Well Integrity in CCS/CCUS Projects

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United States Energy Association

DOE Well Integrity Briefing

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by

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Overview of Well Integrity in CO_2 Projects
(CO_2 Injection for Storage & EOR)

- Well integrity maintained by best practices, e.g.:
  - ~100 yrs. of lessons learned in oil & gas wells
  - ~40% of oil & gas production is sour (CO_2 & H_2S)
  - API standards, specifications, and recommended practices
  - API technical report on CO_2 EOR project design & operations
  - CCP book, esp. chapters on well design & construction
  - CSA Z741 standard for all phases of CCS projects
- CO_2 well integrity issues are:
  - Similar to oil & gas wells
  - More severe than sweet oil & gas production
  - Less severe than highly sour production and acid gas injection
  - Low risk in modern wells and in new wells
  - Higher risk in wells drilled without best practices
- Monitoring & Repairing Leaks Restores Well Integrity

Well Integrity in CO_2 Injection Projects

- >18,000 CO_2 EOR wells worldwide (OGJ)
- 95% of CO_2 EOR wells in USA
- Successful environmental protection
  - Wells designed with multiple pressure barriers
    - No failures of all barriers
  - Monitoring and mitigation is routinely practiced
    - Monitoring helps protect USDW
    - Mitigation keeps flows normal
  - Field-wide monitoring gaining acceptance

Abnormal Flows in CO_2 Injection Projects

- No evidence of leakage into USDW or air
- Abnormal flows ("leakage") found & fixed by,
  - Mass balance measurements
  - Periodic MIT, flow profile logging, etc.
  - Flow path sealing technologies
- Flows far up-hole are rare (>1 barrier fails)
- BUT, risk and costs can threaten project viability – especially offshore
- Frequent flow monitoring can reduce risks

MIT Results in Injection Wells

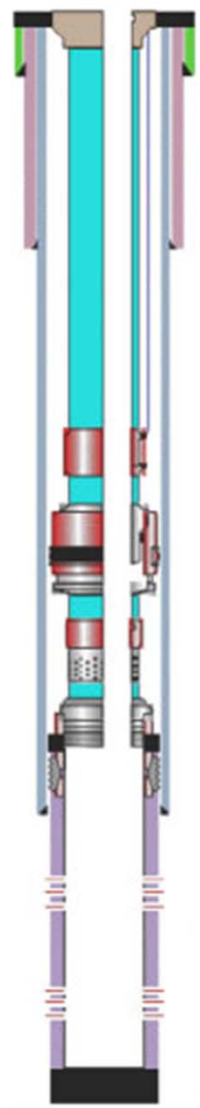
(Koplos et al, 2007)

Texas UIC Data - Class II EOR Wells (1983-2005)

Injection Type	Years	Total # of Wells	Total # of Wells with MIT Failure	% Wells with MIT Failure
acid gas	pre-1995	568	35	6.2%
	1995-1999	594	9	1.5%
	2000-2005	748	61	8.2%
	All Years	**752**	**98**	**13.0%**
CO_2	pre-1995	3,324	135	4.1%
	1995-1999	3,432	46	1.3%
	2000-2005	3,978	298	7.5%
	All Years	**4,105**	**455**	**11.1%**
fresh water	pre-1995	5,395	197	3.7%
	1995-1999	5,703	57	1.0%
	2000-2005	6,175	359	5.8%
	All Years	**6,400**	**596**	**9.3%**
brackish water	pre-1995	10,713	483	4.5%
	1995-1999	12,715	223	1.8%
	2000-2005	14,488	731	5.0%
	All Years	**16,060**	**1,366**	**8.5%**

Designing Wells for Integrity Risks

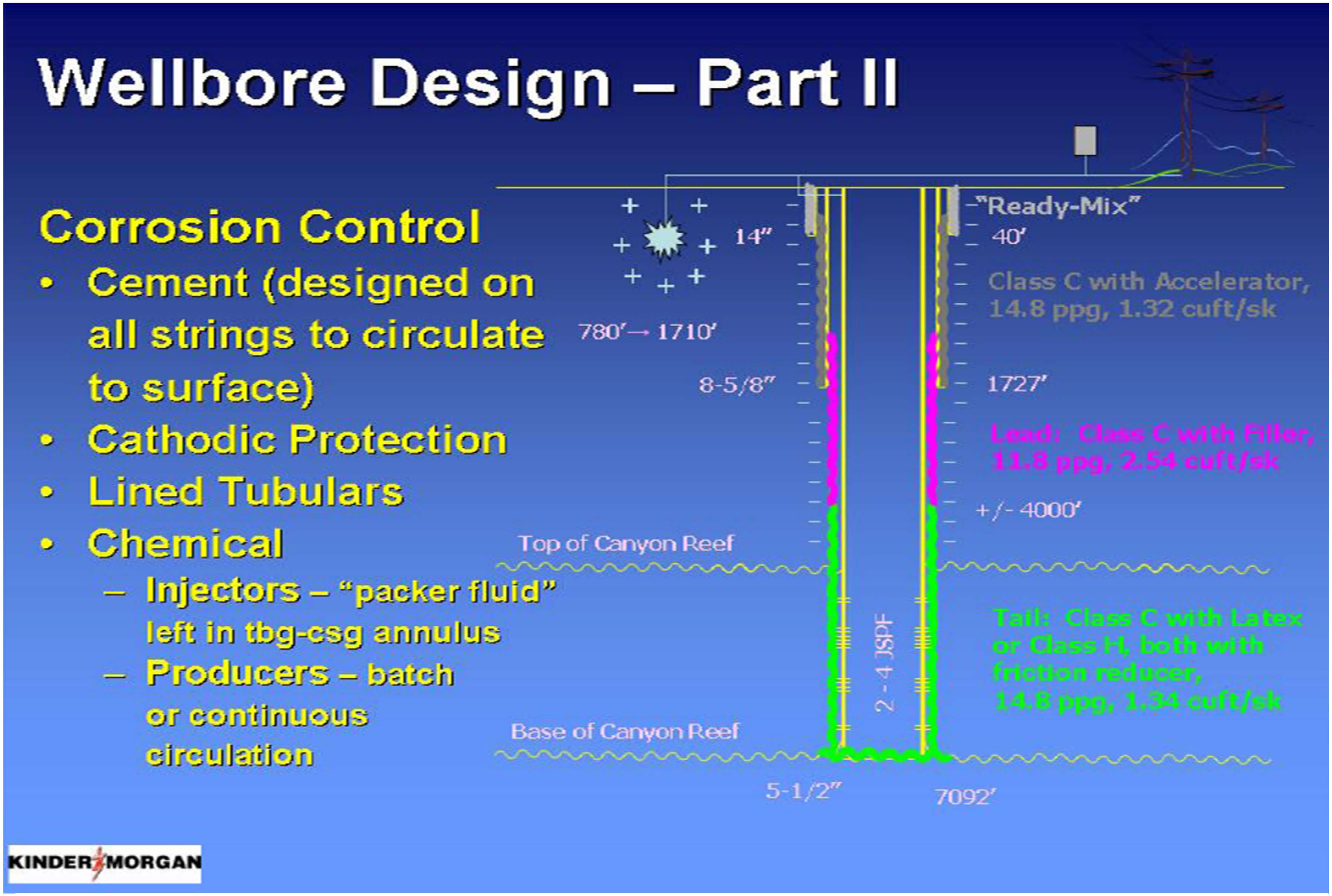
(CCP Book Chapter 2)



Description	Potential Risks and Concerns	Materials
Tubing Hanger	CO_2 corrosion may be associated with well back-flushing provision and process interruptions.	CRA - Generally high Nickel Content
Conductor Casing	Some aquifers have a potential external corrosion risk.	Carbon steel - consider external coating.
Surface Casing		Carbon steel.
Injection Tubing	Provision for periodic back-flushing and process up-sets may yield water exceeding 8,000 mpy	GRE lined Carbon Steel or CRA.
Production Casing	Metallurgy in accordance with industry standards for any contaminants in CO_2.	Carbon Steel - Surface to immediately above base of sealing formation.
Production Liner	Process upsets & provision for back-flushing may result in high water content CO_2 in the injection zone. Also there may be contaminants in the CO_2 such as H_2S.	CRA. Industry standard if required for applicable contaminants.

Abbreviations used: CRA = Corrosion Resistant Alloy; GRE = resin epoxy; NACE = National Association of Corrosion Engineers.

Typical Well Design to Resist Corrosion

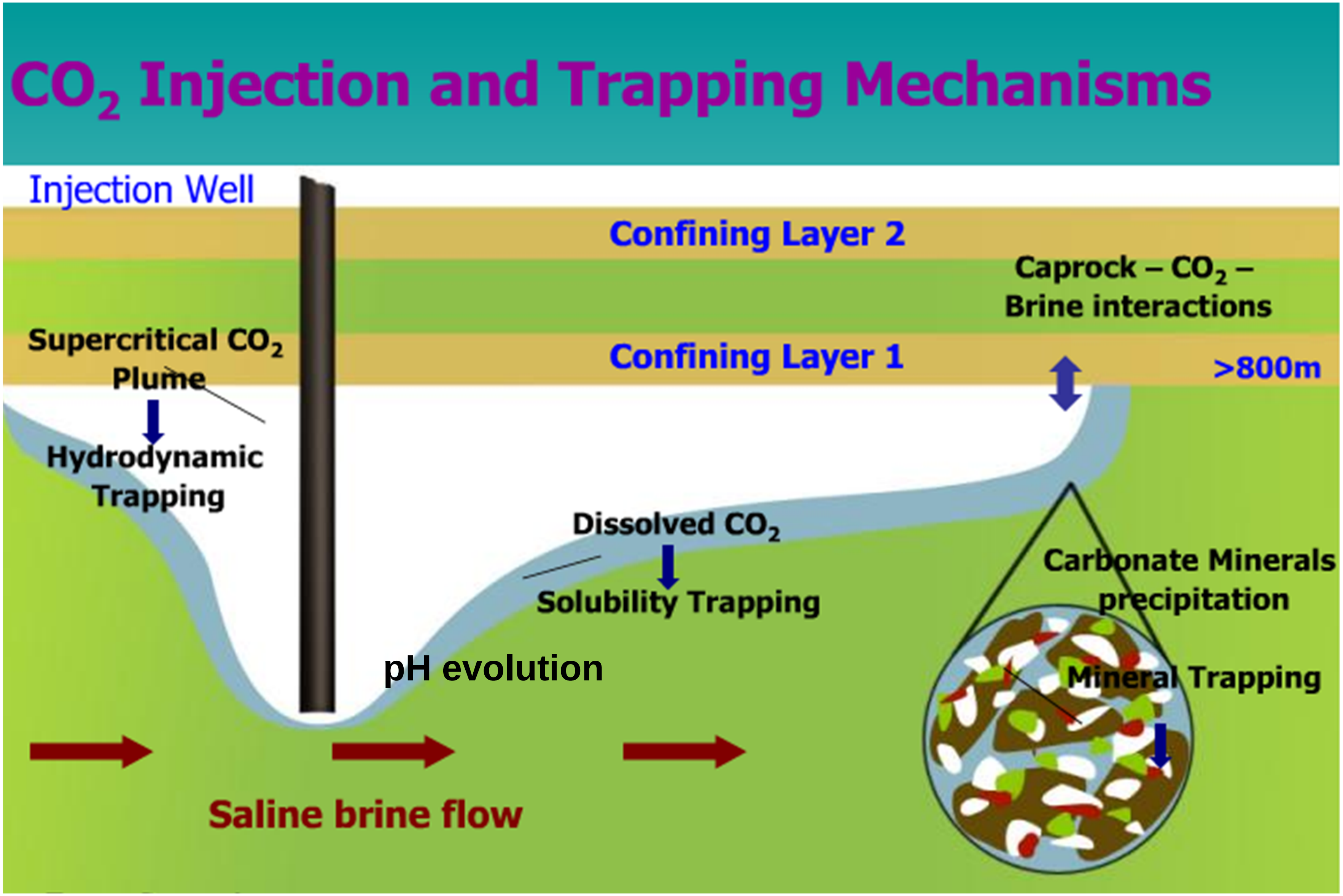


API Report (2007): "Summary of Carbon Dioxide Enhanced Oil Recovery (CO_2EOR) Injection Well Technology"

Planning to Prevent Corrosion

- Determine the severity of corrosion conditions
- Get geochemical data from mud logger or cores
- Use corrosion model predictions over life of well
- Run lab tests with predicted pH values
  - Cement core tests in Hassler Cells
  - Coupon tests for metallurgy in tubulars, DH tools & wellheads
  - Chemical barriers in formation core tests
  - Treatments for packer fluids, drilling & completion fluids
  - Elastomer tests for packer & wellhead sealing elements
- Select well materials based on modeling & lab tests
- Prepare contingency plan for remediation

Modeling pH of CO_2 in Brine

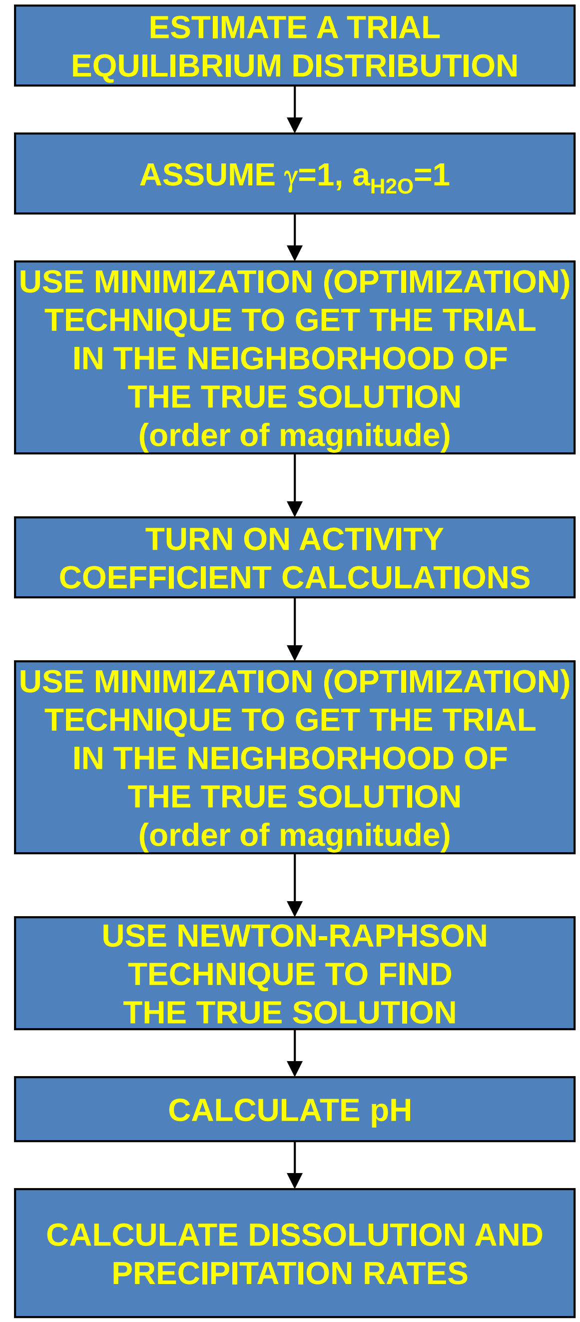


(Zhu, 2009)

Equilibrium and rate calculations for corrosive brines in rocks & soluble minerals

- **Prior to project: design well tubulars, packers, and cements.**
- **Monitor data: provide in situ conditions during flood for remediation.**

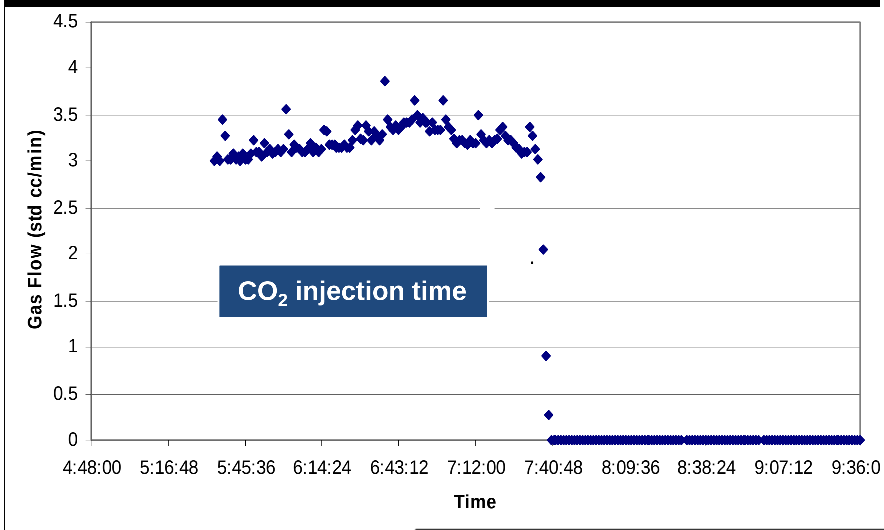
H2O	OH-	KCl(aq)	smectite-na
H+	Al(OH)2+	KSO4-	k-feldspar
Ca+2	Al(OH)3(aq)	MgCl+	chlorite
Mg+2	AlOH+2	MgHCO3+	hematite
Na+	HAlO2(aq)	MgSO4(aq)	pyrite-2
K+	Al+3	NaCl(aq)	smectite-ca
Fe+2	NaAlO2(aq)	NaCO3-	albite~low
SiO2(aq)	CaCl+	NaHCO3(aq)	dolomite-2
HCO3-	CaCl2(aq)	NaHSiO3(aq)	siderite-2
SO4-2	CaCO3(aq)	NaOH(aq)	ankerite-2
AlO2-	CaHCO3+	NaSO4-	dawsonite
Cl-	CaOH+	SO2(aq)	
O2(aq)	CaSO4(aq)	HCl(aq)	
Acetic~Acid(aq	FeCl+	calcite	
CO2(aq)	FeCl4-2	kerogen-os	
CO3-2	FeCO3(aq)	magnesite	
Fe+3	FeHCO3+	quartz	
H2(aq)	H2S(aq)	kaolinite	
HS-	H3SiO4-	illite	
CH4(aq)	HSO3-	oligoclase	



Cements & CWD Prevent Corrosion

- **Challenge: Corrosion prevention and mitigation methods**
  - May occur in old and new wells
- **Solutions:**
  - CO_2 resistant, self-sealing cements (Portland based when pH >4.0)
  - CWD chemical barriers in the rock

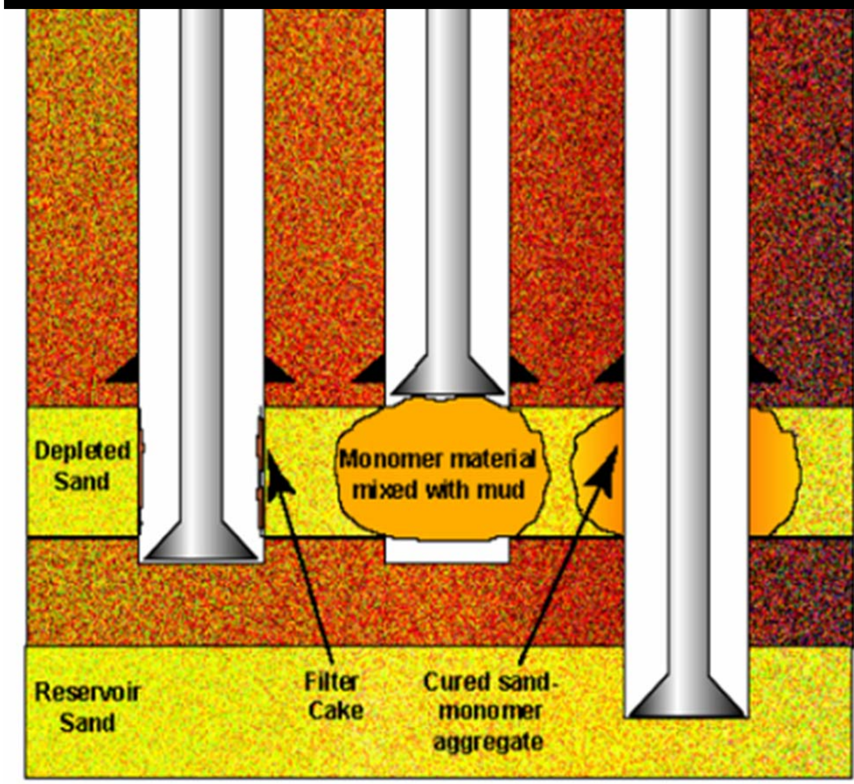
Self-sealing CO_2 cement



Hassler Cell Core Test conditions:
BHST: 220F
CO_2 pressure: 500 psi (water std@RT)
Confined press: 2000psi
Duration: 2 hours
Initial Flow: ~3.4 std cc/min
Final Flow: non-detectable
Time to STOP flow ~6min

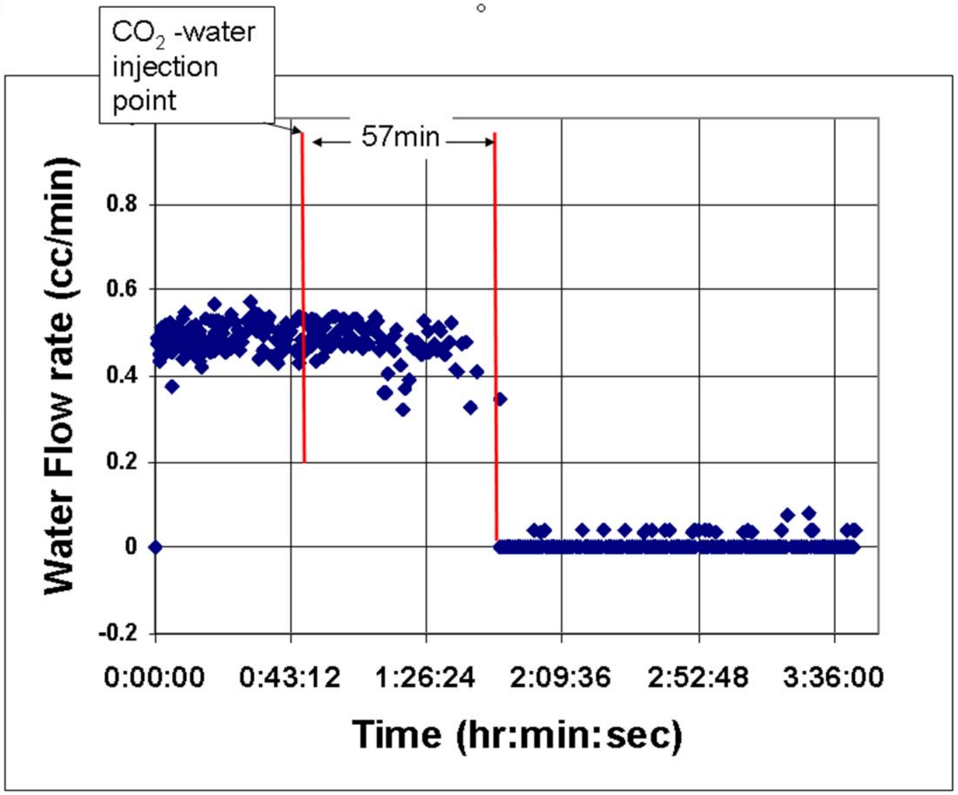
Conformance While Drilling

Protects CO2 Well Integrity by Blocking Rock Permeability



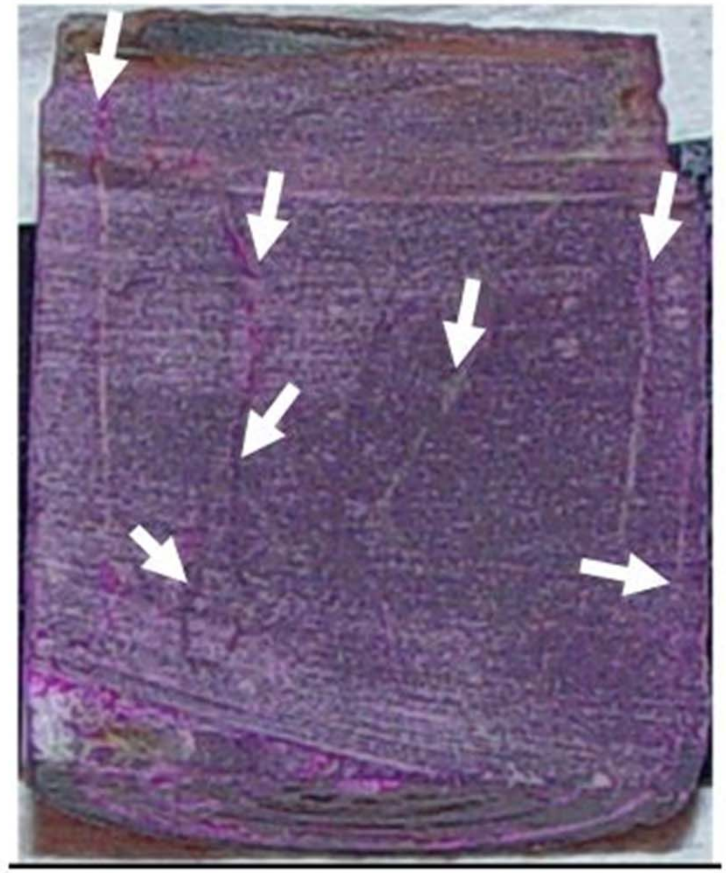
Self-Sealing CO_2 Cement after Stress Cracking

- Dynamic CO_2 flow test
  - Pre-cracked Cement Core Specimen
  - Core flow test using Hassler sleeve



Stress Cracks Sealed by Self-Sealing CO_2 Cement

Typical un-cracked sample



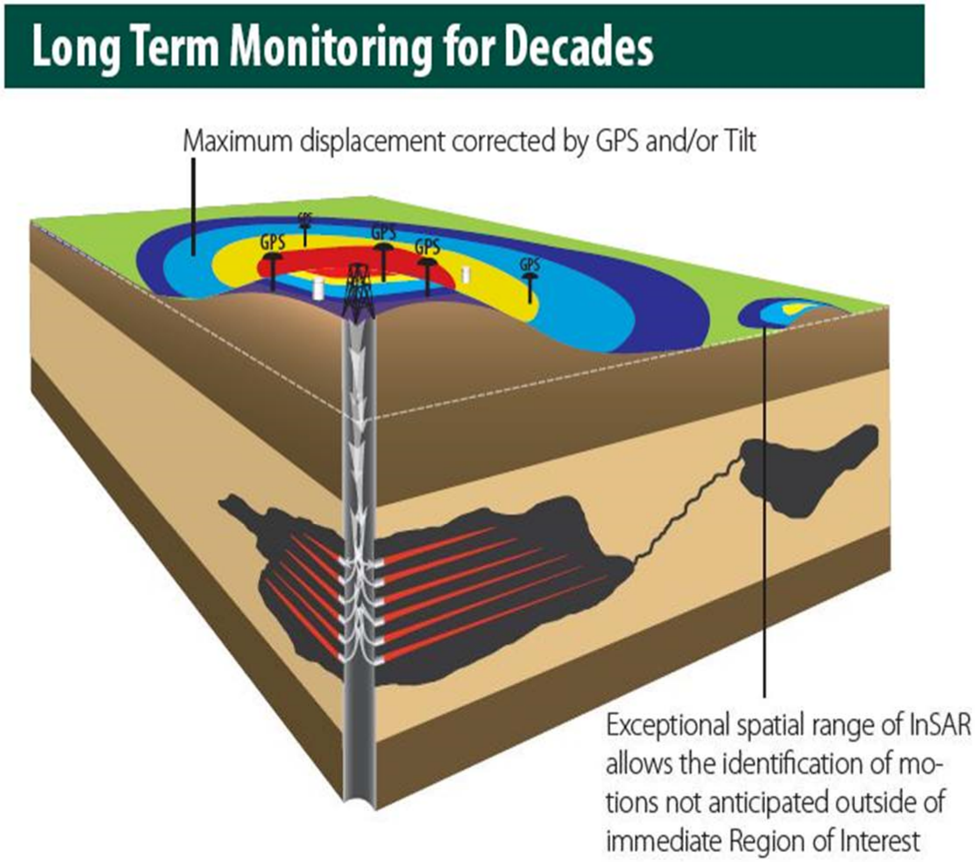
Cracked sample
(arrows show the healed crack)

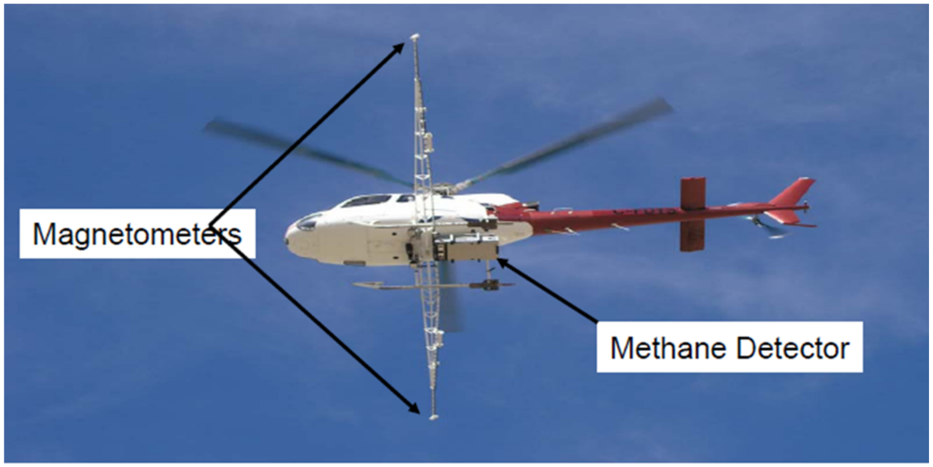
Monitoring, Inspection, Modeling Tools

- Annular pressure monitoring (API RP 90-1 & 90-2)
- Slick-line casing/tubing inspection (impression block, camera, etc)
- Wireline-conveyed logging tools (CBL, calipers, spinners, etc)
- Seismic array surveys & imaging
- Downhole pressure/temperature (P/T) data modeling
- Well flow meters, tracers & P/T gauges for mass balance data analysis
- Micro-deformation measurements & imaging
  - Surface & downhole tiltmeters
  - Satellite-based InSAR (interferometric synthetic aperture radar)
- Fiber optic sensing
  - DAS (Distributed Acoustic Sensing)
  - DTS (Distributed Temperature Sensing)
  - DSS (Distributed Stress Sensing)
- CO_2 flow predictions via reservoir engineering models
  - Benchmarked and calibrated by monitoring data
  - Periodically verified by monitoring data

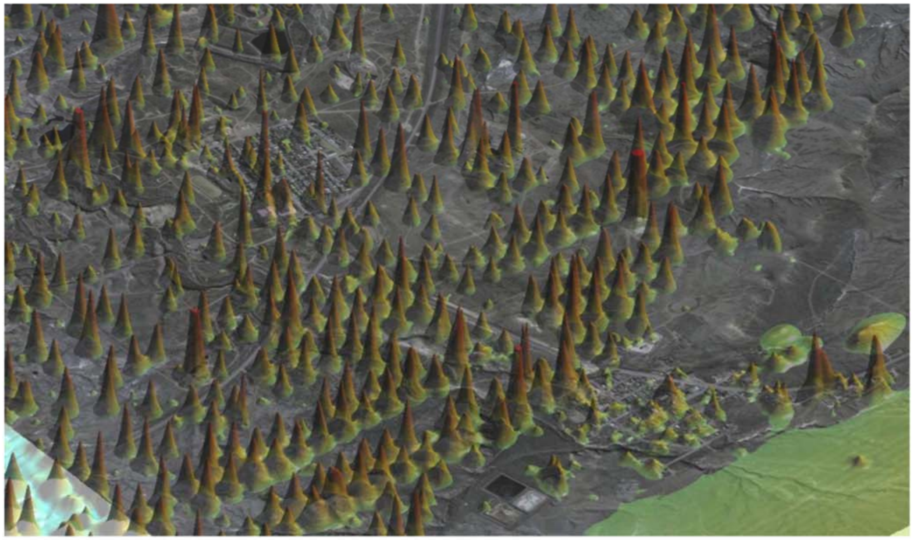
Find Abandoned Wells and Field-wide Monitoring

- Magnetometer surveys locate old/unrecorded wellbores
  - Know when CO_2 flow approaches looks abnormal
  - Compare plume flow to old well locations
- Barrier wells use water injection
  - Control plume movement to AOR
  - Help protect old wells from corrosion
  - Prevent flow under sensitive sites

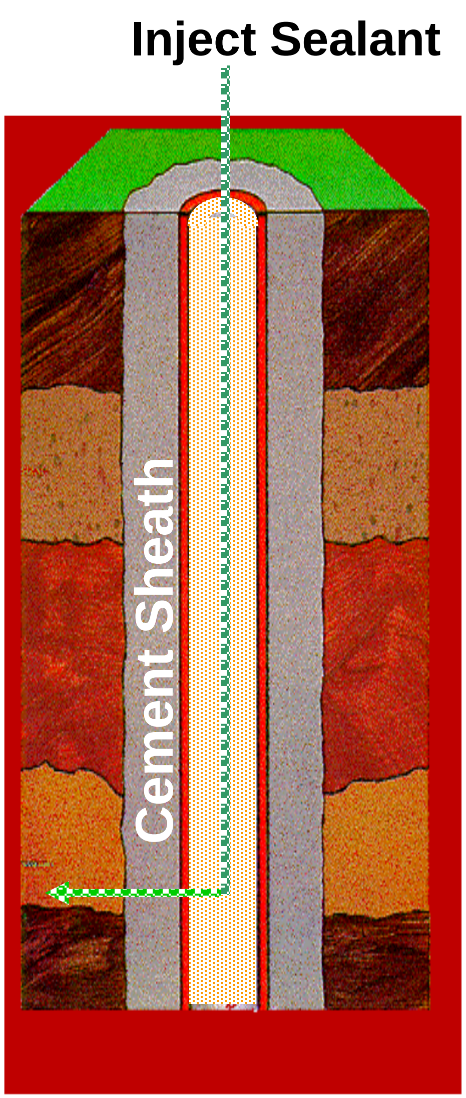




3D Perspective of Magnetic Survey



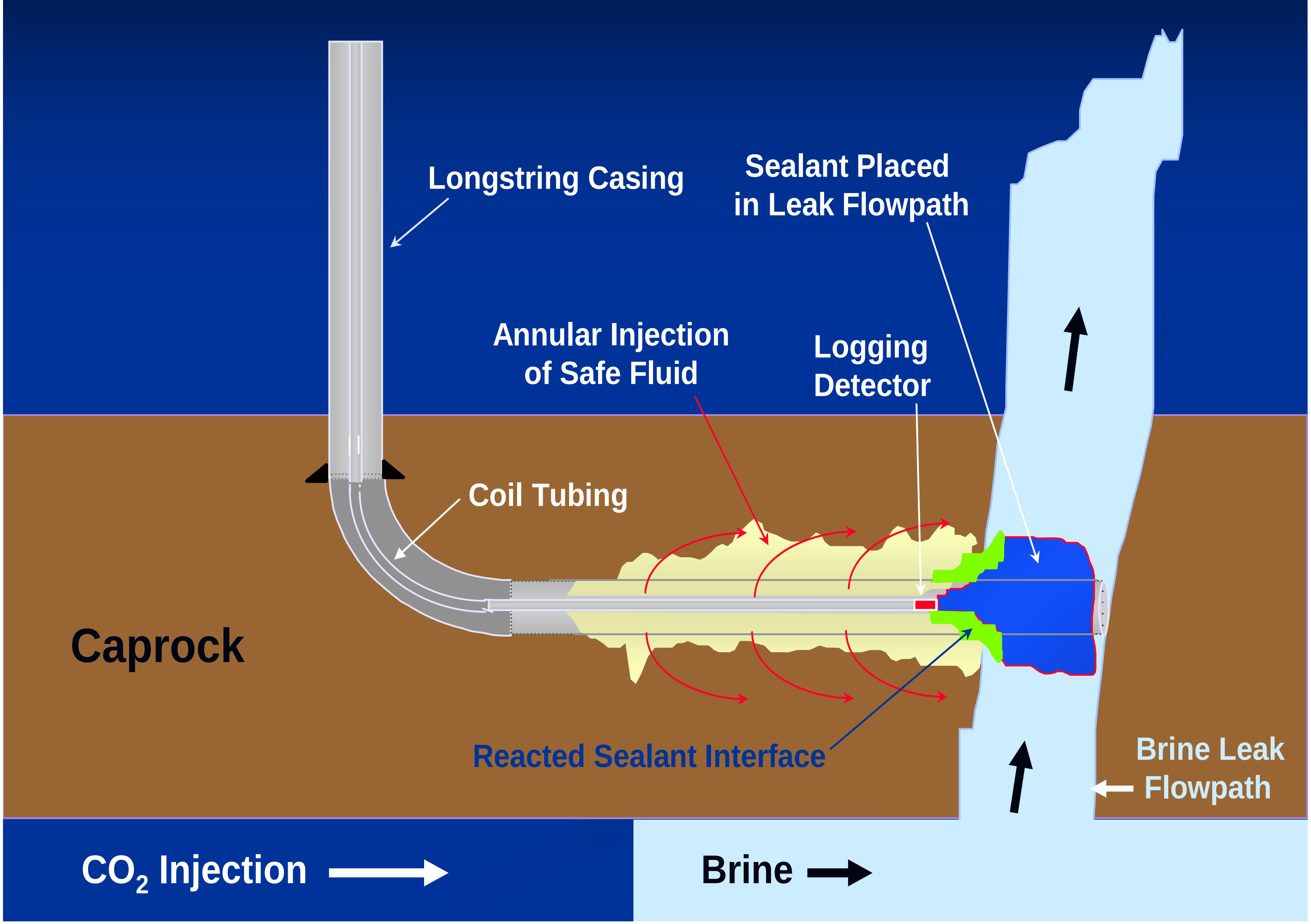
Sealants to Repair Well integrity



- **Primary cements formulated for remedial jobs**
  - **Profile Control Treatments** (SPE Monograph, etc)
  - **Squeeze annular & out-of-zone flows** (SPE103044)
  - **Plug-backs**
- **In-situ cross-linked polymers**
- **In-situ polymerized monomers** (SPE 70068)
- **Latex-resin systems externally activated**
- **Internally or externally catalyzed silicates**
- **Crystallized copolymer** (SPE 101701, etc)
- **Rubber cement squeezes** (SPE 26572)
- **Resin Systems**

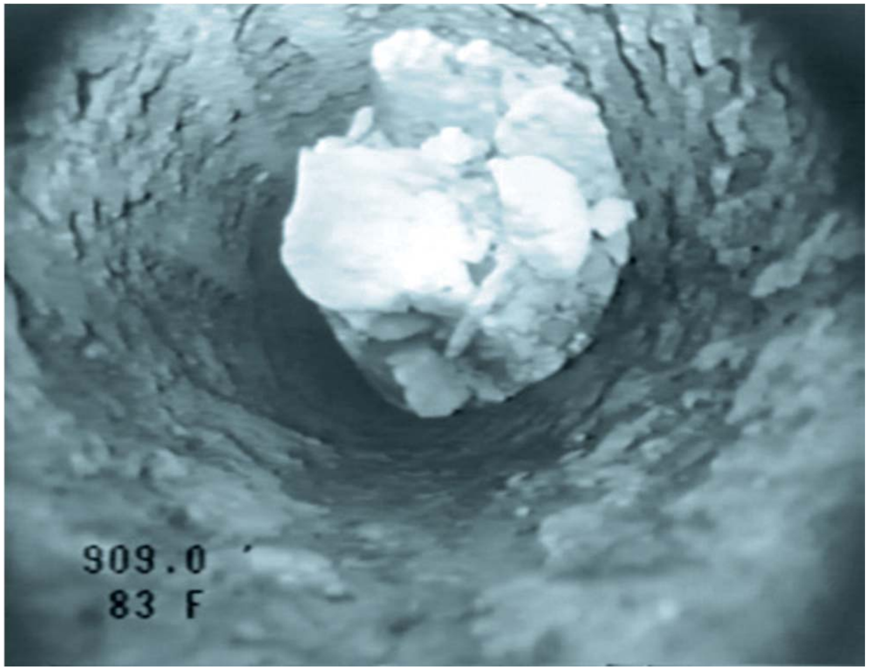
Longevity:....all sealant types must maintain sealing indefinitely

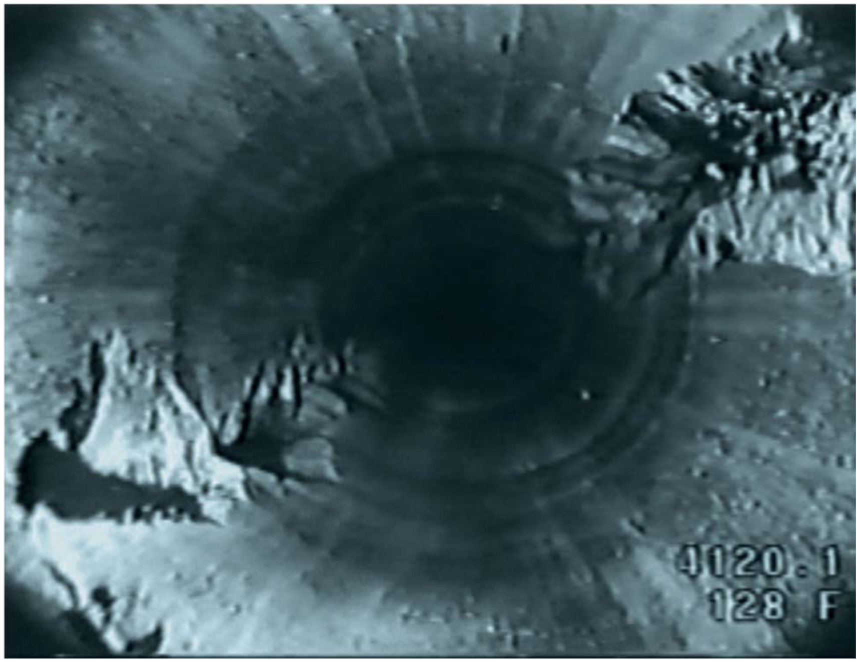
Brine Leak Remediation via Horizontal Well Drilled into Leak Flowpath Created by CO_2 Injection into Saline Aquifer



Repairing Well Integrity

- Challenge: Re-Plugging old wells
    - Old P&A standards may not meet needs for CO_2 EOR or CCS
- Solution:
    - Standard wellbores: re-enter, drill out old plugs, clean wellbore to adequate depth, MIT & diagnostic logs, re-plug with cement, re-test each
    - Non-standard (sub-grade pipe, cement, etc) wellbores: re-enter, drill out old plugs, clean wellbore to required depth, MIT + logs, run wireline pipe inspection, mill out damaged casing in required intervals, plug cement at milled-out intervals & those in regulations, re-test each (bottoms up)

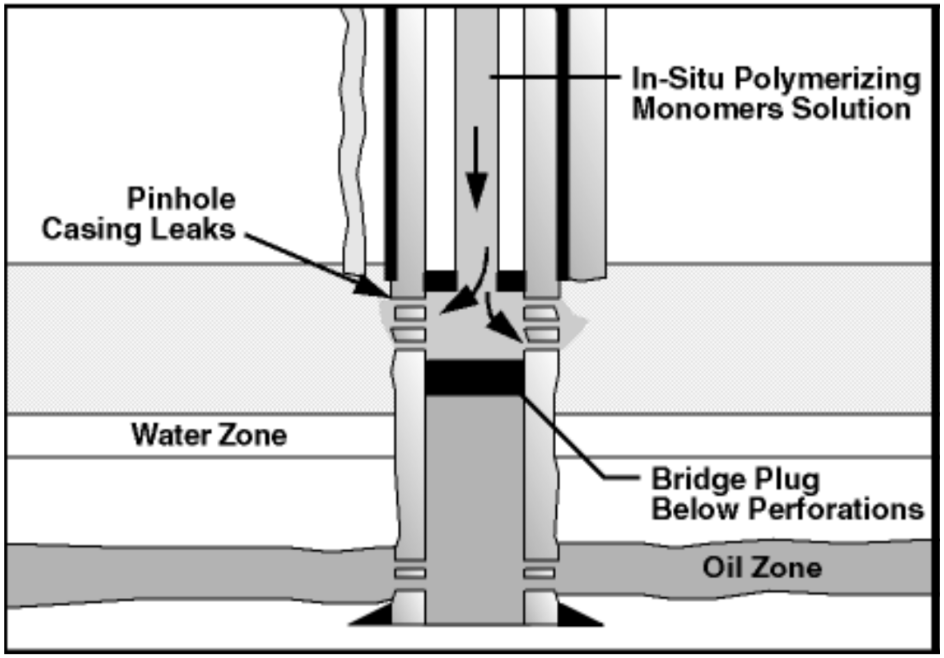




Repairing Well Integrity

- Challenge: Tubing and Casing Leaks
  - May occur in old and new wells
- Solution:
  - Diagnostics to pinpoint detection: pressure communications, MIT, pipe inspection logs, pulsed neutron or other logs, downhole camera, etc
  - Repair: pull/replace-or-repair/re-run/re-test pipe or squeeze
    - Pipe-repair: casing patches, expandable liners, pipe connections, etc
    - CO_2 resistant cement squeezes
    - Chemical sealants: CO_2 resistant gels, resin systems, etc
  - P&A liner section, drill sidetrack, run new completion
  - Repeat diagnostics to confirm sealing integrity: MIT, logs, etc

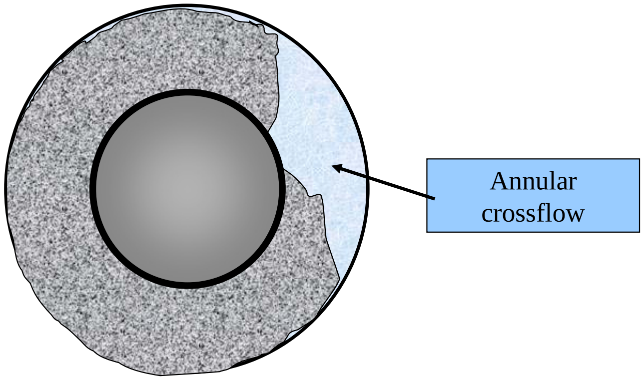
Leaking pipe retrieved

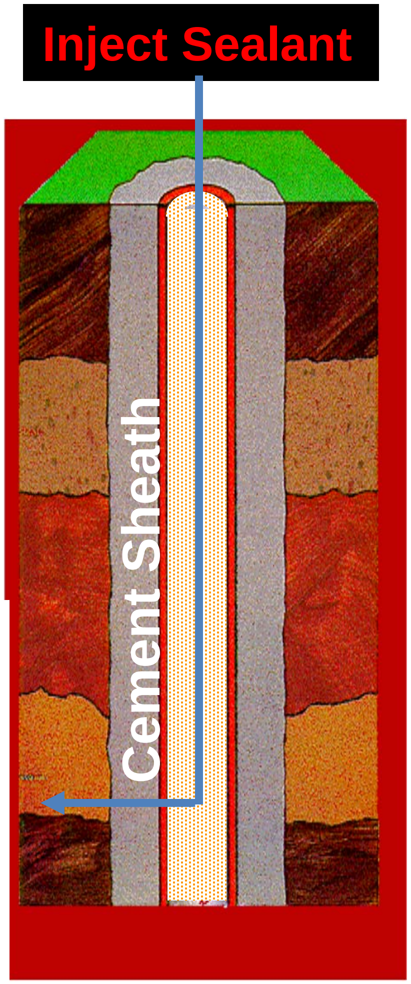


Repairing Well Integrity

- Challenge: Behind casing flow
  - May occur in old and new wells

- Solution:
  - Apply diagnostic tools to pinpoint leak flow path
  - Design/Execute
    - Perforating into leak path
    - Treatments (squeeze sealants)
      - CO_2 resistant cement squeezes
      - CO_2 resistant chemical sealants: gels, resin systems, etc
  - Repeat diagnostics to validate success

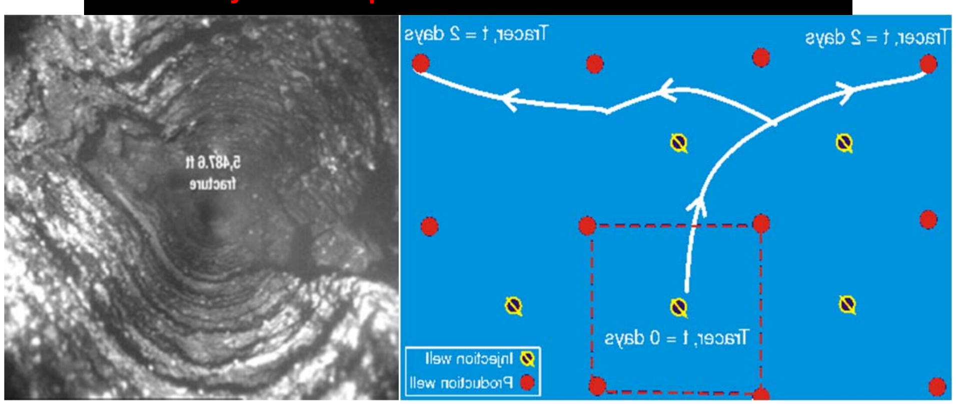


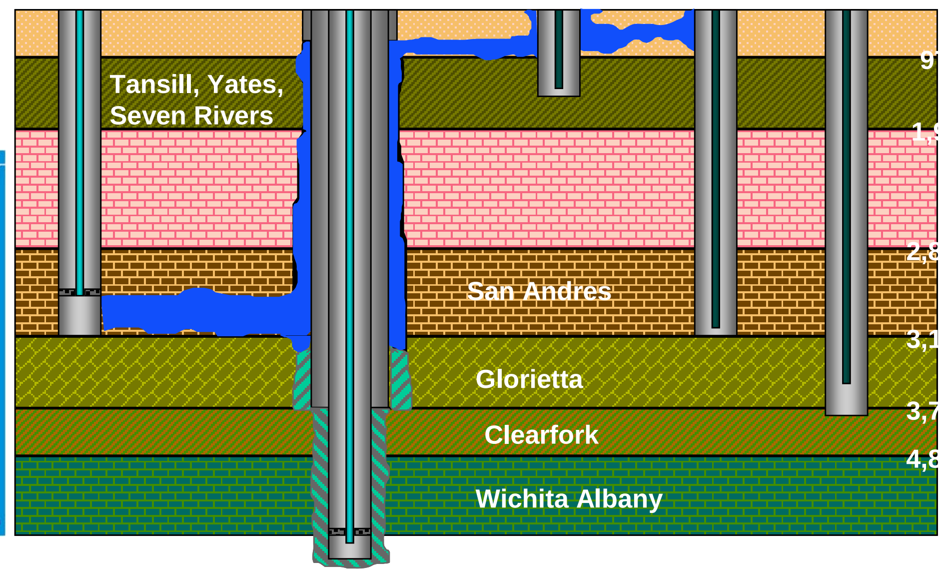


Repairing Well Integrity

- Challenge: Caprock Seal Integrity Failure
  - Leaks via fractures and unsealed faults may occur in some reservoirs
- Solution:
  - Apply diagnostic tools (WL logs, seismic, micro-deformation, etc)
    - Pinpoint leak flow path in fracture or fault between wells
  - Design/Execute
    - If needed, coil-tubing drilling into leak path
    - Treatments (squeeze sealants)
      - CO_2 resistant cement squeezes or gel-cement stages squeezed
      - CO_2 resistant chemical sealants: gels, resins, etc
  - Repeat diagnostics to validate success: sealed leak for CO_2 sweep & containment

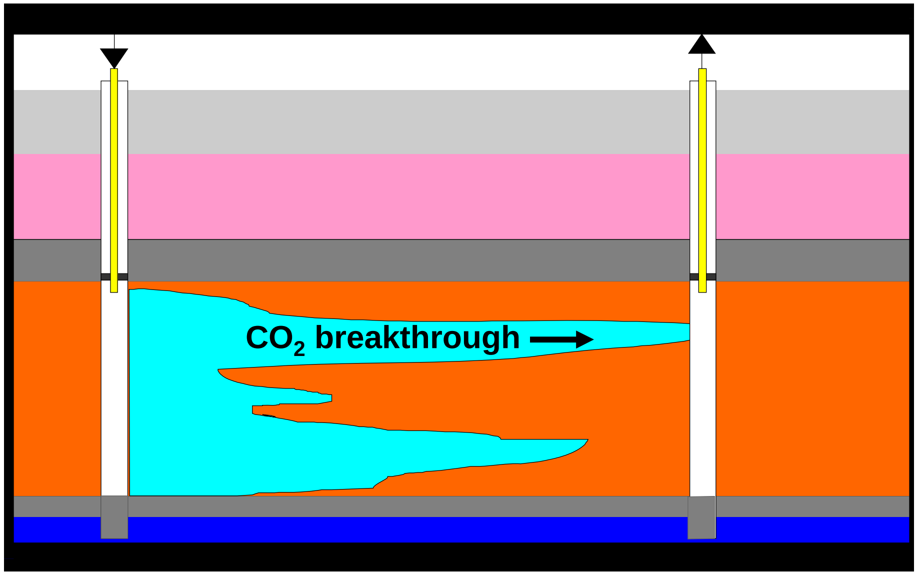
Inter-well communication outside the injection pattern due to fractures

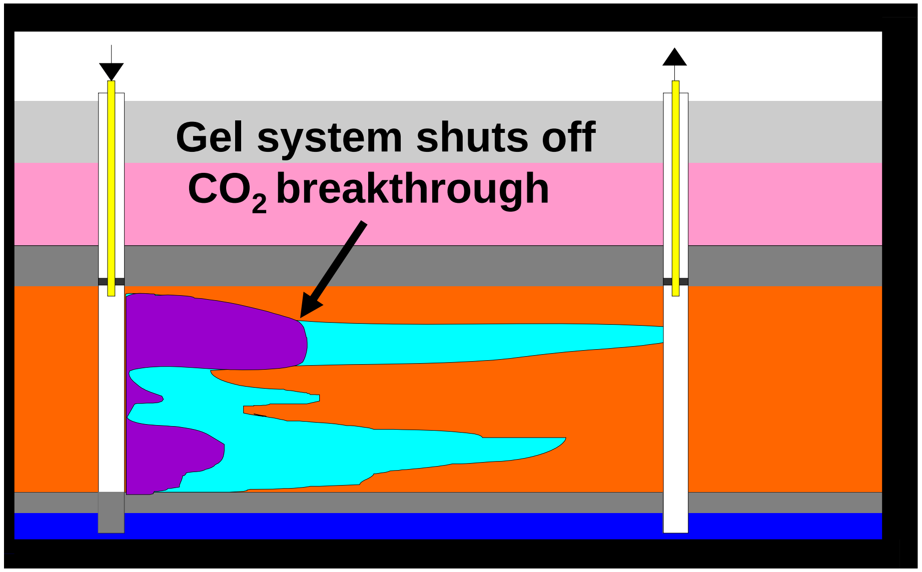




Repairing Well Integrity

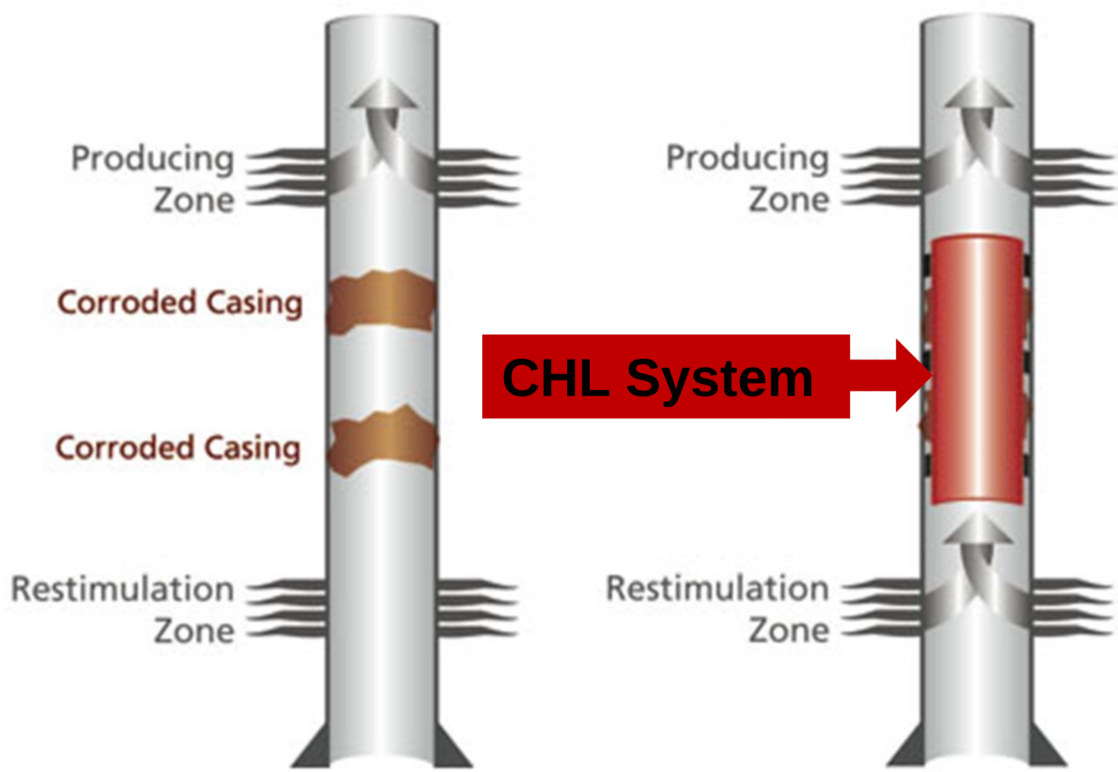
- Challenge:
  - Injection/production perforation-flow profile control (improve sweep & stop losses)
- Solution:
  - Apply diagnostic tools (modeling, seismic, micro-deformation, WL logs, etc)
  - Design/Execute:
    - Treatments (squeeze sealants)
      - CO_2 resistant cement squeezes to seal perf tunnels
      - CO_2 resistant chemical sealants (gels, resins, etc) to seal perm
    - Mechanical devices: flow control valves, etc to control flow into perfs
  - Repeat diagnostic monitoring to confirm success





Repairing Well Integrity

- Cased-Hole Liner (CHL) to patch casing
- Provide cost-effective repairs to any length of casing
- Specialized CR13 expandable liner systems



Thank you

Questions or Comments?