

Downhole metallurgy and corrosion – from the first pipe to current challenges.

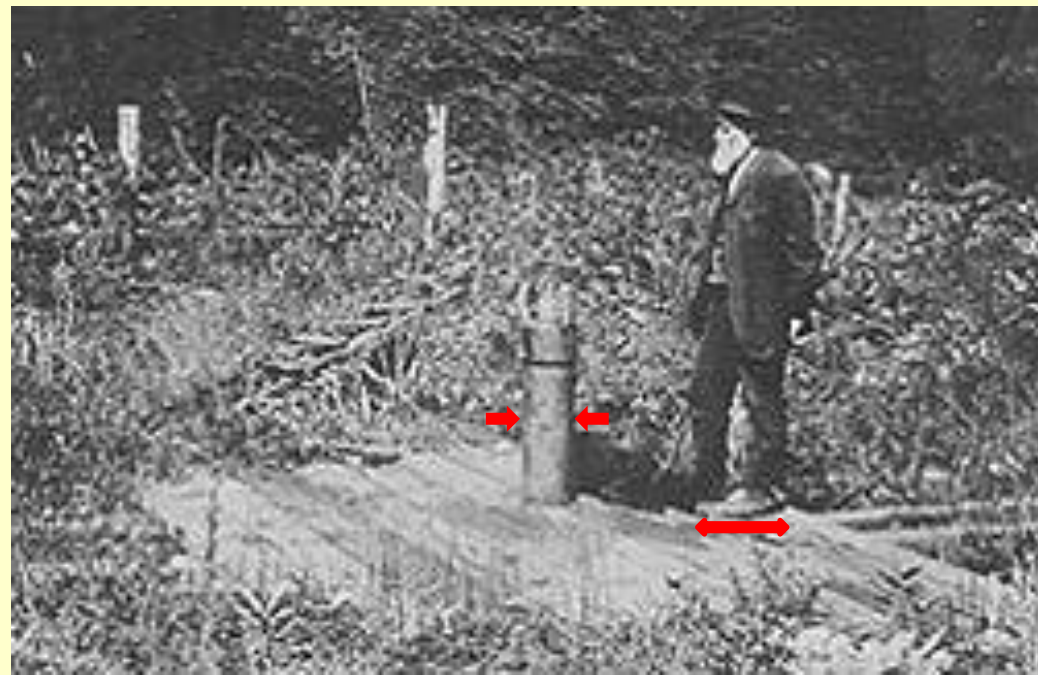
ICorr, IOM3; Aberdeen, 27 November 2018

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Drake Well (1859)

TD: 69.5 ft, 21.18 m

....struck oil in the Riceville Shale....
(August 27)



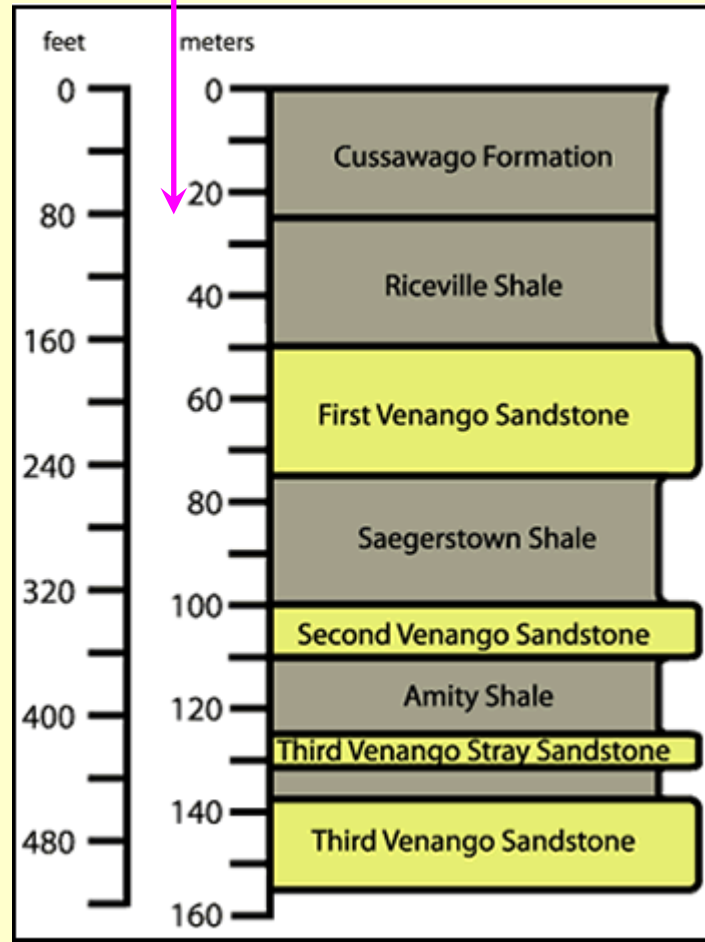
Titusville, Pennsylvania

Abandoned Drake Well in 1896

(Drake Well Museum) ? 12 in boot => ~7 in casing ?
1887: well deepened about 500 ft (153 m).

Hole caved in when only 16 ft (4.9 m) deep.
Drake idea of drive pipe (conductor did not patent!).

Drive pipe: 10 ft joints, cast-iron.
Drove to 'bedrock' at 32 ft (9.8 m) depth.



API Pipe history

(re strength, SSC, metal-loss)

1st API OCTG Spec (#5): 1924

1924 to 1940	Grade	SMYS ksi	SMTS ksi
	Wrought iron [^]	24	42
	Open hearth iron [^]	25	45
	'steel' [^]	25	45
	A*	30	48
	B*	35	62
	C*	45	75
1930	D*	55	95

[^]Lap welded

*Seamless, ERW from 1934

1940 revisions	Grade	SMYS ksi	SMTS ksi
	Wrought iron [^]	24	42
	Open hearth iron [^]	25	45
	'steel' [^]	25	45
	F25 [^] *	25	40
	H40*	40	70
	J55*	55	75
	N80*	80	100

[^]Lap welded

*Seamless & ERW

Year	Grade (SMYS ksi)	SMYS MPa	CRA
1940	H40*	276	
1940	J55*	379	
1940	N80*	552	
1960	P110 ^(*)	758	
1963 - 1990	C75	517	
1968	K55*		
1970 (2011)	C95* (R95)	655	
1972			13Cr trial
1975	(V150)	1034	
1975	L80*	552	
1984	C90	621	
1985	Q125*	862	
1987			L80 9Cr L80 13Cr
1989	T95	655	
1998	M65*	448	
2000			ISO 13680
2010			API 5CRA
2011	C110	758	

Sumitomo SMC110 historical data sheet

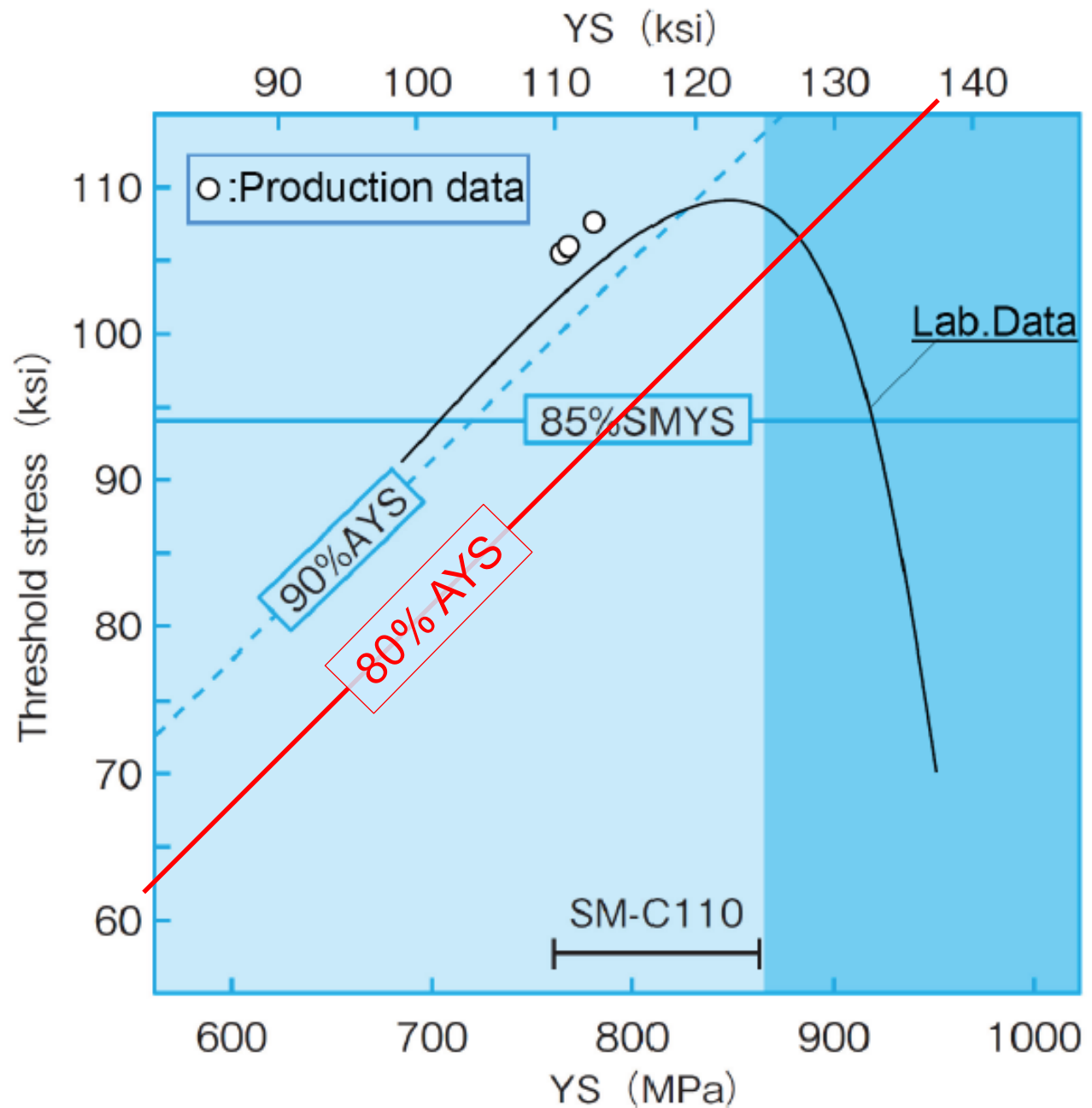


Fig. 3 : SMC110 SSC susceptibility to material Yield Strength and applied threshold stress.
NACE Method A, solution A, 25 deg.C.

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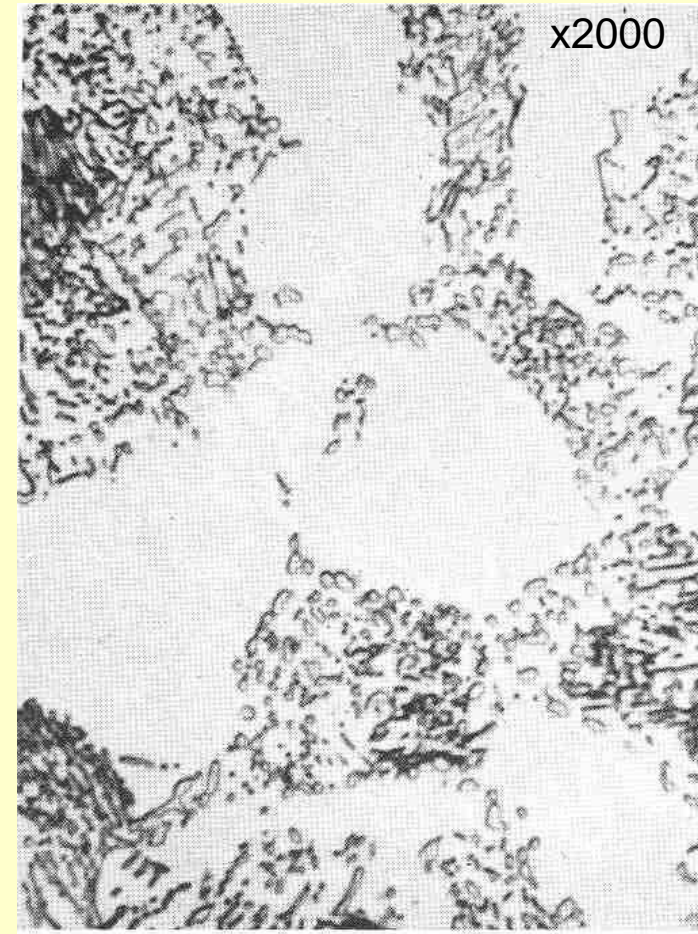
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*Seamless & ERW

Year	Grade (SMYS ksi)	SMYS MPa	CRA	
1940	H40*	276	to prevent metal loss by prolonged flow-wetting	
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Metal loss as ringworm corrosion of carbon steel

'GOOD' pearlite



'BAD' pearlite

RINGWORM corrosion only occurs in pearlitic carbon steels (NOT low-alloy steels) after local heat treatment. It has been 'eliminated' by the API/ISO requirement for full-length HT.

North Sea, metal loss, CRA adoption

1963: NL onshore gas production (Groningen)

1967: UK SNS gas production (BP West Sole)

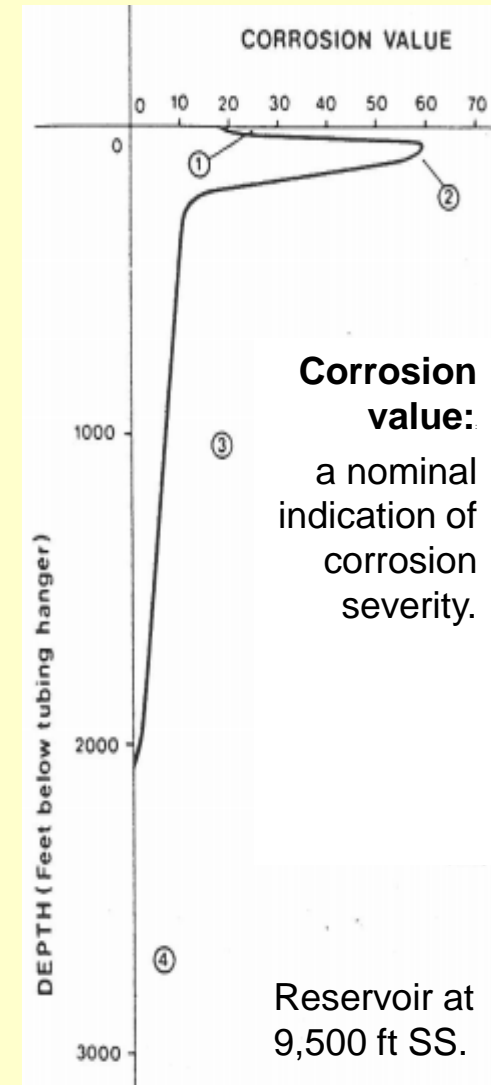
1971: West Sole – tubing failures (N80 after 2~4 years)*

1972: selective 13Cr tubing in West Sole (and elsewhere)

1972: DK N Sea oil: (CO₂ + MIC, N80/L80 =>2013)

1975: UK oil production

1987: API 5CT additions: L80-9CR, L80-13Cr



String inspection summary*

*Gair, D J; Moulds, T P: "Tubular corrosion in the West Sole gas field".

Cold hardened CRAs for HPHT liners & tubing

Issues:

1) **Halite scale** potential from high chloride (solids-saturated) formation water.



5 mm thick specimen

2) **residual stresses** unknown consequences of redistribution during test specimen preparation.



OD: 8.03 in, 204 mm

Options: ignore or investigate?

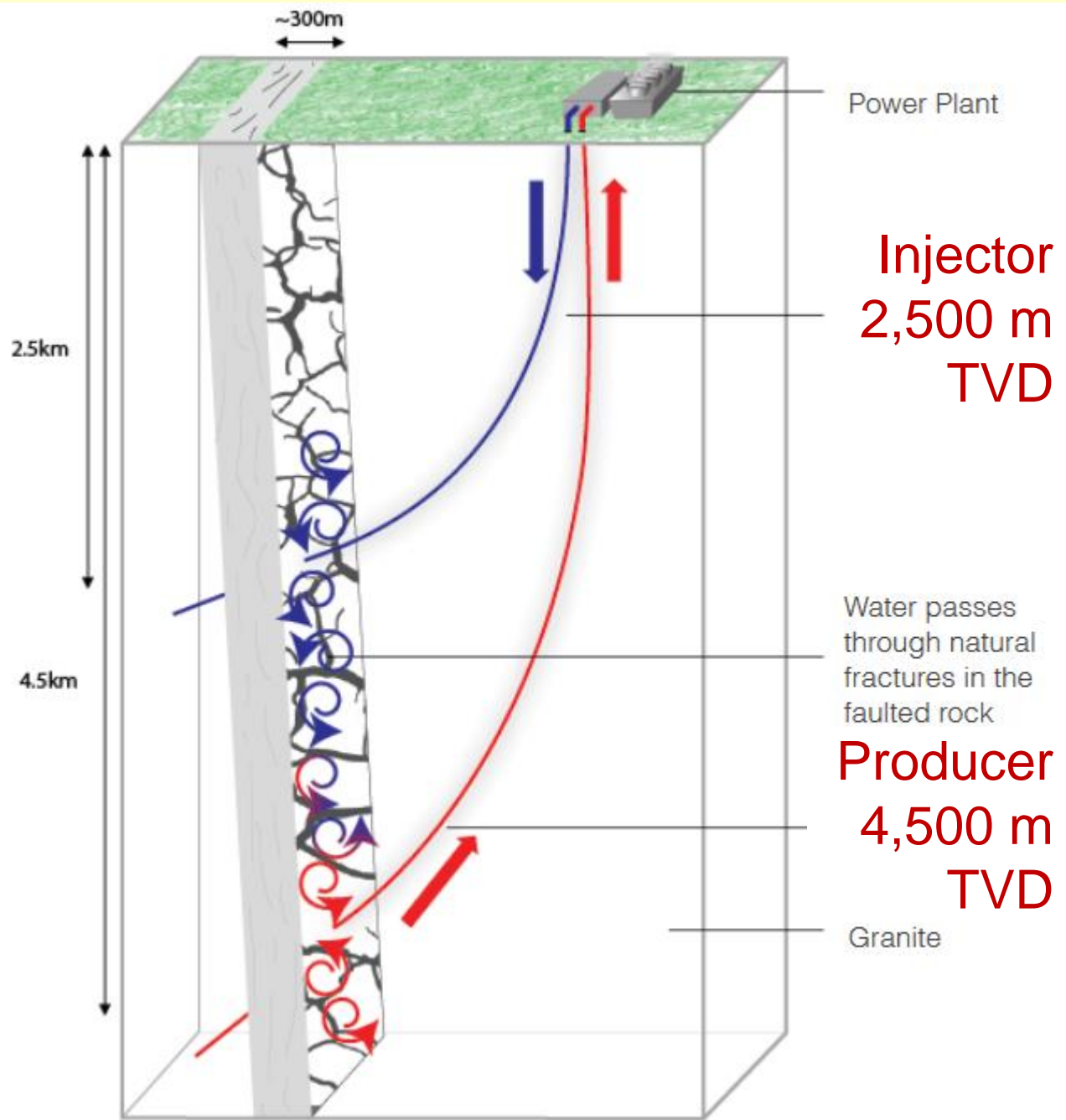
Geothermal

Cornwall: United Downs Deep Power Project

Producer BHT:
~190°C.

Deepest historical
mine: ~1,000 m.

Previously (1980s.): UK H
Dry Rock geothermal
research programme.



Geothermal Waters, Metallurgy

Waters & contaminants are variable:-

Natural/primary waters (by source): Magmatic, Amagmatic;

by type: Acid-sulphate: SO_2 , HCl, (NH_4) ;

Neutral chloride: CO_2 , H_2S , (H_2) ;

Alkali carbonate: HCO_3^- ;

Mixed!

Flow may be NATURAL or ENHANCED by injection / circulation
Hence: Enhanced or Engineered Geothermal Systems (EGS)

Water may change over time.

Sources: Williams, et al: https://www.energy.gov/.../updating_classification_geothermal_resources_paper.pdf
EU (GEOCOM) project: www.geothermalcommunities.eu/assets/.../3.2.Corrosion&Scaling.pdf

Metallurgy: any from Oilfield practice (API, ISO) & Ti.

Salton Sea, Ca: Ti-6-4-Ru hot-rolled seamless at 10-3/4, 13-3/8 in OD.

Replaced extruded Ti38644/Pd and thicker 'steel'.

Carbon Storage

CCS in 3 of 4 IPCC pathways for 1.5°C

(Oct 2018) <https://is.gd/BW5zWs>

Component	Unit	UK N	UK S	CarbonNet, AU.	
		MAX	MAX	Lower	Upper
CO ₂	%vol	>0.99	>99.94	93.5	
*N ₂ , H ₂ , Ar, CH ₄	%vol	0.01			
*N ₂ , H ₂ , Ar, O ₂ , CH ₄	%vol	-		2	5
N ₂	ppmv	0.006	350		
O ₂	ppmv	1	150		
H ₂ O	ppmv	50	24, (100)	100	
CO	ppmv	10		900	5,000
NO _x	ppmv	10		250	2,500
SO _x	ppmv	10		200	2,000
H ₂ S	ppmv	0.5		100	100
HCl	ppmv	1			
Amines	ppmv	2			
Hg	ppb	1			
NH ₄	ppmv	5			
Aldehydes	ppmv	20			
HCN		-		by risk assessment	
Hydrocarbons	ppmv	10		5,000	
*'Non-condensables'			(upset)	Lower/Upper: 2 scenarios	

DECC UK Studies:

Longannet =>

Goldeneye

SSE, Shell

Kingsnorth => Hewett

E.ON, RDS

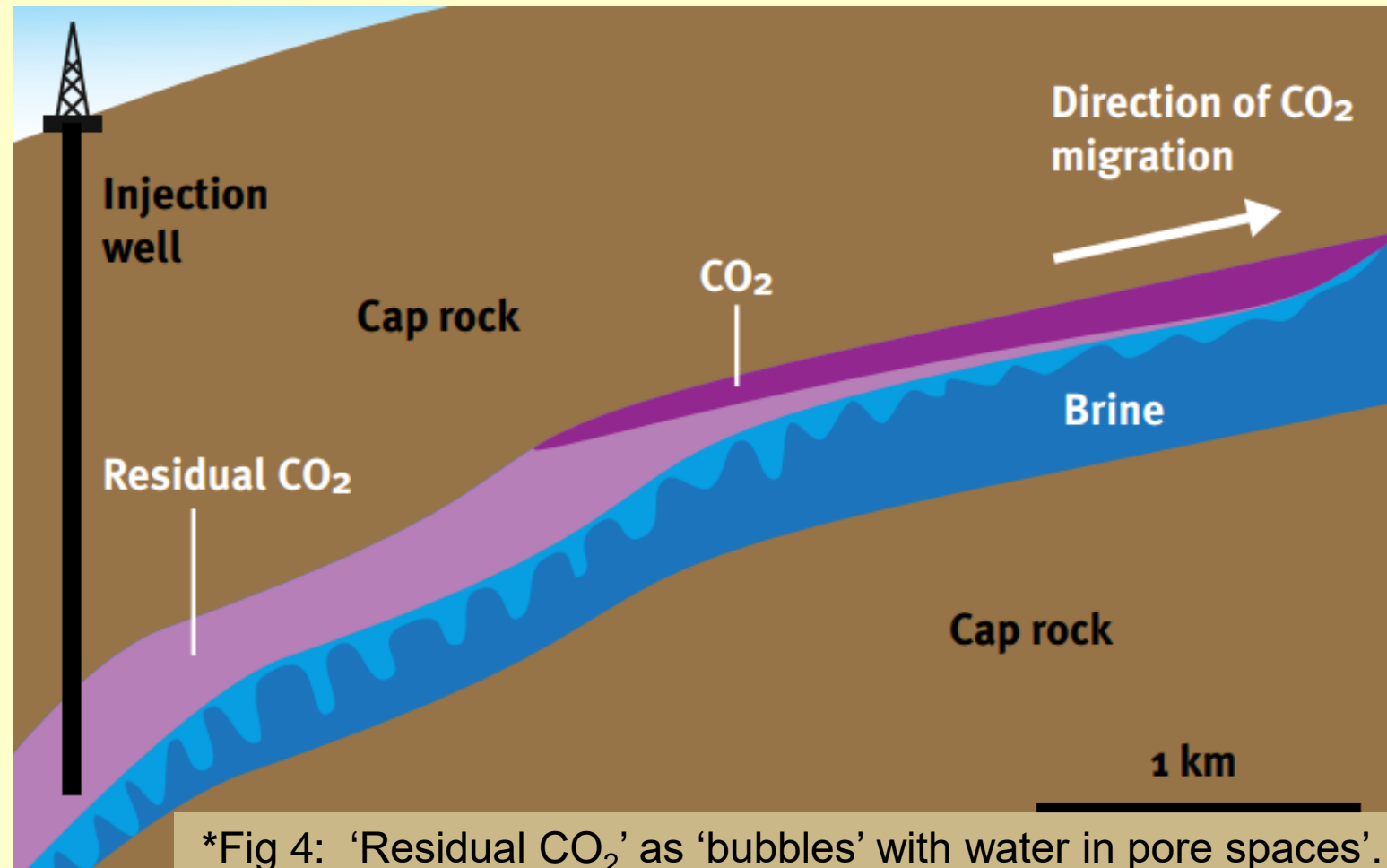
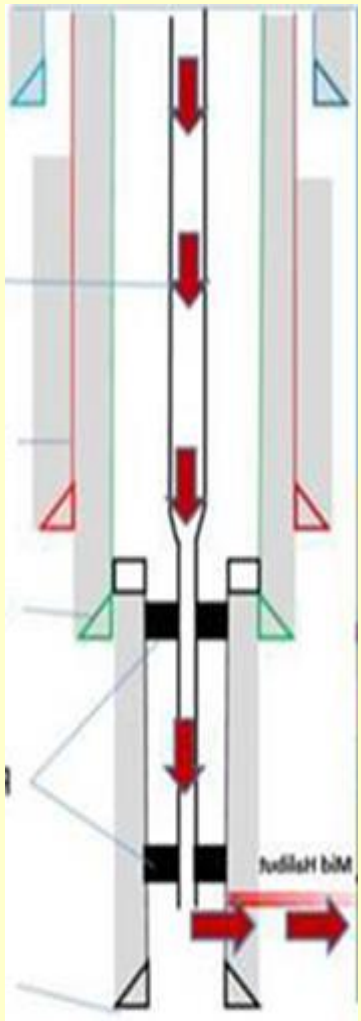
<https://is.gd/9ueA8x>

CarbonNet, Australia:

Multi-source CO₂ from Victoria's Latrobe Valley to offshore storage in Gippsland Basin.

<https://is.gd/E8c1CE>

Carbon stores



*Fig 4: 'Residual CO₂' as 'bubbles' with water in pore spaces'.

*Imperial College, Grantham Institute for Climate Change; Briefing paper #4 (2010/2011).

Carbon dioxide storage, Prof M Blunt.

***Disposal potential:** 1 Mt CO₂ per well/y (~19,000 b/d).

6Gt CO₂/y = 50% coal emissions or 20% fossil fuel emissions;

REQUIRES: ~6,000 wells??

Summary

1. 1859~2018: we have been burying metal in wells for 159 years and look like continuing.
2. Downhole metallurgy has been under constant development to meet strength and corrosion challenges.
3. Strength and corrosion resistance continue to challenge oil and gas practice; expect more of the same for carbon-emissions mitigation wells.
4. Lack of deterministic corrosion test protocols is a continuing 'problem' for H₂S-resistant low-alloy steels and CRAs. This forces 'judgemental' selections.