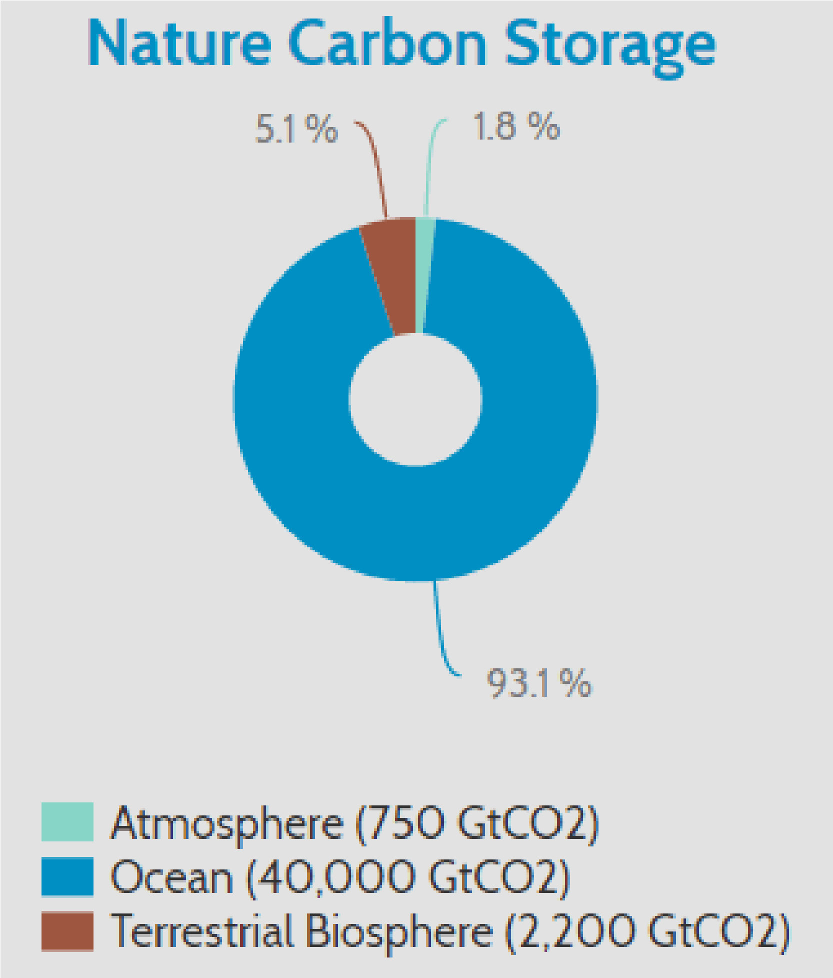
Why Ocean ？

Global Carbon Cycle shows the movement of carbon between land, atmosphere, and oceans.



https://timgsa.baidu.com/timg?image&quality=80&size=b9999_10000&sec=1515998452582&di=d3ed1ba7908534b365d1e8c8c252ab85&imgtype=jpg&src=http%3A%2F%2Fimg0.imgtn.bdimg.com%2Fit%2Fu%3D4052906540%2C3959475615%26fm%3D214%26gp%3D0.jpg

Global Carbon Cycle: Distribution of Atmosphere、Ocean and Terrestrial Biosphere



Transportations


Pipeline


Ships

http://www.eog-asia.com/dnv-gl-conducts-largest-controlled-release-of-co2-underwater-pipeline/

• Transporting CO_2 from the capture site to the storage site is necessary for CCS projects.

• It is expected that we can sequester a large volumn of CO_2 in the deep ocean, thus pipelines and ships are feasible in this case, which are two of the most mature transportation systems for CO_2 at present. There also has some possibilities that transportation systems has been improved greatly in the future.

Influence factors	
transport volume	transport distance
geographical conditions	flexibility requirements
investment decision time	……

Pipelines:
- Large volumn, low costs.
- Over 3,100 km of CO_2 pipelines worldwide.
- Capacity: about 44.7 million tonnes per year of CO_2.
- Engineering Standardization: CFR part 195 (USA)、CSA Z662(Canada)、DNV-RP-J202(EU)、 DNV RP-J202(NOR)

Ships:
- More flexible.
- Transport of CO_2 by ship in smaller volume (i.e. <1500 m^3) is currently practiced in the industry.
- Shipping at lower pressure is preferred.

Threats while Transporting CO_2

Identified threats to CO_2 pipelines categorized into "CO_2 specific" and "typical for any pipeline"		
Threat	*Typical to Any Pipeline*	*Specific to CO_2 Pipelines*
Time Dependent		
External corrosion	•	
Internal corrosion	(•)	•
Stress Corrosion Cracking	•	
Fatigue	•	•
Degradation of materials	•	•
Manufacturing, welding, and equipment defects exposed to CO_2	•	
Stable		
Manufacturing and welding defects not exposed to CO_2	•	

Identified threats to CO_2 pipelines categorized into "CO_2 specific" and "typical for any pipeline"		
Threat	*Typical to Any Pipeline*	*Specific to CO_2 Pipelines*
Time Independent		
Third Party Damage	•	
Incorrect Operations	•	
Weather/Outside Force	•	
Equipment defects not affected by CO_2	•	
Equipment Failure	•	•
On-bottom Stability	•	•
Operational		
Repair/Welding Issues		•
Shut in		•
Blow Down/ Depressurization		•

Some of the threats listed in Table are shown as both "Typical to Any Pipeline" and "Specific to CO_2 Pipelines", as there are additional or different issues related to these threats for a CO_2 pipeline. The threats are divided into time-dependent, time-independent and operational.

Sources: Veritas, D. N. (2010). Design and Operation of Co 2 Pipelines. *Practice*, (April).

CO_2 Sequestration

Overview of CO_2 sequestration technologis

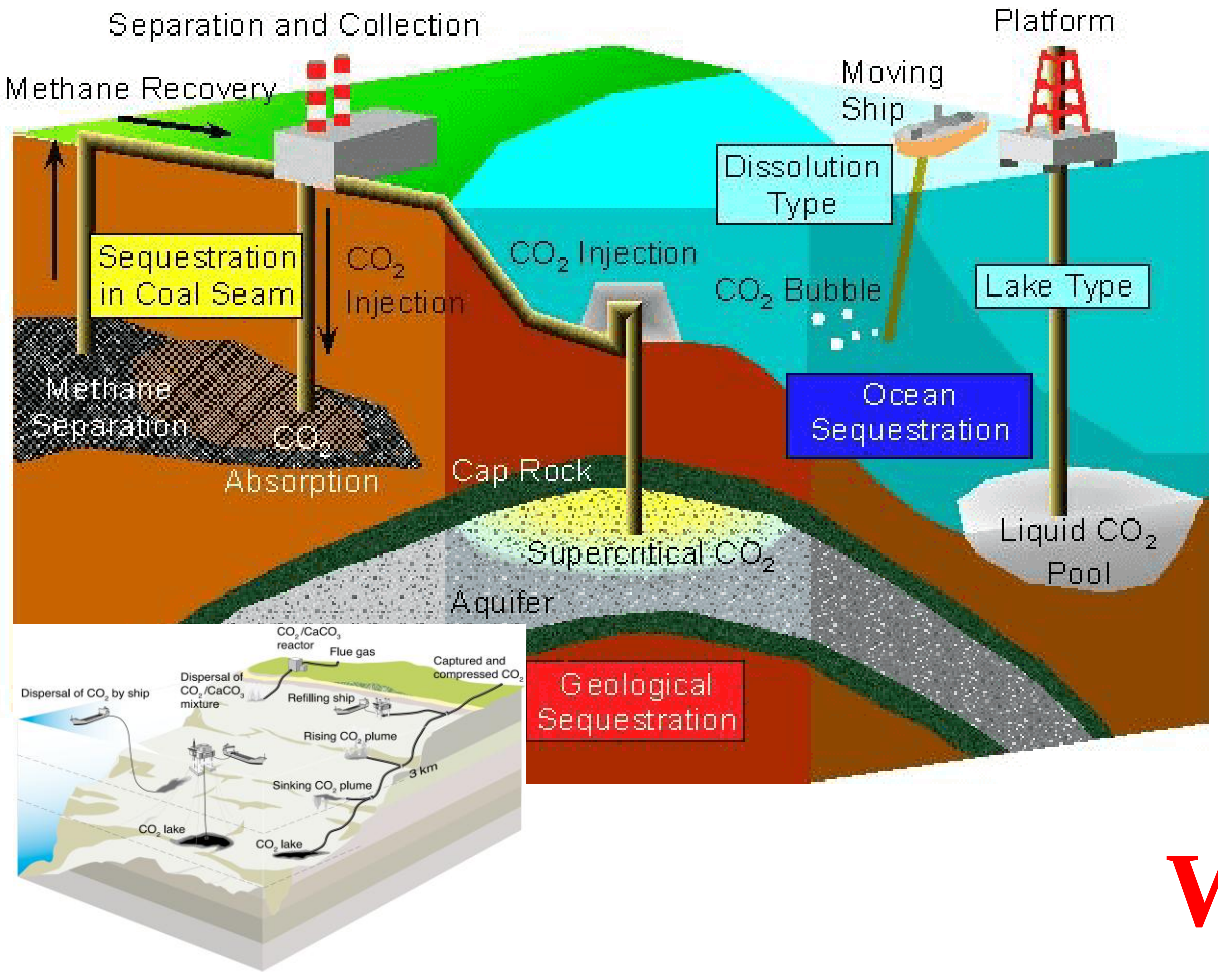
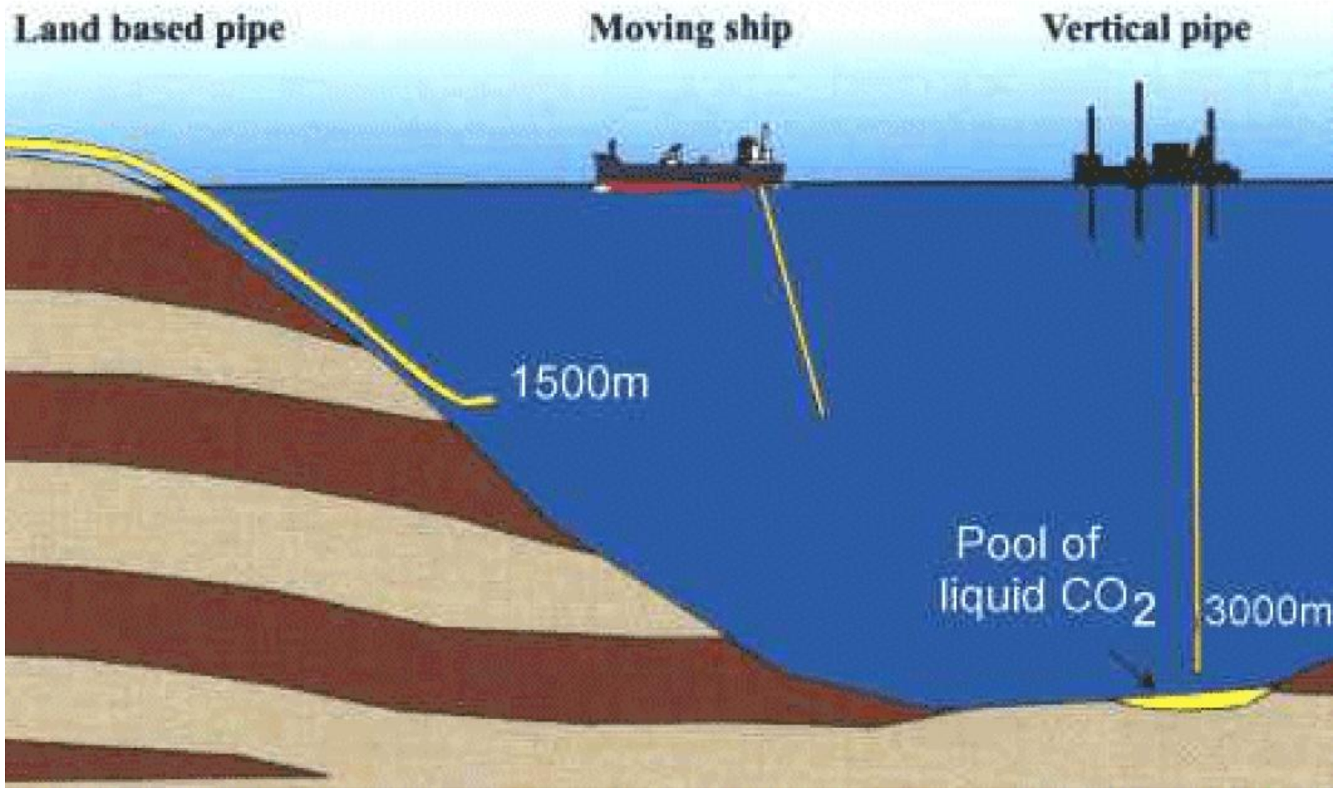


Illustration of Direct Injection Methods.



Why below 3000m ?

Souce: Ke. Liu, Fundamentals of Energy Engineering

Artwork courtesy: Sean Goddard, University of Exeter.

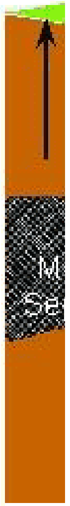
CO

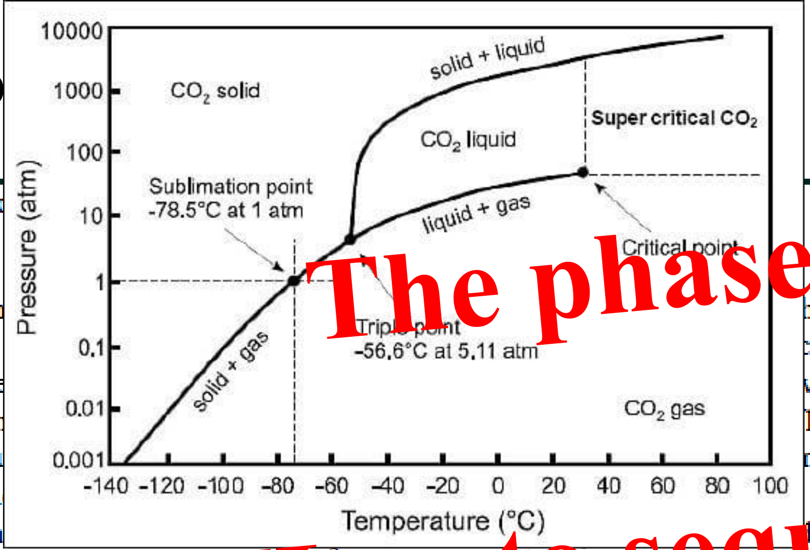
Chemic

The sur... Carbon ... pressure ... the exch... is in equ... since th... CO_2 rea... ion (HCO_3^-), carbonate ion (CO_3^{2-}), and hydrogen ion (H^+) by the reactions:

...he total D... acid in s... ween air a... hen the carbon ... r, there will be n... dissociates into b...

Meth





The phase of CO_2?

CO2 sea water phase diagram showing the conditions where CO2 can exist as gas, liquid, solid hydrate, or aqueous phase in seawater (Monterey Bay). The pressure of seawater is increasing with the depth of the ocean, and liquid phase CO2 is stable when temperature and pressure is falling in the region below the dashed line, while gas phase CO2 is stable under conditions above the dashed line. CO2 will become carbon dioxide hydrate (CO2·6H2O,a solid ice-like crystalline substance) when contacting with the seawater and at temperature and pressure in the shaded region. The solidline curve shows the relationship between the temperature and the depth (at a site off the coast of California), which tells that liquid and hydrated CO2 can exist below about 400m.

How to sequester CO_2?

$$CO_2(g) + H_2O \Leftrightarrow H_2CO_3(aq) \Leftrightarrow HCO_3^- + H^+ \Leftrightarrow CO_3^{2-} + 2H^+$$

The CO_2 added to the ocean will turn into HCO_3^-, and thus generate more H^+ and dec... concentration of CO_3^{2-}, with the result of decreasing pH and making ocean more acid... When alkaline minerals, such as $CaCO_3$, are dissolved in the seawater, the Total Alka... increased. Increasing the Talk in the seawater increases the solubility of CO_2. The rea... represented by this equation:

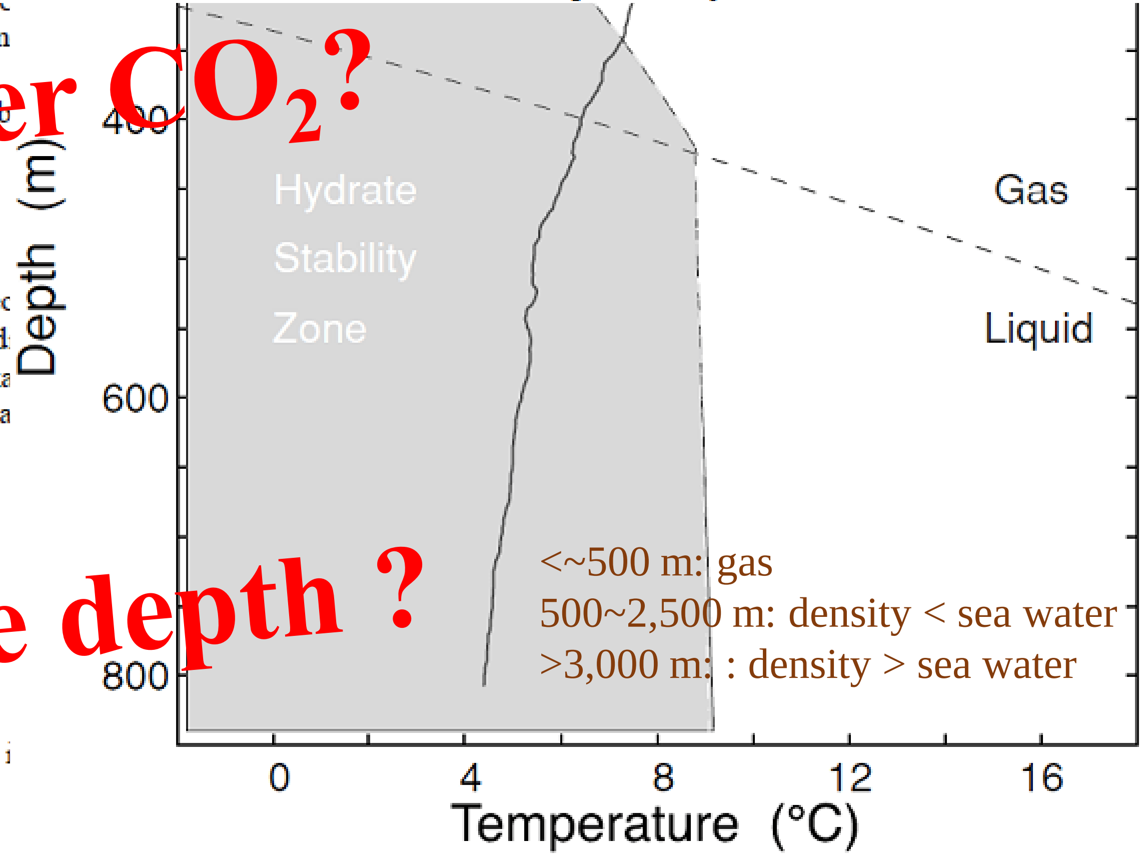
$$CaCO_3(s) \Leftrightarrow Ca^{2+} + CO_3^{2-}$$

The Total Alkalinity (TAlk) can be approximately expressed as:

$$TAlk = HCO_3^- + CO_3^{2-} + OH^-$$

Since most DIC is in the form of HCO_3^-, the main reaction for the dissolving $CaCO_3$ i... ocean water is[203]:

$$CaCO_3(s) + CO_2(g) + H_2O \Leftrightarrow Ca^{2+} + HCO_3^-$$



What is the depth ?

<~500 m: gas

500~2,500 m: density < sea water

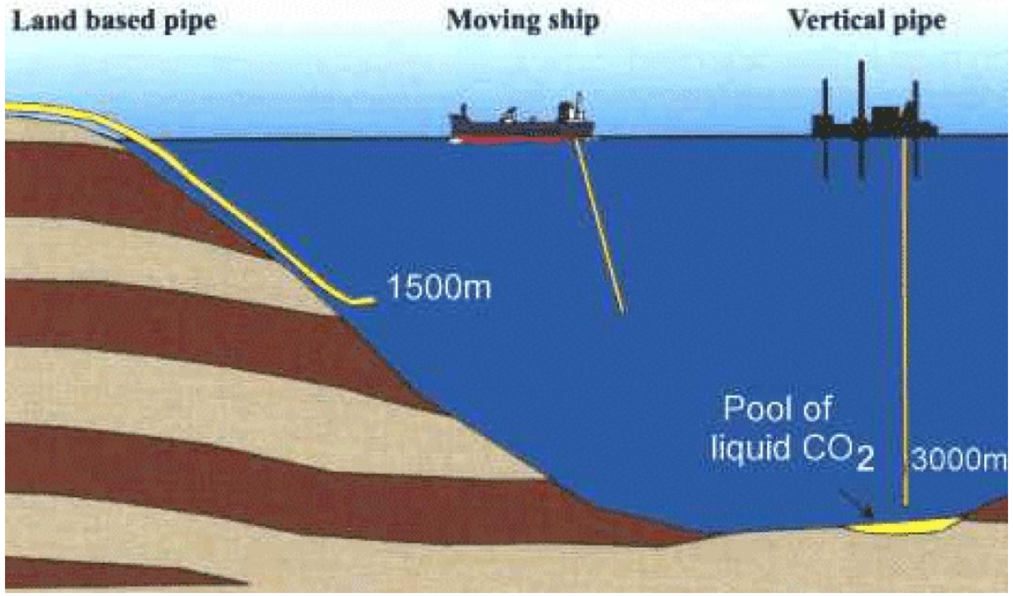
>3,000 m: : density > sea water

Souce: Ke. Liu, Fundamentals of Energy Engineering

Artwork courtesy: Sean Goddard, University of Exeter.

CO$_2$ Sequestration

How much CO$_2$ retained ?



Fraction of CO$_2$ retained for ocean storage as simulated by seven ocean models for 100 years of continuous injection at three different depths starting in the year 2000.

Year	Injection depth 800 m	1500 m	3000 m
2100	0.78 ± 0.06	0.91 ± 0.05	0.99 ± 0.01
2200	0.50 ± 0.06	0.74 ± 0.07	0.94 ± 0.06
2300	0.36 ± 0.06	0.60 ± 0.08	0.87 ± 0.10
2400	0.28 ± 0.07	0.49 ± 0.09	0.79 ± 0.12
2500	0.23 ± 0.07	0.42 ± 0.09	0.71 ± 0.14

Costs for ocean storage at depths deeper than 3,000 m.

(The costs for the moving ship option are for injection depths of 2,000-2,500 m.)

Ocean storage method	Costs (US\$/tCO$_2$ net injected) 100 km offshore	500 km offshore
Fixed pipeline	6	31
Moving ship/platform[a]	12-14	13-16

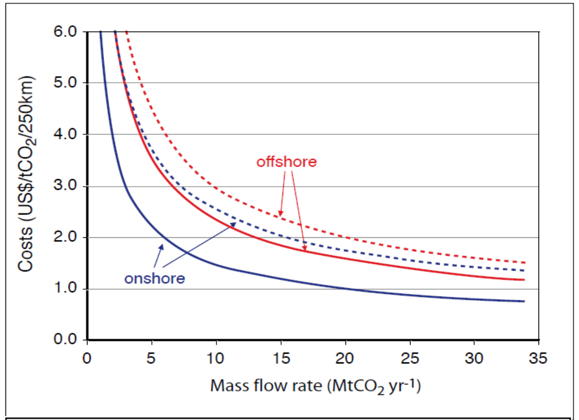
Veritas, D. N. (2010). Design and Operation of Co 2 Pipelines. *Practice*, (April).

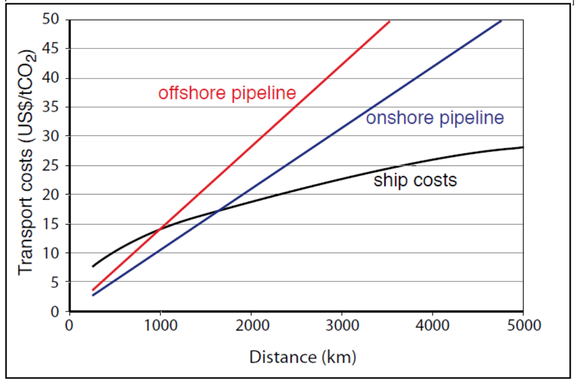
Costs Analysis

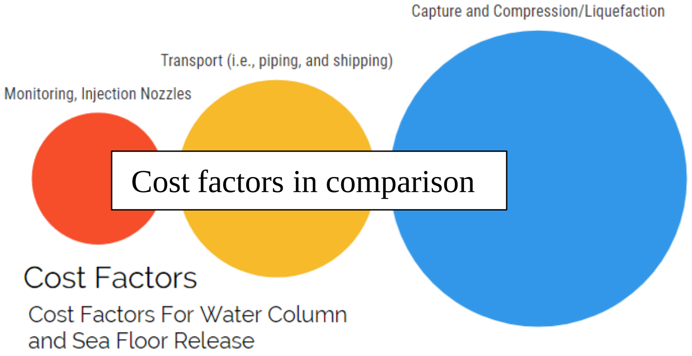
Range of total costs for CO_2 capture, transport and geological storage based on current technology for new power plants using bituminous coal or natural gas

Power plant performance and cost parameters[a]	Pulverized coal power plant	Natural gas combined cycle power plant	Integrated coal gasification combined cycle power plant
Reference plant without CCS			
Cost of electricity (US$/kWh)	0.043-0.052	0.031-0.050	0.041-0.061
Power plant with capture			
Increased fuel requirement (%)	24-40	11-22	14-25
CO_2 captured (kg/kWh)	0.82-0.97	0.36-0.41	0.67-0.94
CO_2 avoided (kg/kWh)	0.62-0.70	0.30-0.32	0.59-0.73
% CO_2 avoided	81-88	83-88	81-91
Power plant with capture and geological storage[b]			
Cost of electricity (US$/kWh)	0.063-0.099	0.043-0.077	0.055-0.091
Cost of CCS (US$/kWh)	0.019-0.047	0.012-0.029	0.010-0.032
% increase in cost of electricity	43-91	37-85	21-78
Mitigation cost (US$/t$CO_2$ avoided)	30-71	38-91	14-53
(US$/tC avoided)	110-260	140-330	51-200
Power plant with capture and enhanced oil recovery[c]			
Cost of electricity (US$/kWh)	0.049-0.081	0.037-0.070	0.040-0.075
Cost of CCS (US$/kWh)	0.005-0.029	0.006-0.022	(-0.005)-0.019
% increase in cost of electricity	12-57	19-63	(-10)-46
Mitigation cost (US$/t$CO_2$ avoided)	9-44	19-68	(-7)-31
(US$/tC avoided)	31-160	71-250	(-25)-120

(a) All changes are relative to a similar (reference) plant without CCS. See Table TS.3 for details of assumptions underlying reported cost ranges.
(b)Capture costs based on ranges from Table TS.3; transport costs range from 0-5 US$/tCO2; geological storage cost ranges from 0.6-8.3 US$/tCO2.
(c)Same capture and transport costs as above; Net storage costs for EOR range from -10 to -16 US$/tCO2 (based on pre-2003 oil prices of 15-20 US$ per barrel).







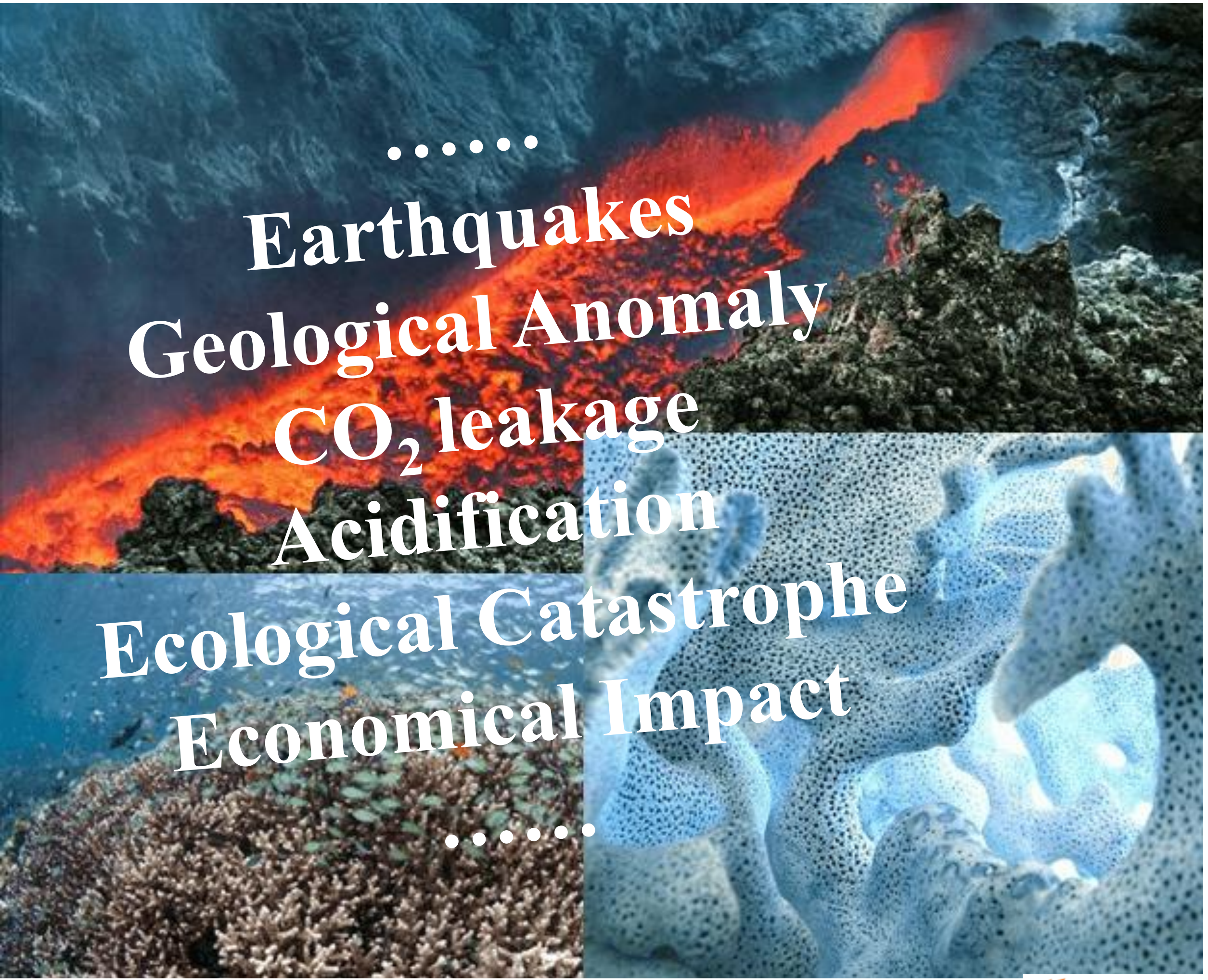
Transport costs for onshore pipelines and offshore pipelines

Transport costs for onshore pipelines and offshore pipelines, in US$ per tCO_2 per 250 km as a function of the CO_2 mass flow rate. The graph shows high estimates (dotted lines) and low estimates (solid lines).

Costs, plotted as US$/tCO2 transported against distance, for onshore pipelines, offshore pipelines and ship transport

Costs, plotted as US$/$tCO_2$ transported against distance, for onshore pipelines, offshore pipelines and ship transport. Pipeline costs are given for a mass flow of 6 $MtCO_2$ yr-1. Ship costs include intermediate storage facilities, harbour fees, fuel costs, and loading and unloading activities. Costs include also additional costs for liquefaction compared to compression.

Major Concerns for OCCS



Common Risks: Acidification

联合国《生物多样性公约》秘书处本月在公约缔约国大会上提交的一份报告中称，如果海洋酸化的情况未能得到缓解，到2100年，其对世界经济的影响将相当于每年造成超过1万亿美元的损失。

中国新闻网援引日本共同社的报道称，造成经济损失的主要原因是珊瑚礁遭受重大打击。珊瑚礁提供的水产资源和旅游资源维持着近4亿人的生计。而如果算上其他损失，损失金额还将进一步上升。

报告称，工业革命以来的不到两百年中，海洋表面的pH值下降了0.1（海水呈弱碱性，pH值略高于8.0），而如果二氧化碳排放量以目前的速度增加，到本世纪末pH值可能会再下降0.3。报告还警告称，可能需要花费数千年时间才能让海洋生物从海水酸化的影响中恢复。

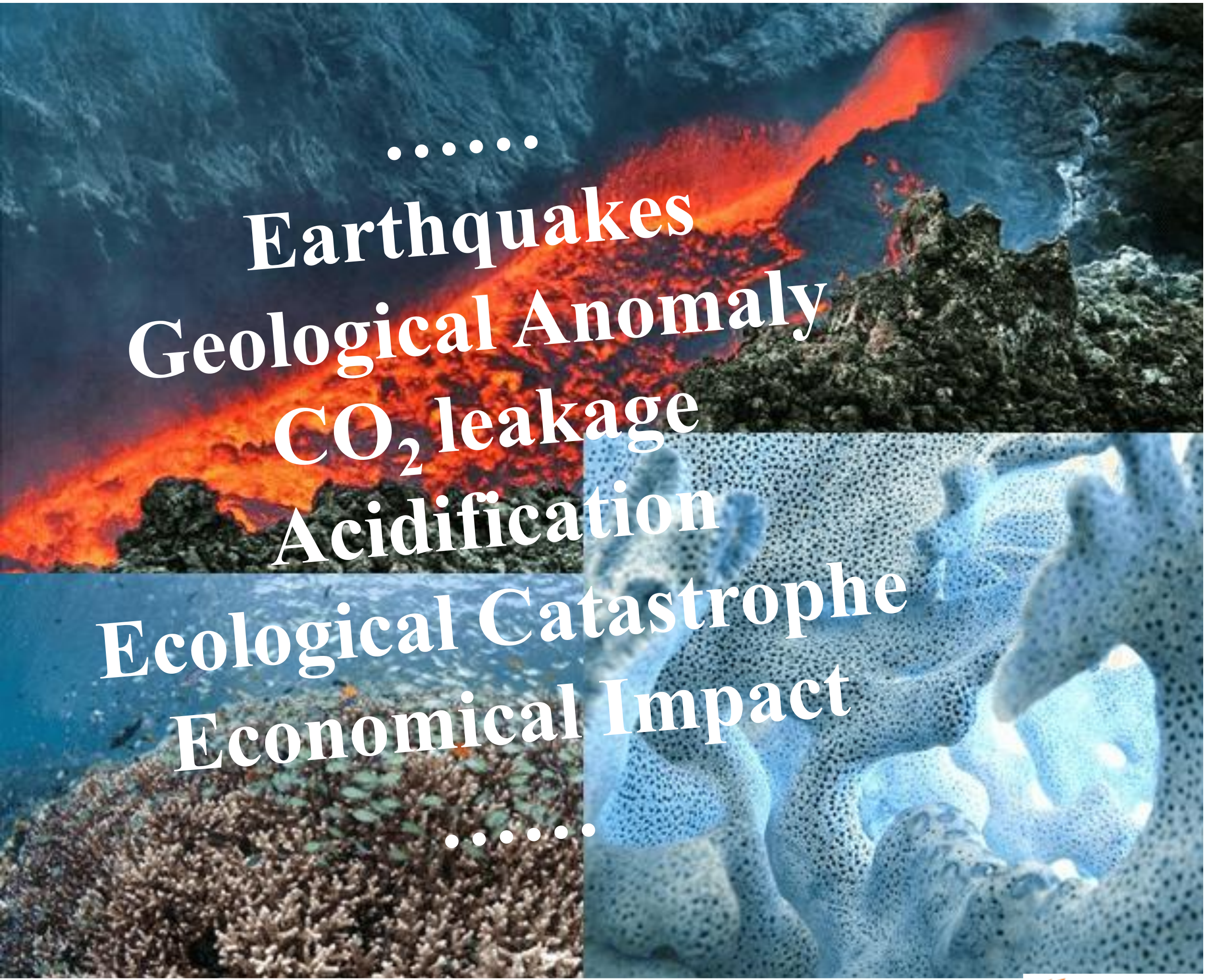
报告的撰写人之一，法国学者加图索(Jean Pierre Gattuso)向法国国际广播电台表示，到2100年，许多海洋生物会消失，尤其贝壳类生物的种类可能减少70%，而其他海洋生物种类也会减少30%至40%。http://www.jiemian.com/article/204283.html

How ph value would be influenced by the CO_2 leakage ?

Further study

	Injection depth		
Year	800 m	1500 m	3000 m
2100	0.78 ± 0.06	0.91 ± 0.05	0.99 ± 0.01
2200	0.50 ± 0.06	0.74 ± 0.07	0.94 ± 0.06
2300	0.36 ± 0.06	0.60 ± 0.08	0.87 ± 0.10
2400	0.28 ± 0.07	0.49 ± 0.09	0.79 ± 0.12
2500	0.23 ± 0.07	0.42 ± 0.09	0.71 ± 0.14

Major Concerns for OCCS



Common Risks: Acidification

Ocean sequestration, in other words, would speed up the otherwise centuries- or millennialong process of establishing equilibrium between the atmosphere and the entire ocean. It would not decrease acidification of the entire ocean, but it might limit acidification in the surface waters that are of greatest economic interest to people. And giving people time to improve more efficiency technologies and strategies to reduce green house gas emissions. In a world of limited resources, it may represent the most efficient way to store a lot of carbon quickly.

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Further study

PROSPECTIVE

- There are **no published papers specifically on site selection** for intentional ocean storage of CO_2; hence, further study needs to be done in order to select sites for ocean storage.

- **Monitoring and verification should be done** in order to monitore the potential leakages from subsea geologic storage, or for verification that such leakage does not occur.

- **Tmechanism behind oceanic carbon capture and sequestration and the consequences still need further studies**.

- In view of public precaution toward the ocean, the strategy will require that **all parties (private, public, non-governmental organizations) be included in ongoing research and debate**.

CONCLUSION

Among all these considerations for OCCS are technical feasibility, environmental consequences, economical feasibility (costs,etc.), safety, and international issues (including cross border transport).

Ocean sequestration would **speed up the centuries- or millennialong process of establishing equilibrium** between the atmosphere and the entire ocean. It would not decrease acidification of the entire ocean, but it might limit acidification in the surface waters that are of greatest economic interest to people, gives people time to improve more efficiency technologies and strategies to reduce green house gas emissions.

In a world of limited resources, it may represent the most efficient way to store a lot of carbon quickly. So, **OCCS might be one of the best emergency strategies in dealing with climate change and global warming when great climate catastrophe occurs**.

Oceanic Carbon Capture and Sequestration (OCCS): One of The Most Feasible Emergency Strategies Dealing With Climate Change and Global Warming.

Thanks for listening !

Q&A