

Offshore CO2 EOR

The ~~Sceptics~~/Realists View

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It's not just money - though that's key!

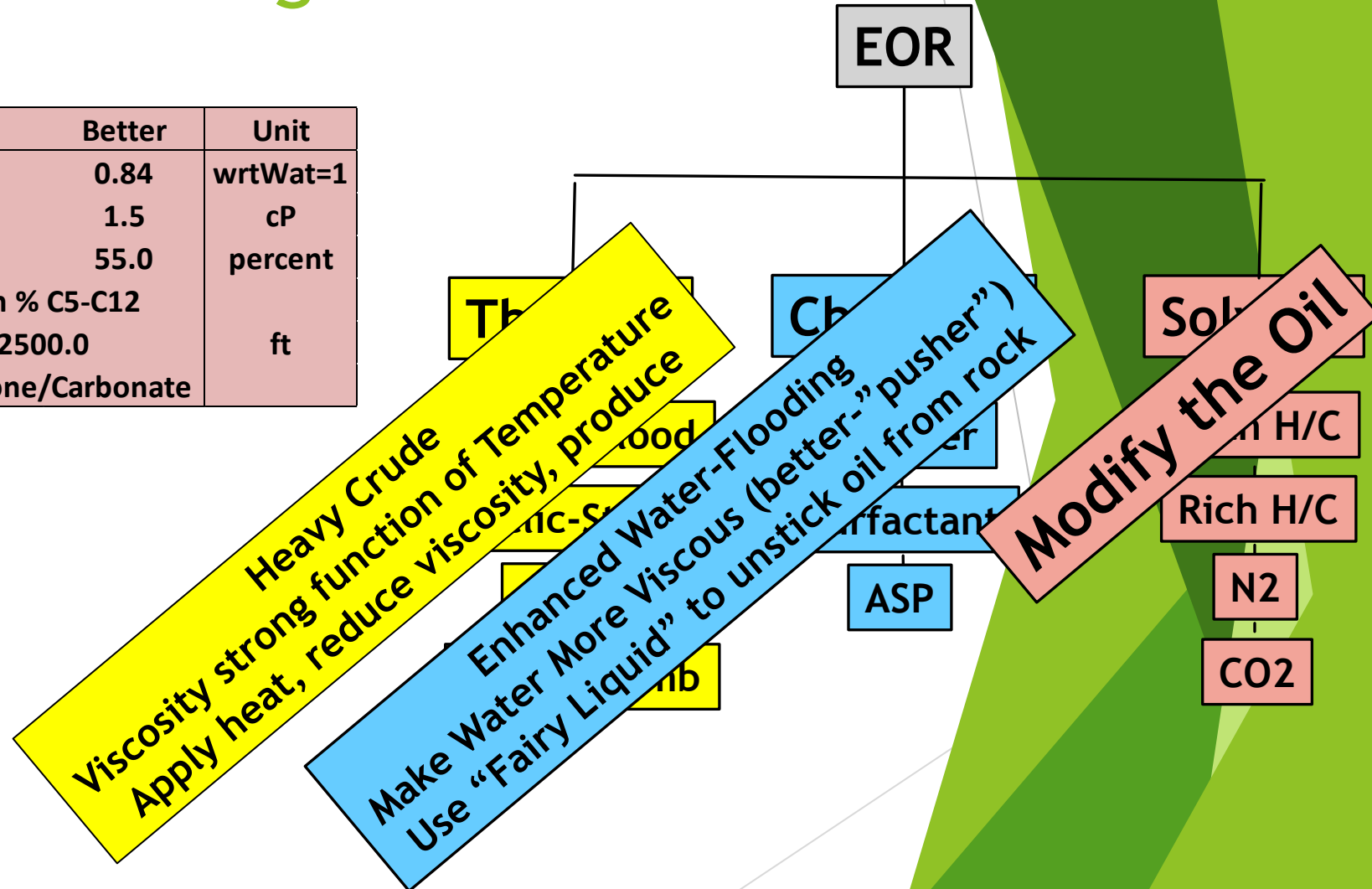
- ▶ EOR Screening
- ▶ CO2 EOR - How does it work?
- ▶ When it works, it works: The Permian Basin
- ▶ And what about the Geology (caution - I'm an RE)
- ▶ Can you see the problem yet?
- ▶ Facilities challenge
- ▶ The “best candidate” in Europe
- ▶ There are optimists
- ▶ And finally, economics

EOR High Level Screening

- ▶ Taber et al, SPE 35385

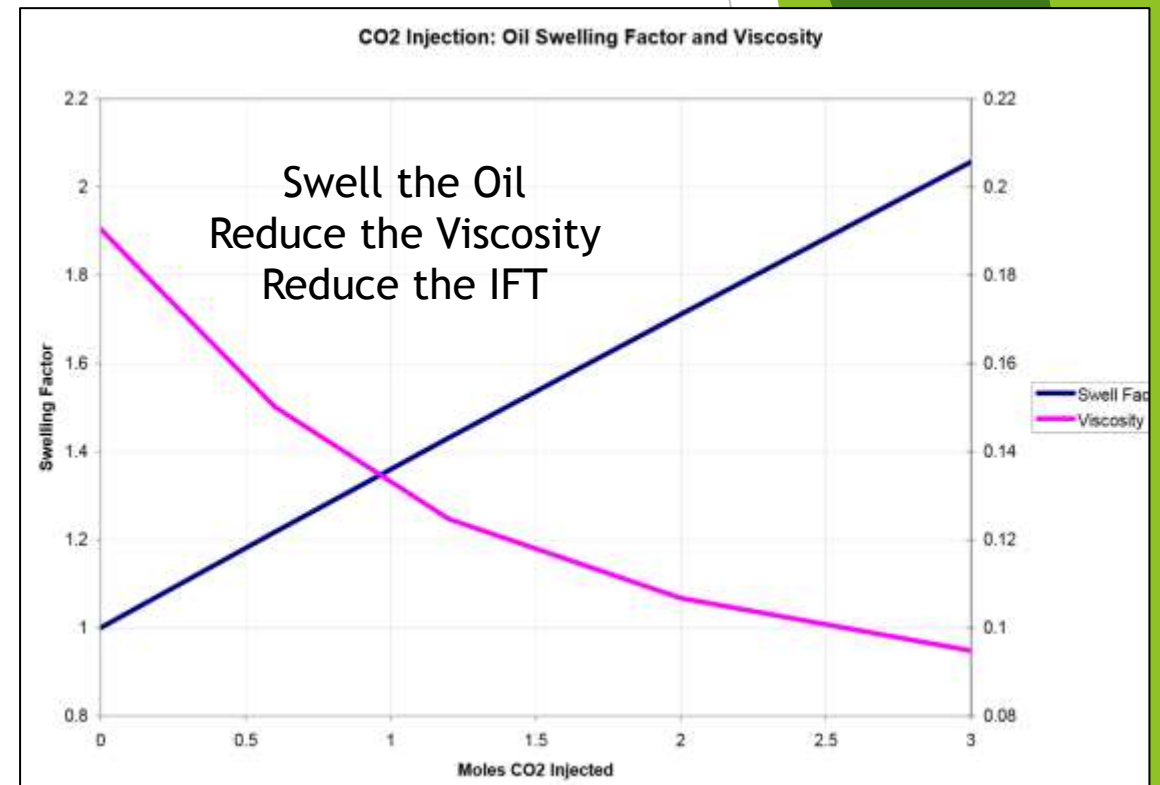
	Operator	Good	Better	Unit
Oil Gravity	Less Than	0.92	0.84	wrtWat=1
Viscosity	Less Than	10.0	1.5	cP
Oil Saturation	Greater Than	20.0	55.0	percent
Oil Composition		High % C5-C12		
Depth	Greater Than	2500.0		ft
Formation Type		Sandstone/Carbonate		

- ▶ Thickness & Permeability
 - ▶ Thickness - “Wide Range”
 - ▶ Permeability - “Not Critical”
 - ▶ Will discuss this shortly
- ▶ “Successful” W/F usually a pre-condition for CO2 EOR
 - ▶ But doesn’t guarantee it!!

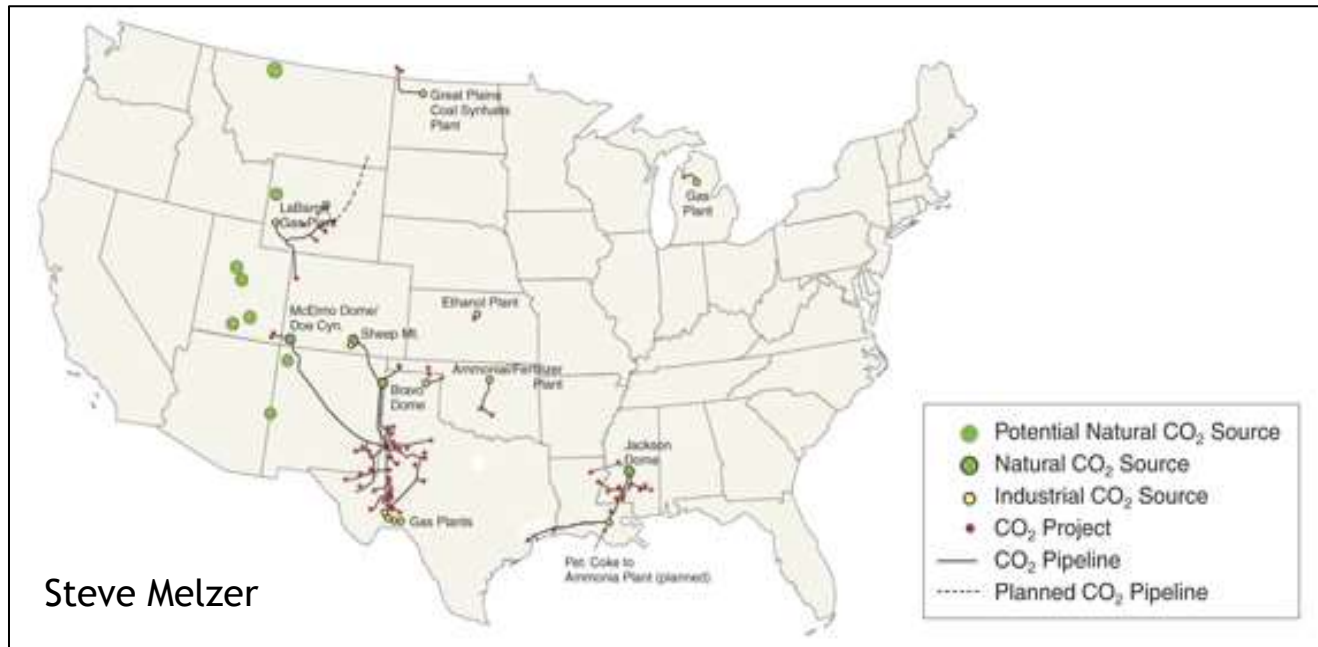


CO2 EOR - How does it work?

- ▶ If $P > 1071$ psi (73.9 bar) and $T > 31.1$ °C, CO2 is in Super-Critical (S/C) state
 - ▶ Density is liquid-like (but usually less than the target oil!)
 - ▶ Viscosity is vapour-like
- ▶ CO2 must “dissolve” in the remaining oil in place
 - ▶ First Contact Miscibility (FCM)
 - ▶ Vapourising Gas Drive
 - ▶ Condensing Gas Drive
- ▶ If it does dissolve
 - ▶ Incremental Recovery Factor (RF) 10-15%
 - ▶ Denbury Resources (Mississippi) get 20% by “carpet bombing” their fields



CO2 EOR - When it works, it works!



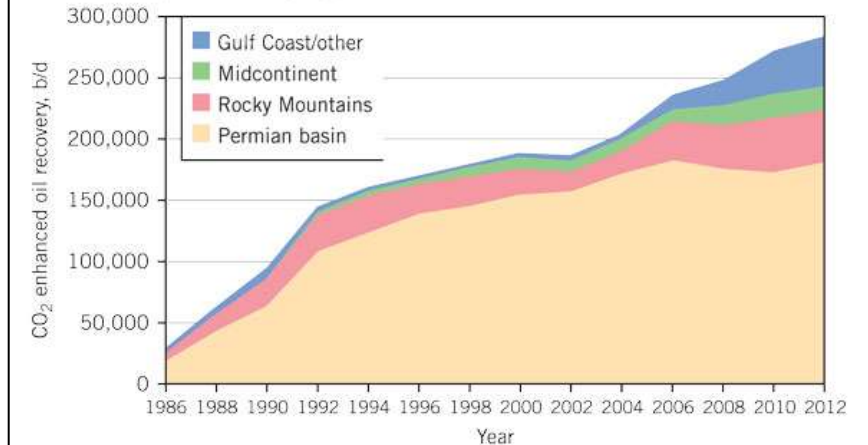
Since first flood in 1972 (SACROC) over 2 Billion barrels oil produced via CO2 EOR

Most CO2 (historically) from CO2 Fields, 65 Mt/yr

CO₂-EOR OIL PRODUCTION HAS RISEN STEADILY THE PAST 5 YEARS

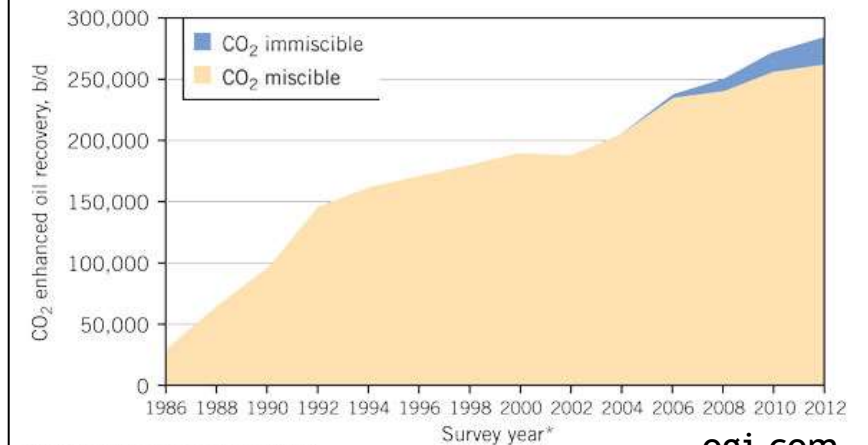
FIG. 2

CO₂-EOR oil production by region



Sources: Advanced Resources International Inc. and Oil & Gas Journal, 2012.

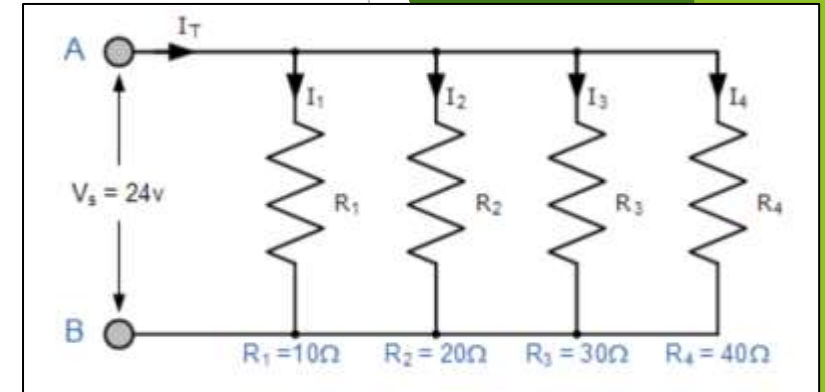
CO₂-EOR oil production by technology



*Data are for EOR production rate at end of prior year.
Sources: Advanced Resources International Inc. and Oil & Gas Journal, 2012.

What about the Geology? Caution - I'm an RE

- ▶ The best (to date) North Sea reservoirs tend to be thick (H) and have high permeability (K) as production rate $\propto KH$
- ▶ Heterogeneity, heterogeneity, heterogeneity ...
 - ▶ If there's a high permeability streak, the CO2 will find it
 - ▶ If the reservoir is thick and has vertical connectivity, its likely the CO2 will gravity override the target oil
- ▶ Viscosity of S/C CO2 ≈ 0.05 cP
 - ▶ 10 times more mobile than water
 - ▶ 10-100 times more mobile than the oil we seek
- ▶ It doesn't fully dissolve in the oil - immiscible flood or displacement
 - ▶ RF is halved, say less than 5% incremental oil

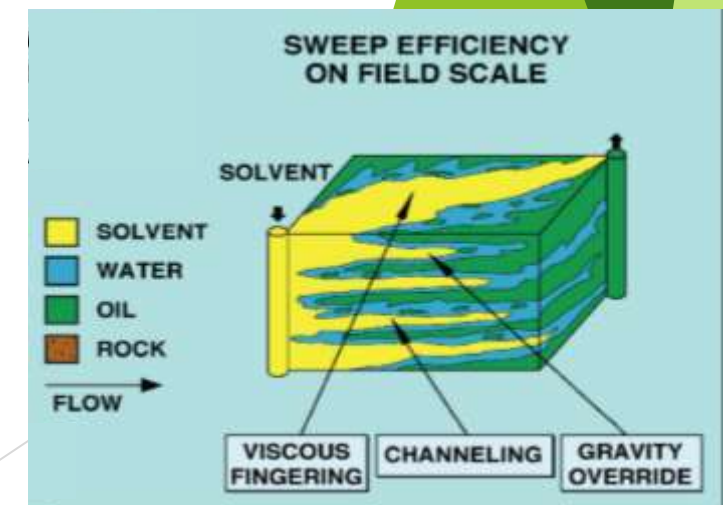


Ohm's Law

$$i = \frac{1}{R} V$$

Darcy's Law

$$v = \frac{K dP}{\mu dx}$$



Can you see the problem yet?

- ▶ Permian basin reservoirs are usually low permeability (less than 10 mD) carbonates, highly stratified (thin zones) with poor vertical communication
- ▶ Most important factor affecting RF is field scale sweep efficiency
 - ▶ Control by reducing inter-well spacing
 - ▶ Increase injection rate
 - ▶ Reconfigure well patterns
 - ▶ Increase CO2 slug size
 - ▶ Vary ratio of Water to CO2 slug sizes/timing (WAG)
- ▶ Onshore: Simulate, Lab Tests, Single Well Pilot, Single Pattern Pilot
 - ▶ Incremental spend, build confidence, reduce risk
- ▶ Offshore: It's all or nothing, invest billions and hope it works!

Well Spacing
Onshore - 100's m
Offshore - 1000's m



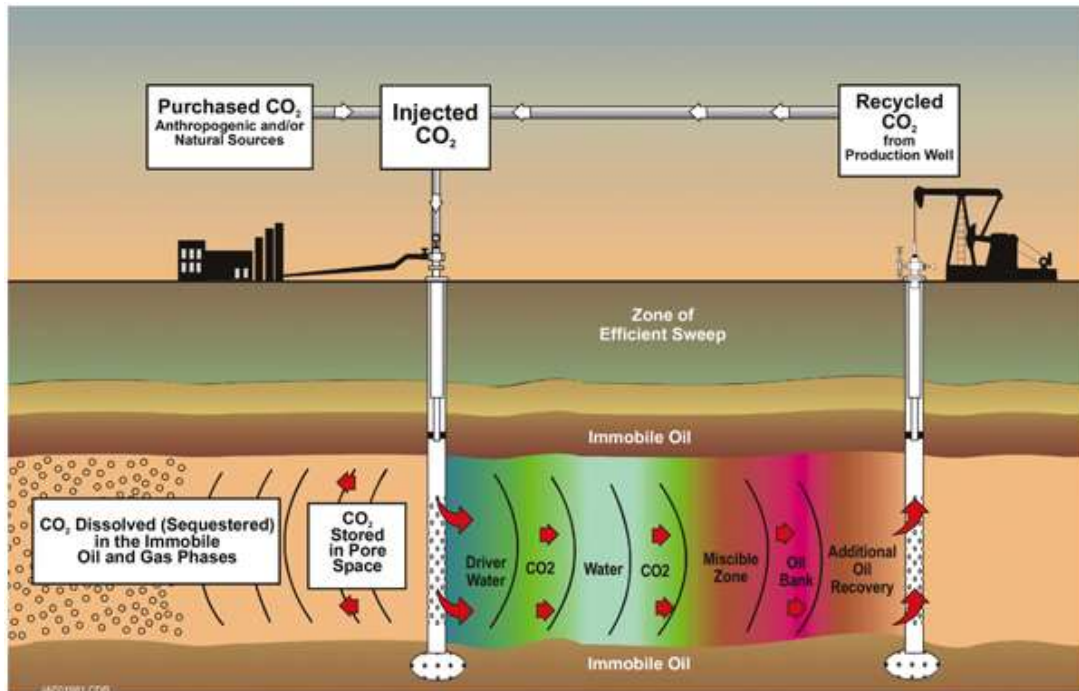
How do you retro-fit all this onto this?



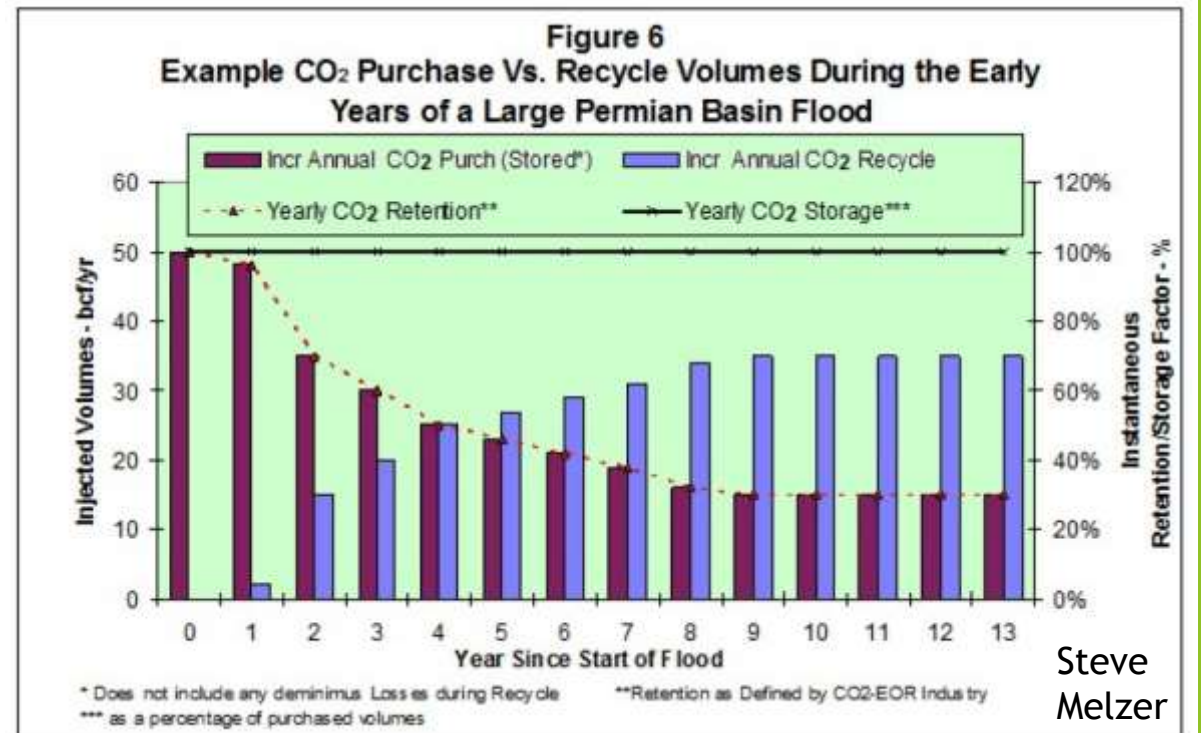
And this has to stay afloat for another 20-30 years

Facilities Challenge

- ▶ If the process works, CO₂-saturated oil will be produced
- ▶ It has to be processed, captured, and re-injected
 - ▶ Retro-fitting existing facilities ~ 3x cost of designing/fitting up-front



Source: Advanced Resources International and Melzer Consulting, Optimization of CO₂ Storage in CO₂ Enhanced Oil Recovery Projects, prepared for UK Department of Energy & Climate Change, November 2010.

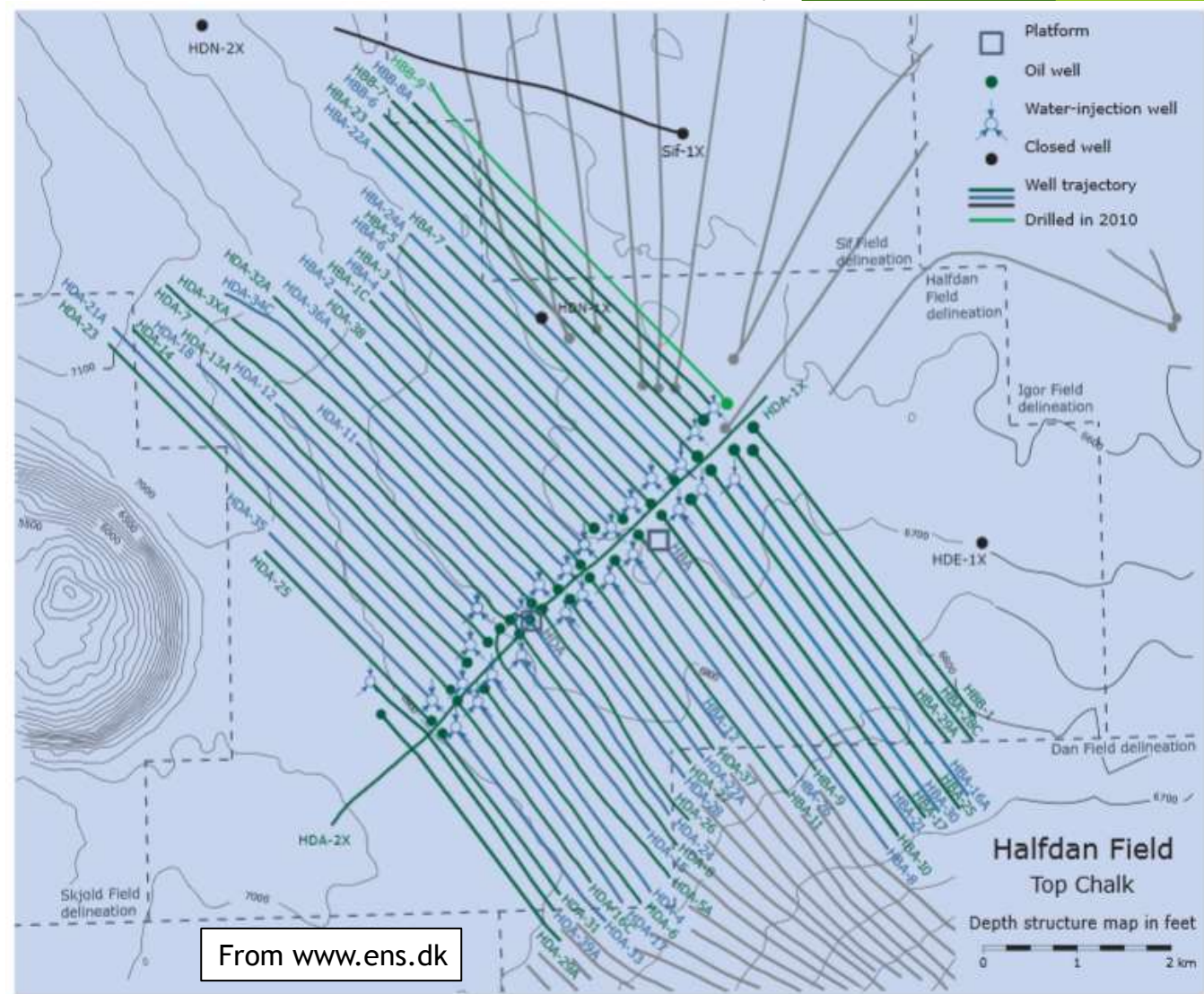


Steve Melzer

The “best candidate” in Europe

- ▶ Halfdan field, Danish Sector
 - ▶ Operator Maersk; Partners Shell & Chevron
 - ▶ STOIP \approx 2 Bstb, RF < 30% by Water-Flood
- ▶ Chalk: high porosity, very low permeability
 - ▶ Best $K \approx$ 2 mD, hence 3 km long wells
 - ▶ About 150-200 m apart
 - ▶ Producer, Injector, Producer, ...
 - ▶ 10-15 Vertical Frac's in plane of the well
- ▶ Relatively low heterogeneity
 - ▶ The CO₂ will probably contact most oil
- ▶ But time from injector to producer is ...

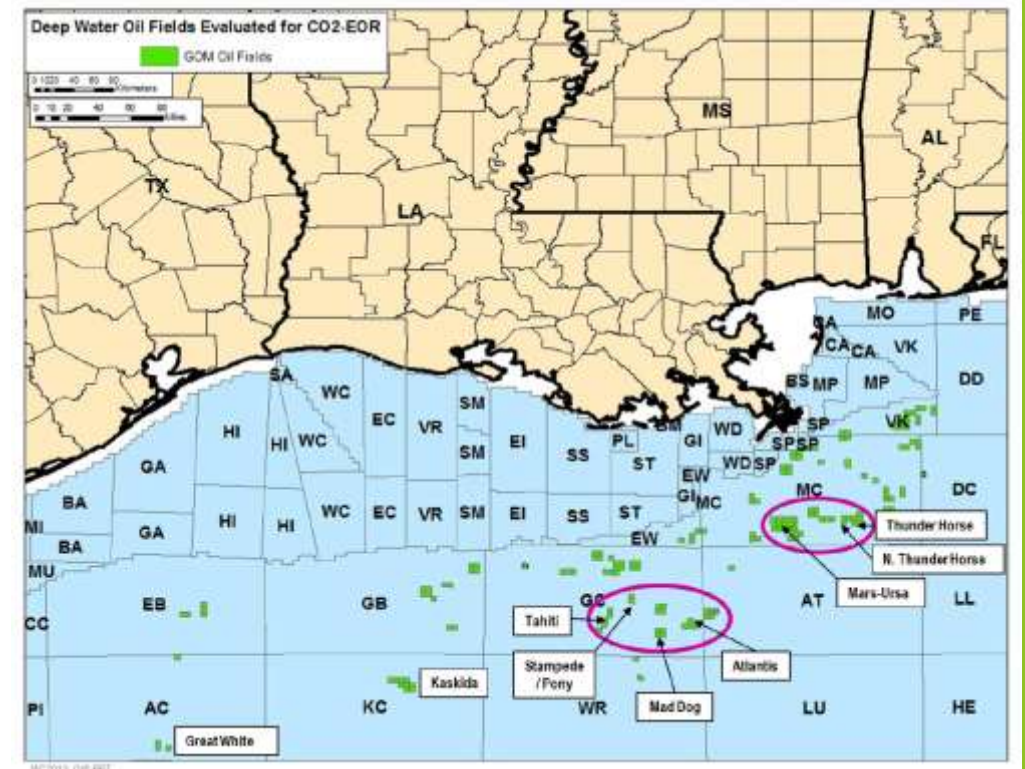
4 years!



There are optimists

- ▶ US Department of Energy: National Energy Technology Lab
 - ▶ <http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Publications/Offshore-GOM-resource-Final.pdf>
 - ▶ Google “CO2 EOR Offshore Assessment” (05 June 2014) aimed at Gulf of Mexico
- ▶ Benefits are offshore storage of CO2 from Gulf Coast Power & Industrial Plants
 - ▶ 15 Bstb of incremental recovery and 3.9 Gt of storage
- ▶ Requires “Next Generation” CO2 EOR Technology
 - ▶ Existing technology needs \$100+ oil and recovers less than 1 Bstb
- ▶ Next Generation Technology being
 - ▶ Improved reservoir conformance
 - ▶ Advanced CO2 flood design
 - ▶ Enhanced Mobility Control
 - ▶ Increased Volumes of Injected CO2

Inject more (who pays?)
Control where it goes



And finally, ECONOMICS

- ▶ 20-30 years to perform a CO2 flood
 - ▶ Look at price volatility over last 10 years
 - ▶ Doesn't include last month (less than \$50/stb)
- ▶ Who pays for the CO2?
- ▶ Offshore costs prohibitive
 - ▶ Especially pipelines, wells & facilities
 - ▶ Existing facilities will probably need replacing
- ▶ Require stable fiscal setting
 - ▶ Do you trust politicians not to change the rules?
- ▶ How do you mitigate the risks?

