Addressing subsurface aspects of large-scale CCS

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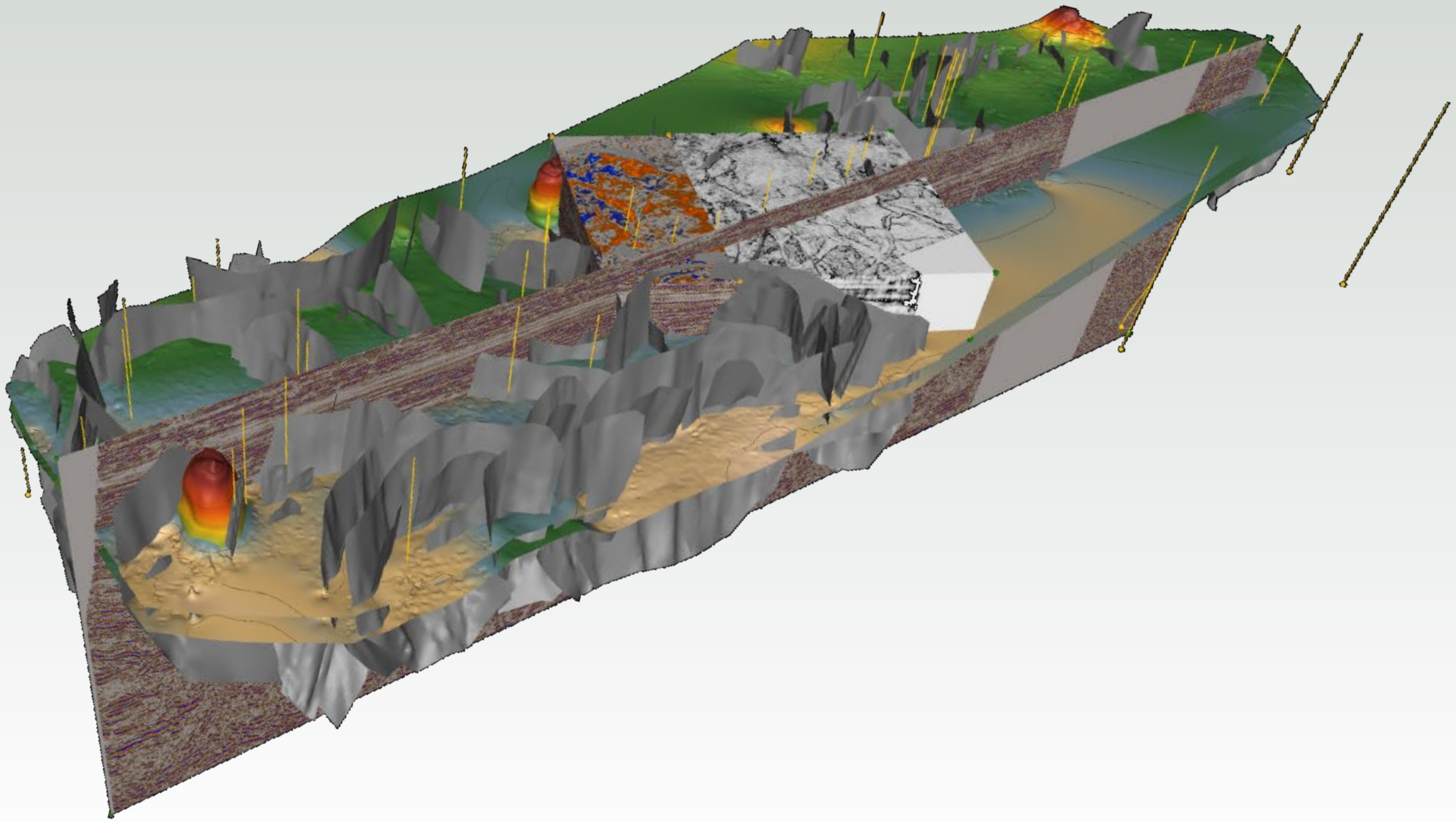

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High-level Considerations

- What is the challenge being addressed: Gigton-scale storage is daunting – Extraordinary mass and pressures
- How is it being addressed: Analog, scaled up
- What will result if we overcome this challenge: Nations can confidently commit to CCS without risk of wasting resources

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Summary of Ringrose and Meckel, 2019

- **Global expectations for CCS**
  - IEA, IPCC
  - CCS is essential for realizing a global emissions reduction strategy consistent with 2DS aspirations.
- Globally, it is the **continental margin** geology that can most rapidly accommodate the large-scale CCS anticipated.
- There are many well-established **global geologic similarities** in these basins, and prior petroleum exploration provides an exceptionally well-documented starting point for deploying CCS in these settings.
  - Pressure is the resource of consequence, not porosity.
- While offshore CCS is suitable many places it does not have to be deployed everywhere to achieve global benefit, and **focus can be on the most prospective and economic regions**.
- The **most plausible scenario** for giga-ton scale deployment requires a well development model similar to historic Norwegian hydrocarbon exploitation to be applied for CCS in **5-7 regions globally**, with a reasonable mean well injection rate of approximately 0.67 Mt/yr.
  - It will only take **a fraction of the historic worldwide offshore petroleum well development rate** to achieve the global requirements for GCS.

SCIENTIFIC REPORTS
natureresearch

Maturing global CO_2 storage resources on offshore continental margins to achieve 2DS emissions reductions

P. S. Ringrose[1,2]* & T. A. Meckel[3]

Appendix: Methods used in supporting the paper

UT NEWS E&E NEWS

https://news.utexas.edu/2019/12/09/research-shows-ramping-up-carbon-capture-could-be-key-to-mitigating-climate-change/

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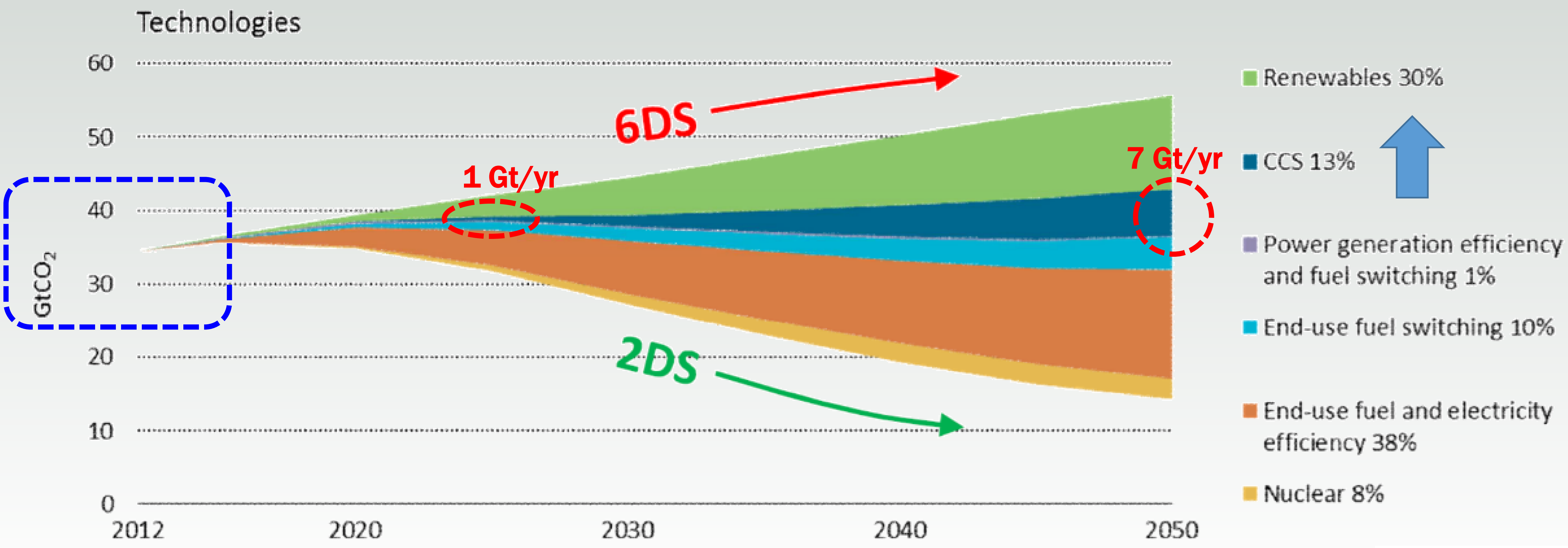
IEA Perspective? ~7 Gta CCS by 2050



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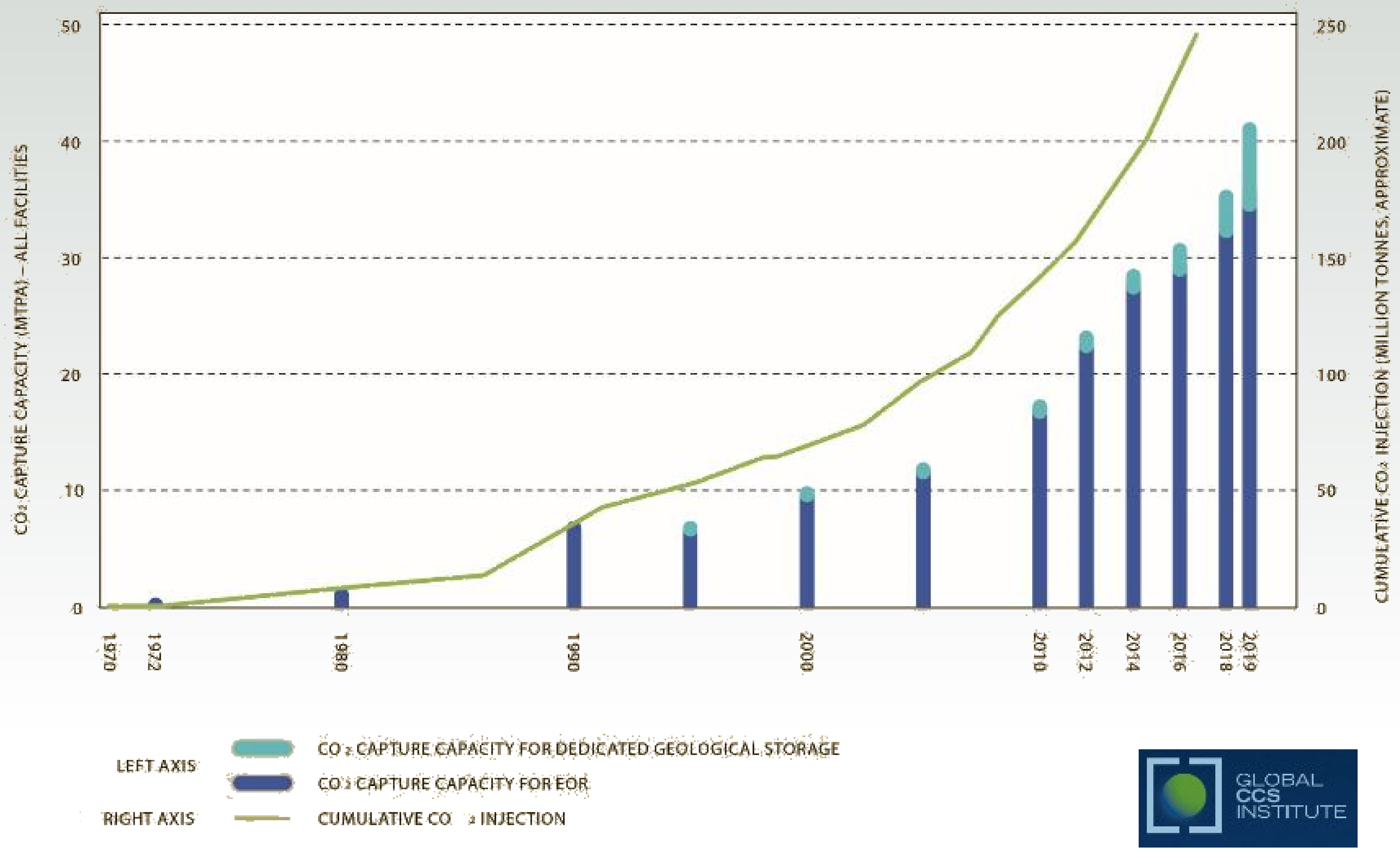
IPCC AR5 SYR from Table SPM.2 (2014)

Mitigation cost increases in scenarios with limited availability of technologies [d] *[% increase in total discounted [e] mitigation costs (2015–2100) relative to default technology assumptions]*				
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy
450 (430 to 480)	138% (29 to 297%) 4	7% (4 to 18%) 8	6% (2 to 29%) 8	64% (44 to 78%) 8

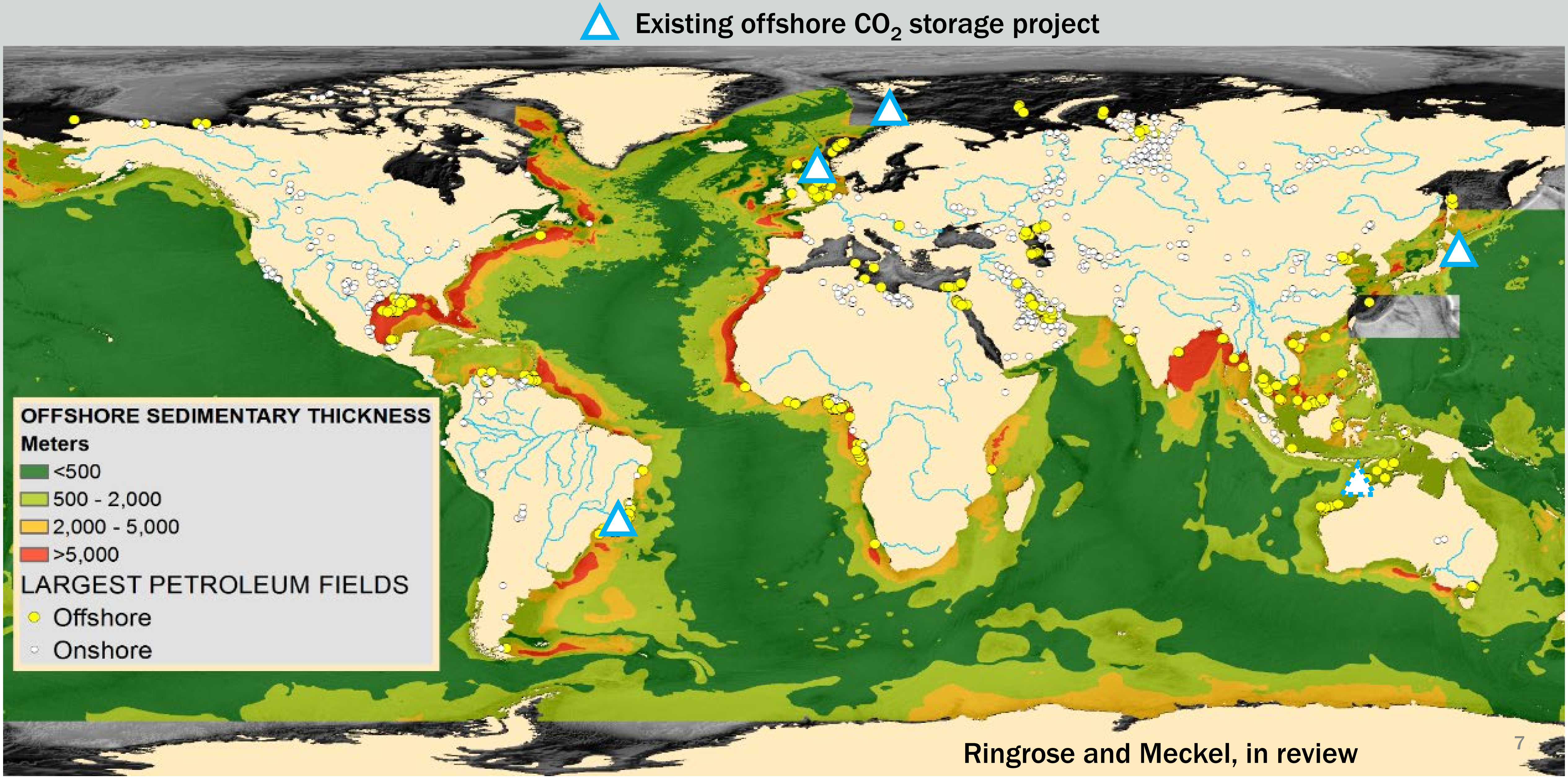
~40 Million Tons per year
250 Mt cumulative

FIGURE 5: Annual CO_2 capture capacity and cumulative CO_2 injection for all full-chain CCS facilities. Analysis based on data from Global CCS Institute CO_2 RE database.



GLOBAL CCS INSTITUTE

Where?
Offshore continental margins are the most promising for near-term Gigatonne-scale storage



Ringrose and Meckel, in review

Comparison of historic oil and gas recovery strategies with the proposed CO_2 storage resource.

Oil and gas domain	Primary production	Secondary recovery	Tertiary recovery
Recovery mechanisms used	Pressure depletion	Pressure support (mainly waterflood)	Gas & CO_2 injection, chemical flooding
Typical recovery factor (% HCIP)	< 30 %	30 to 50 %	40 to 80 %
CO_2 storage domain	**Class-A projects**	**Class-B projects**	**Class-C projects**
Pressure management approach	Projects with minimal pressure constraints	Projects constrained by pressure limits	Projects with active pressure management
Typical pore space utilized (% Pore Volume)	<6% of open aquifer systems	<4% of confined aquifer systems	>5% for targeted confined aquifer systems

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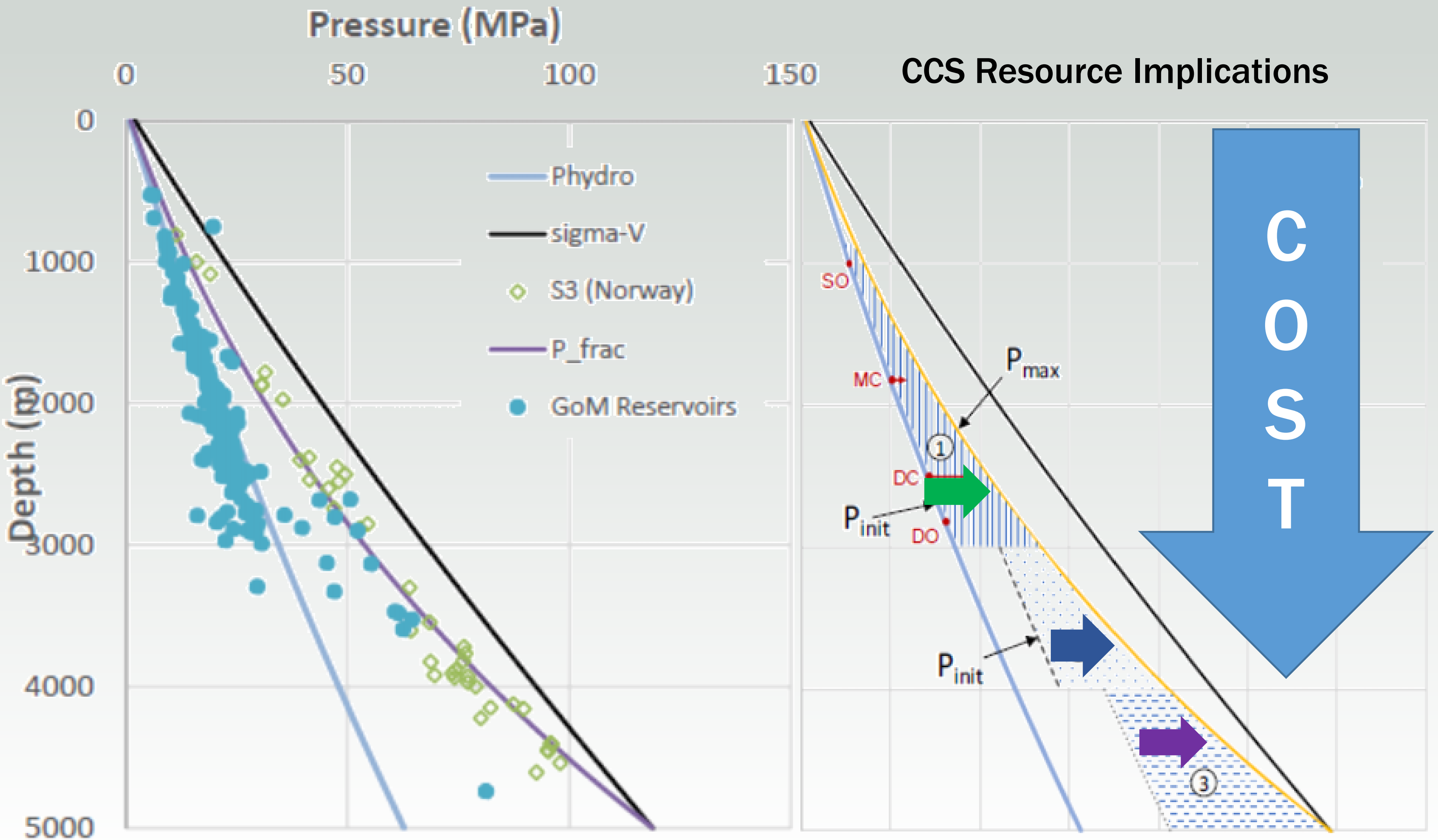
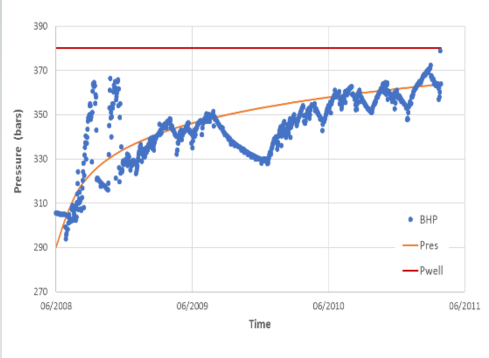
Pressure will be the primary factor limiting capacity





Class A:
Normal pressure (CENOZOIC)

Class B:
Elevated pressure (MESOZOIC)

Class C:
High pressure, brine extraction?

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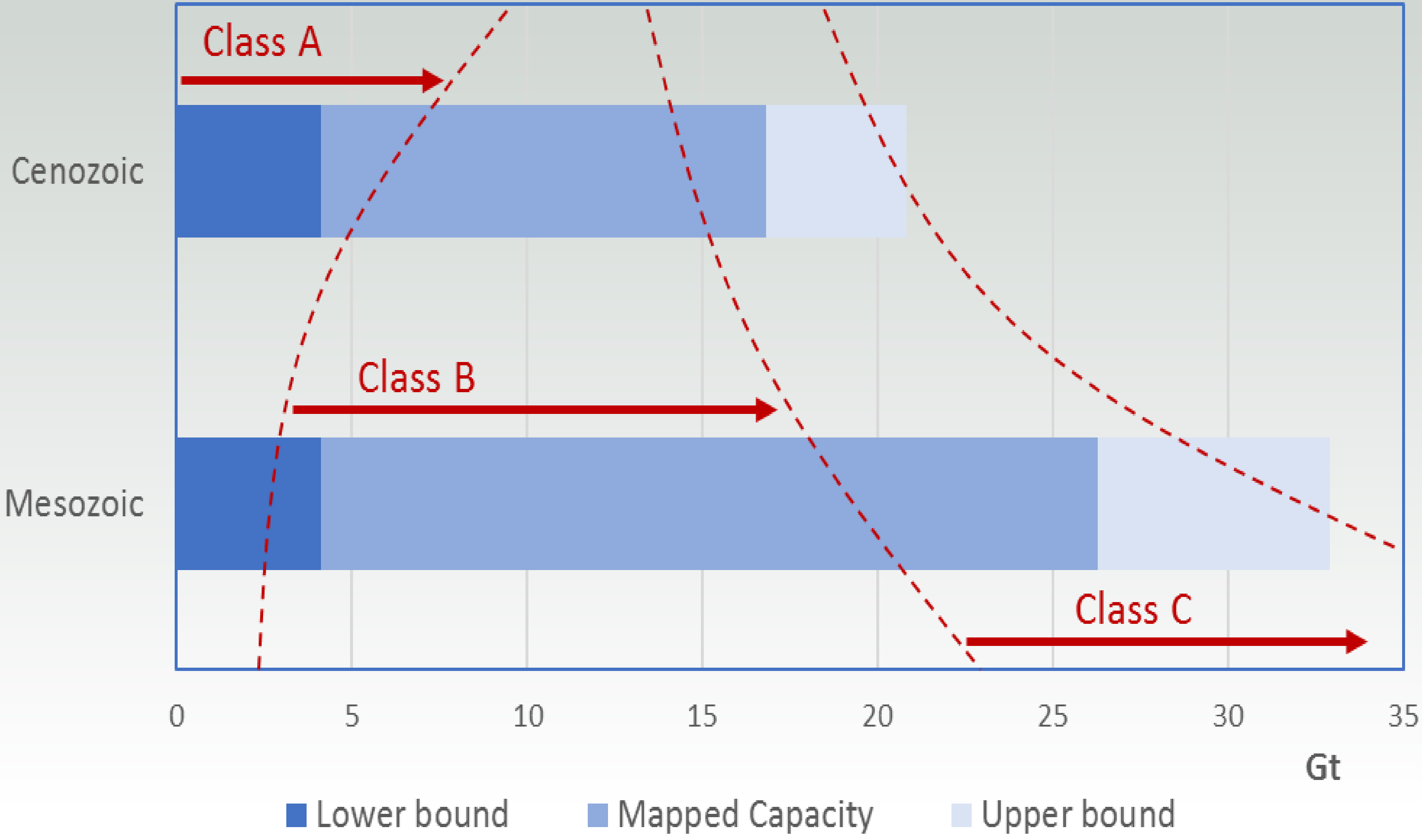

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Average injection rates from 5 projects
Onshore mean = 0.53 Mta   Offshore mean = 0.70

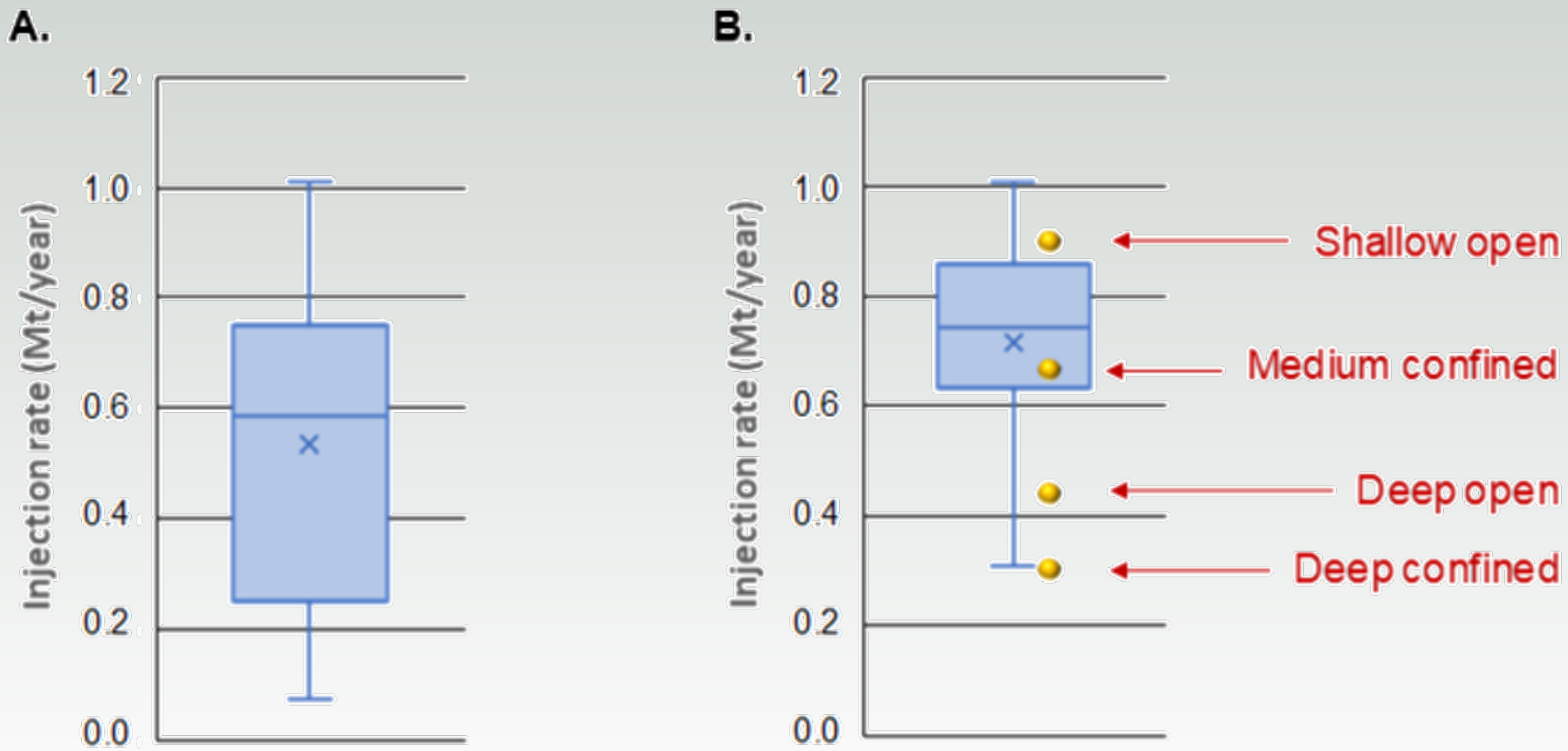
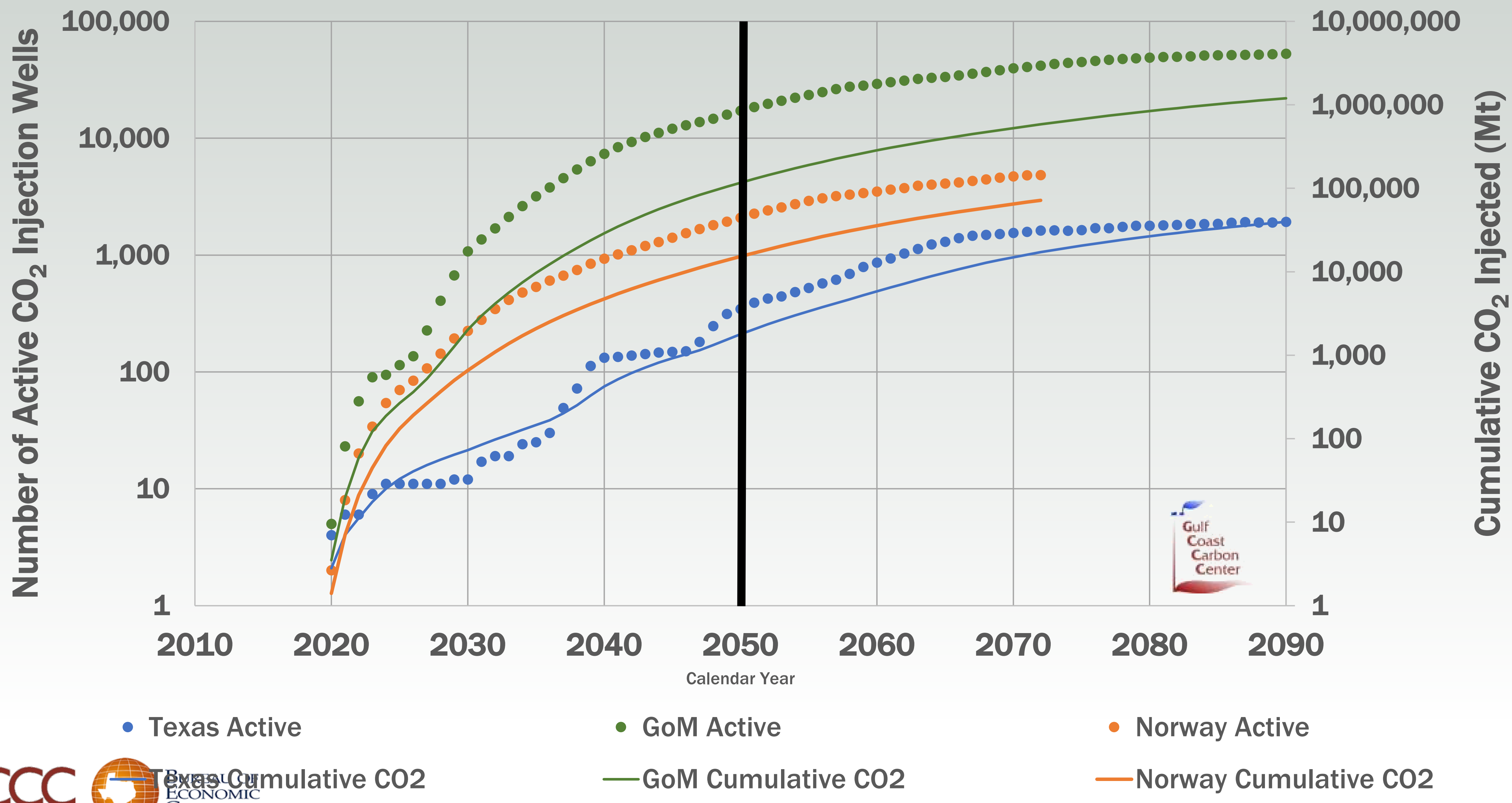


Figure A7. (A) Box and whisker plots of rate distributions data from all storage projects in operation and (B) Similar plot for offshore wells compared with mean rates for model scenarios (yellow symbols).

What scale and timeframe?



Ringrose and Meckel, in review

What scale and timeframe?

2020+ Scenario	Offshore Well model	Number of regions	Avg. Well Inj. Rate (Mt/yr)	# active wells in 2050	Incremental Rate in 2050 (Mt/yr)	Cumulative Mass in 2050 (Mt CO_2)	Comment
A	Texas	1	0.7*	345	242	1,781	Goals not met
B	Texas	5	0.7*	1,725	1,208	8,904	Goals not met
C	Texas	5	4.058	1,725	7,000*	51,617	Incremental rate goals met, but not cumulative; injection rate high
D	Norway	1	0.7	2,083	1,458	15,243	Goals not met
E	Norway	1	3.36	2,083	7,000*	73,164	Incremental rate goals met, but not cumulative; injection rate very high
F	Norway	5	0.672	10,415	7,000*	73,164	Most plausible
G	GoM	1	0.7*	17,155	12,009	116,523	Unlikely one region will develop this aggressively; Incremental goal exceeded; Close to cumulative goal
H	GoM	1	0.408	17,155	7,000*	67,916	Injection rate low, not cost effective; Cumulative goal not met

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Ringrose and Meckel, 2019

Summary of Ringrose and Meckel, 2019

CCS can deliver needed scales on needed time frames.

- Globally, 10–14 thousand CO_2 injection wells will be needed globally by 2050 to achieve this goal.

The most plausible scenario requires a well development model similar to historic Norwegian hydrocarbon exploitation to be applied for CCS in 5-7 regions globally, with a reasonable mean well injection rate of approximately 0.67 Mt/yr.

Extra slides

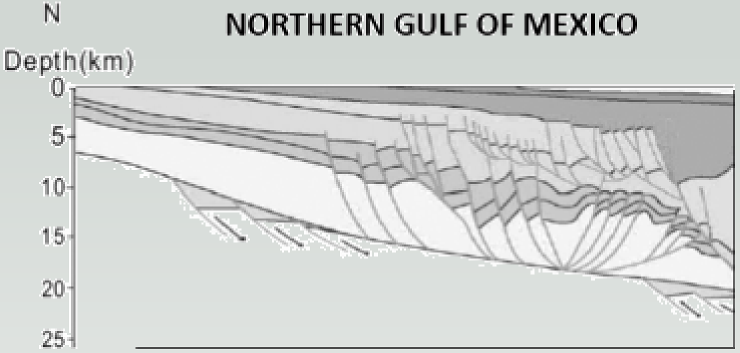
- To obtain a preliminary cost estimate for this potential global offshore drilling programme, we note that offshore injection well costs are of order ~50–100 M€ (55–110 MUSD) per well, assuming a 2015 reference case.
- The offshore drilling costs in terms of emissions avoided are therefore of order 2.9–5.5 €/tonne (3.2–6.3US$/tonne) for our mean well rate of 17.5Mt per well.
- This does not include the costs of capture, transport or platform infrastructure, but indicates that offshore saline aquifer storage can be a cost-effective emissions-mitigation measure in a world where the cost/penalty of emitting to atmosphere rises above the current level of 20–60 US$/tCO2e

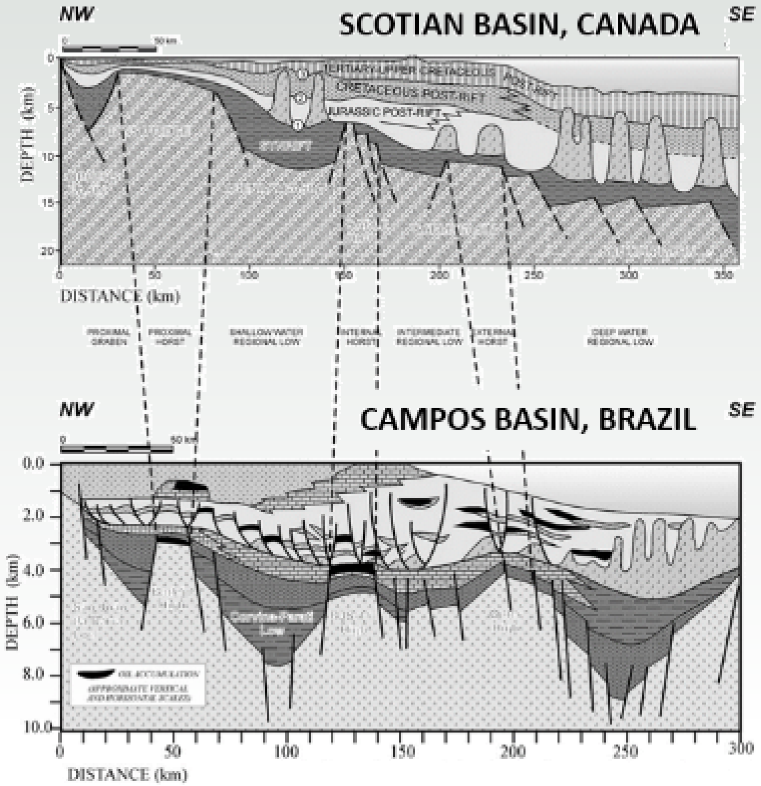
Injection Well Experience

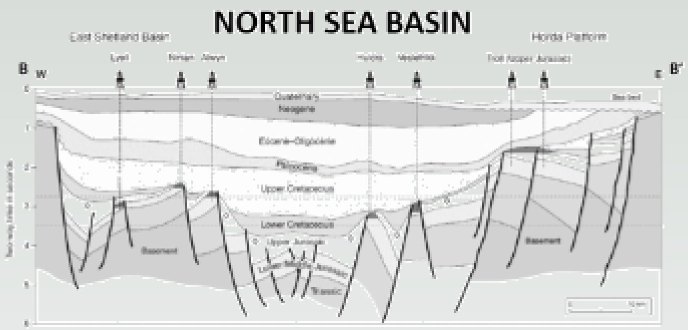
Project	Sample (injection years)	Injection rate per well (Mt/year)	Equiv. rate (t/hour)	Estimated formation permeability (Darcy) / porosity
Sleipner (peak)	1	1.01	115	1-8 / 0.36
Sleipner (mean) [16, 34]	21	0.85	97	
Snøhvit-Stø (mean)	8	0.61	70	0.01-0.8 / 0.12-0.20
Snøhvit-Tub (mean) [47,49]	3	0.33	38	
Quest (mean) [50]	3	0.58	66	0.1 / 0.17
Decatur (mean) [51,52]	1	0.33	38	0.185 / 0.20
In Salah (mean) [53,54]	18	0.21	24	0.01 / 0.18

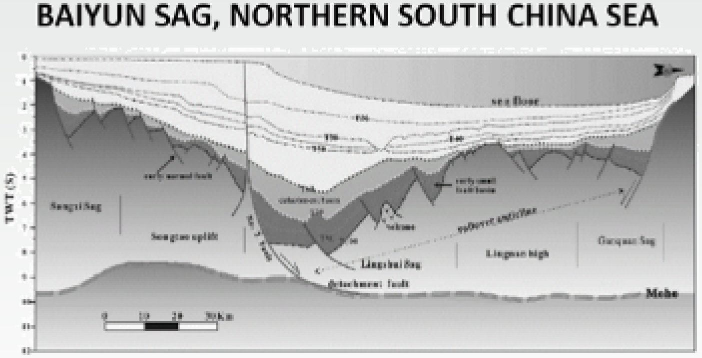
	All wells	Offshore only
N	60	34
Mean	0,532	0,695
Median	0,583	0,725
S.D.	0,271	0,222
1.645 times S.D.	0,446	0,364
P90 rate	0,086	0,330
P10 rate	0,978	1,059

Structural & sequence-stratigraphic similarities for EOR and saline CCS









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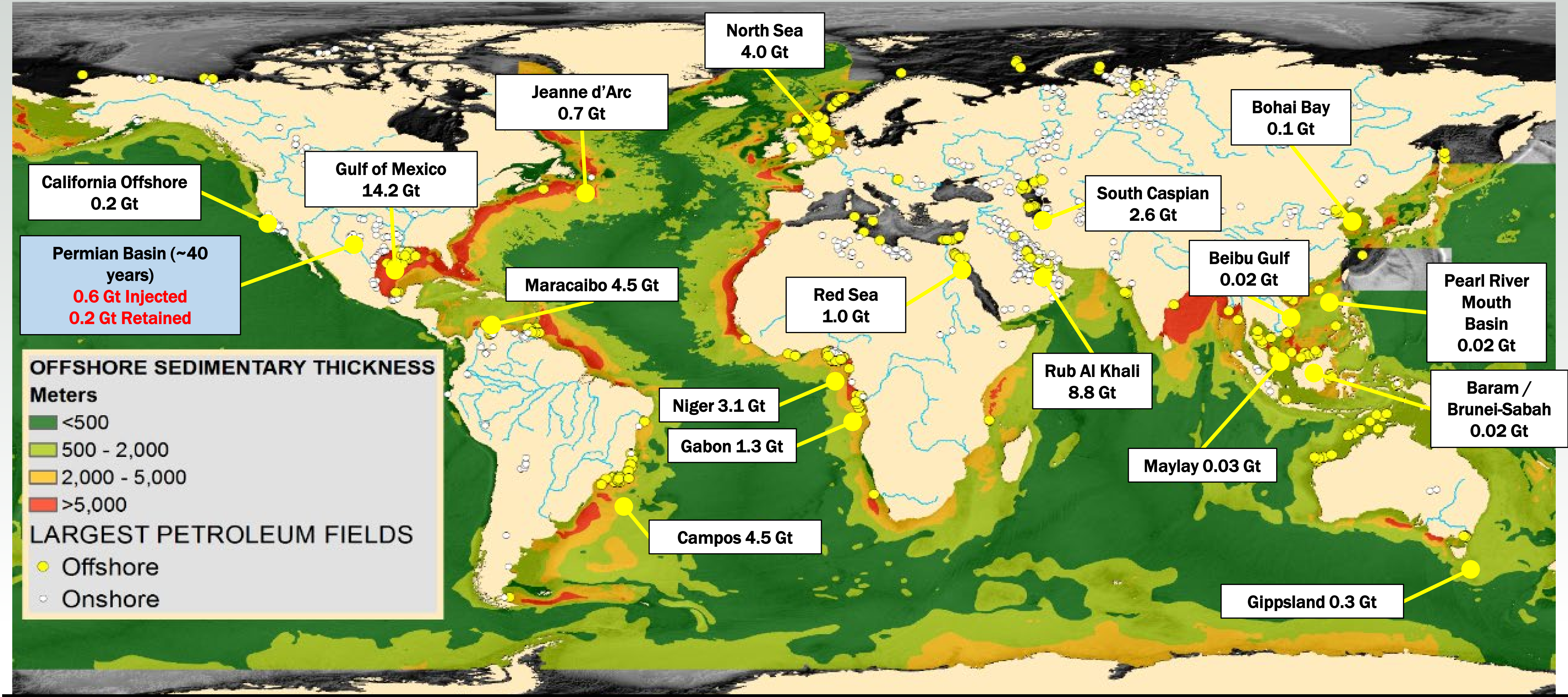
Estimate of Potential Future Global Use of CO2 for Offshore EOR = ~50 Gt

Remember, need ~7 Gt CCS per year globally by 2050.



EOR Source: ISO/TC265 Carbon Dioxide Capture, Transportation and Geological Storage – Carbon Dioxide Storage using Enhanced Oil Recovery (CO2-EOR): Cyphers, Koperna, and Godec