

CO₂ ENHANCED OIL RECOVERY,
SURVEILLANCE DURING CO₂ EOR
and
Some Comments on CCS Policy Progress in
the U.S.

Presentation at the Blue Ribbon Panel Meeting
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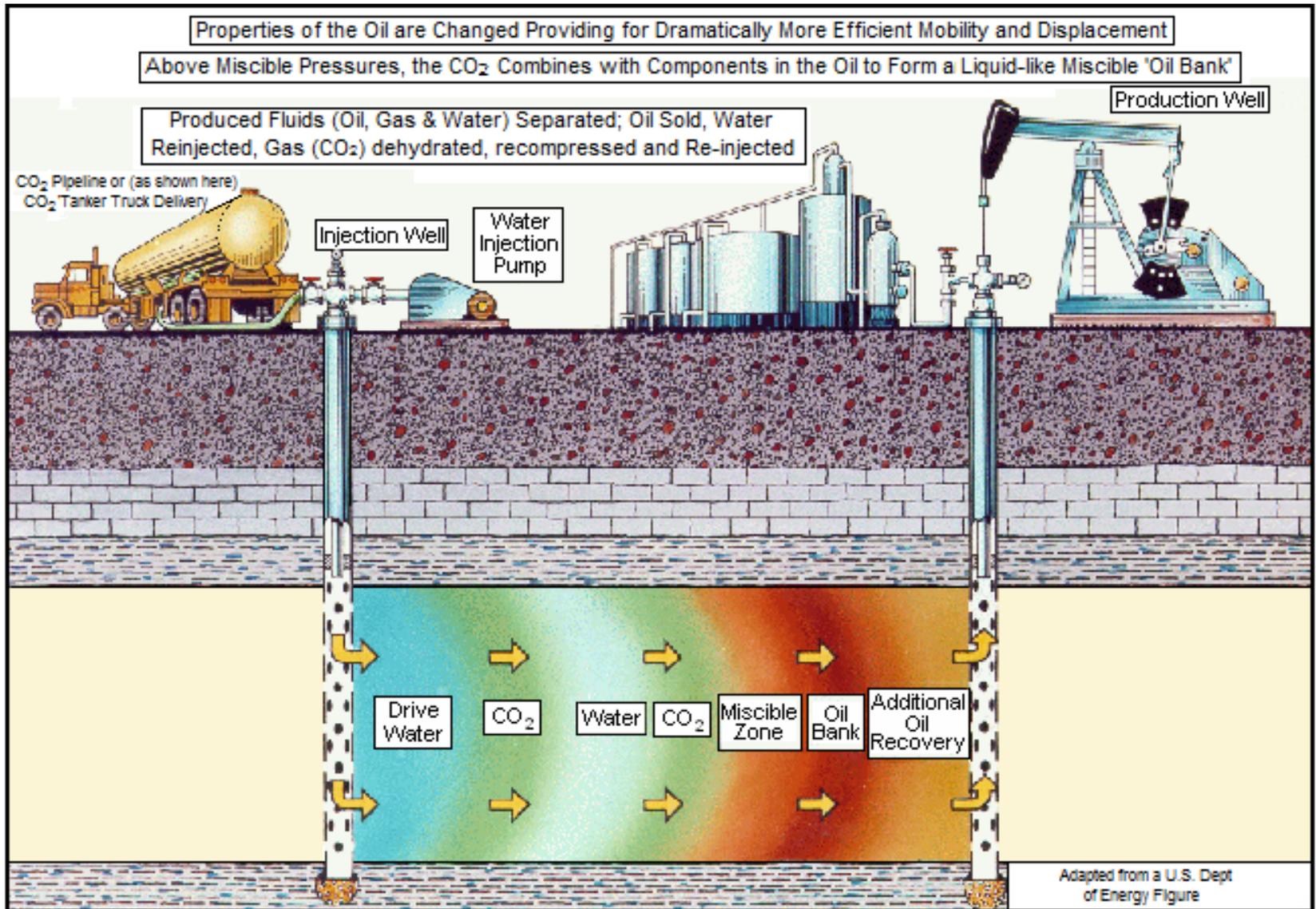


CO₂ ENHANCED OIL RECOVERY, SURVEILLANCE DURING CO₂ EOR and CCS POLICY PROGRESS IN THE U.S.

- I. CO₂ EOR – Basic Principles
- II. Surveillance: Definition and Objectives
- III. Surveillance vs. Monitoring
- IV. Proven Tools
- V. Challenges *(through the eyes of the Injecting companies)*
- VI. CCS Policy and Regulatory Overview
- VII. A View on Where is this Going in the U.S.
- VIII. Questions/Discussion



CO₂ EOR Schematic (WAG*)



* Water Alternating Gas; Note: Many CO₂ EOR Projects are Continuous CO₂ Injection (no WAG)



Many of the Following Insights (Slides) Come from the CEED CO₂ Flooding Shortcourses*

14. CO₂ Injection in Subsurface Reservoirs: Geological Parameters Affecting CO₂ EOR and CO₂ Storage, December 2007 (Repeated at the SPE Intn'l Conference on SPE International Conference on CO₂ Capture, Storage, and Utilization, Nov '09)
13. CO₂ Sourcing for Enhanced Oil Recovery, December 2006
12. CO₂ Flood Surveillance and Monitoring, December 2004
11. Wellbore Management in CO₂ Floods, December 2002
10. Reservoir Modeling and Simulation for CO₂ Flooding, December 2001
9. Issues for Beginning CO₂ Flooders, December 2000.
8. CO₂ Flooding: Sandstones vs. Carbonate Reservoirs, December 1999.
7. CO₂ Facilities and Plants, December 1998.
6. CO₂ Measurements and Metering, December 1997.
5. How to Put Together a CO₂ Flood, December 1996.
4. How CO₂ Flood Surveillance Helps Assure a Successful EOR Program, May 1996.
3. Equipping and Day-to-Day Operations of a CO₂ Flood, December 1995.
2. Is My Field a Candidate for CO₂ Flooding?, September 1995 (Twice).
1. Making Money on CO₂ Flooding...Some Innovative Development Concepts for Independents..., May and July (repeat) 1995.

* Presented as a Part of the Annual CO₂ Flooding Conference held each December in Midland, Tx



Surveillance: Definition and Objectives

- THE EOR Industry in the U.S. currently injects ~3 bcfpd (60 million tons/yr) of “new” purchased CO₂.
- Their cost of carbon (CO₂) is at an average value of roughly \$1.00 / mcf or almost \$20/ton.
- The aggregate value of that commodity CO₂ to the companies is \$3 million per day or over a \$billion/yr.
- CO₂ is produced with the fluids (requires recycling)
- **Keeping track of the CO₂** and knowing that it is making money for them is ACUTELY critical.
- The Industry calls that Surveillance



CO₂ FLOOD SURVEILLANCE vs. CCS MONITORING, VERIFICATION & ACCOUNTING (MVA aka MMA, MMV)

SUBSURFACE NEEDS

FLOODING

- 1) INJECTION IN ZONE
- 2) FLOW PATHS
- 3) PRESSURE CONTAINMENT
- 4) WELLBORE INTEGRITY
- 5) SWEEP EFFICIENCY
- 6) N/A ?

MVA

- INJECTION IN ZONE
- FLOW PATHS
- PRESSURE CONTAINMENT
- WELLBORE INTEGRITY
- N/A ?
- LONG TERM STORAGE



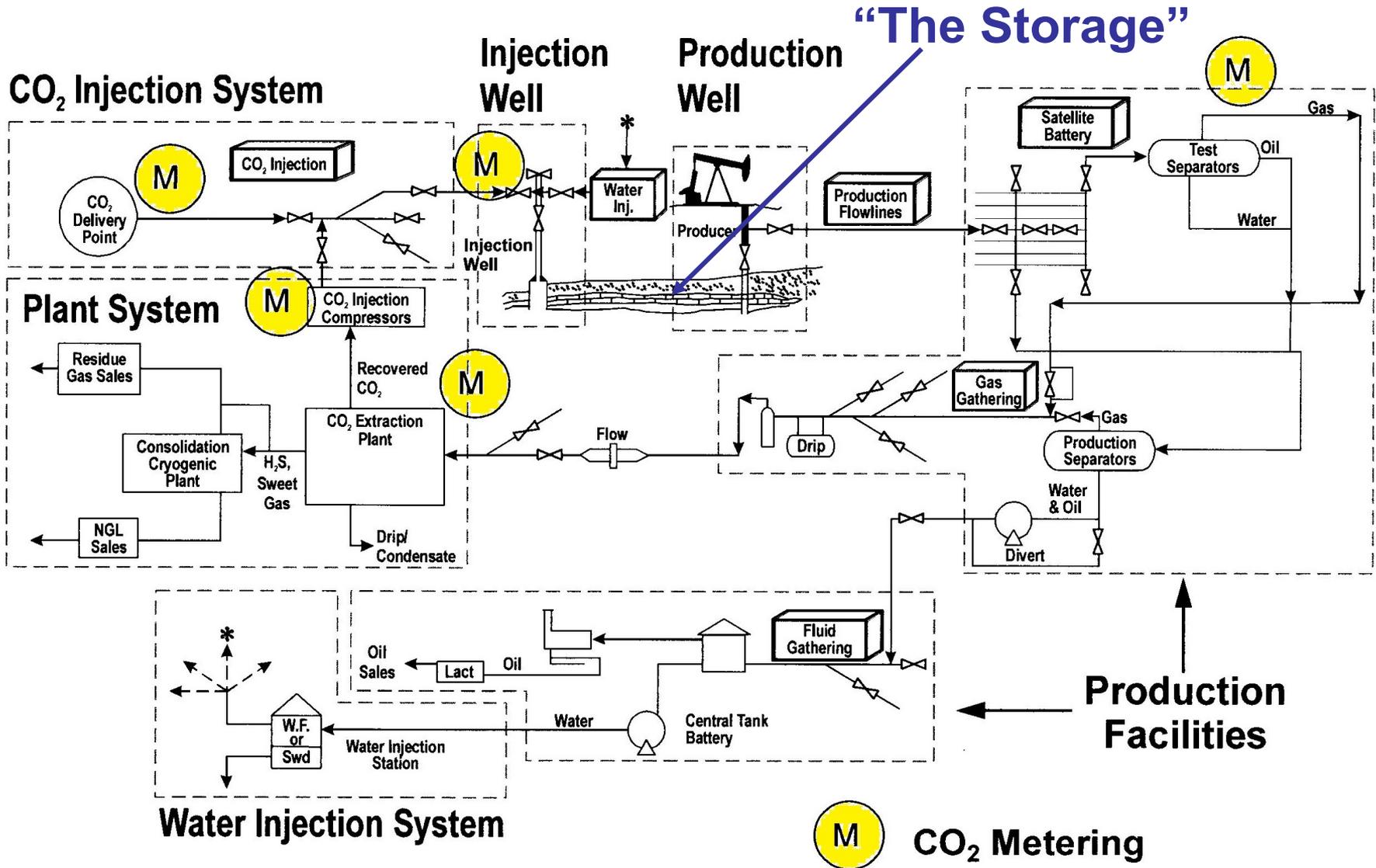
How Does the Industry Do it?

*A Mix of **Purist** and **Practical** Approaches*

- First, we put CO₂ in reservoirs that have had proven trapping capability (where it will stay)
- Carefully meter it at Custody Transfer points
(mass, density, occasionally composition – orifice meters, over the years, have become the standard, Turbine Meters also used)
- Efficiently (re)Capture it at producing wells
- Meter it less expensively at collection/
redistribution points (Because There Are Many of these)
- Check for Losses at key points (stay efficient)



CO₂ Flood Production Systems



Source: Practical Aspects of CO₂ Flooding, Figure 5.1

The Experience: Historical Source of CO₂ “Losses”

- Subsurface
 - Lateral Off-lease
 - Surface
 - Plant Upsets (Power outages)
 - Flow Through to Oil
 - Amine Regeneration
 - Pipeline Blowdown
 - Well Workovers
 - Consumption of the Oil Produced
 - Power for Lift, Compressors and Processing
- Very minor (but ‘Cumulative’)



Benefits of Concurrent EOR & Storage (CCS EOR)

- Public Perceptions about Commercial vs. Waste Injection
- Regulatory Infrastructure
- Domestic Oil (Less Imports)
- Less Cost to Tax- or Rate-payor
- Retention has been Demonstrated for 30+ years
- Storage Capacity (Voidage)

Complications of Concurrent EOR & Storage

- Production (Recycle) and CO₂ Dilution (gas composition)
- More Complicated Monitoring (Surface & Subsurface)
- Transportation (Pipeline Access) to get to EOR



Proven Tools

Subsurface

- Logging
 - Open Hole (Density/Neutron, Sonic, Resistivity/Induction, C/O)
 - Cased Hole (Casing Integrity, Temperature)
- Seismic Reflection Techniques
- Surface*
 - Metering (Predominately Orifice-type but Wedge- and Turbine-types are popular to save money within unit)
 - Density
 - Composition
 - IR

* Emissions are Carefully Monitored for Applicable Criteria Pollutants



Metering

(Section to be presented if time permits)

- if behind schedule, skip to slide 26 -



DEFINITIONS

- Accuracy: The Degree of Conformity of an Indicated Value to a Recognized Accepted Standard of Value
- Repeatability: The Degree of Agreement of Repeated Measurements of the Output for the Same Value of Input Made Under the Same Operating Conditions over a Period of Time



CATEGORIES OF METERS

- CUSTODY TRANSFER
 - NEED FOR ACCURACY (SINCE PURCHASE/SALE INVOLVED)
 - USUALLY IN BULK
- ALLOCATION
 - USED WHERE COSTS ARE AN ISSUE
 - MANY METERS REQUIRED

CUSTODY TYPE EXAMPLE: DENVER CITY METER STATION



Re: The 16" Centerline Pipeline; Presentation at the 2003
CO₂ Flooding Conference, J Gross, Kinder Morgan



Types of Meters

- Differential Pressure (Predominately Used)
- Displacement
- Velocity
- Mass

DIFFERENTIAL PRESSURE METERS

Differential pressure meters have some type of restriction which creates a difference in pressures which is proportional to the stream's flowrate.

TYPES:

- Venturi
- Flow Nozzle
- Orifice
- Wedge
- Elbow

**Both Cust Transfer and
Allocation Applications**

**Only Allocation
Applications**



DISPLACEMENT METERS

Displacement meters include those devices which have sliding vanes or rotating elements that segment the flowing stream into discrete volumes and have some methodology of counting the number of volumes.



VELOCITY METERS

Velocity meters employ paddles, rotating paddle wheels or rotating turbine blades to measure the velocity of a stream which can be translated into its flow rate.

MASS METERS

Direct mass flow meters involve a tube (or tubes) in the shape of a bend or loop that is vibrated at high frequency and the Coriolis effect is used to determine the stream's mass flow rate.

CUSTODY TRANSFER MEASUREMENT

- \$\$\$\$ Changing Hands
- Accuracy Critical
- Measured In Dense (Critical) Phase

SECONDARY DEVICES

- Chart Recorder
- Flow Computer
- Transducers (Transmitters)
 - Differential Pressure
 - Static Pressure
 - Temperature
- Densitometer

CATEGORIES OF METERS

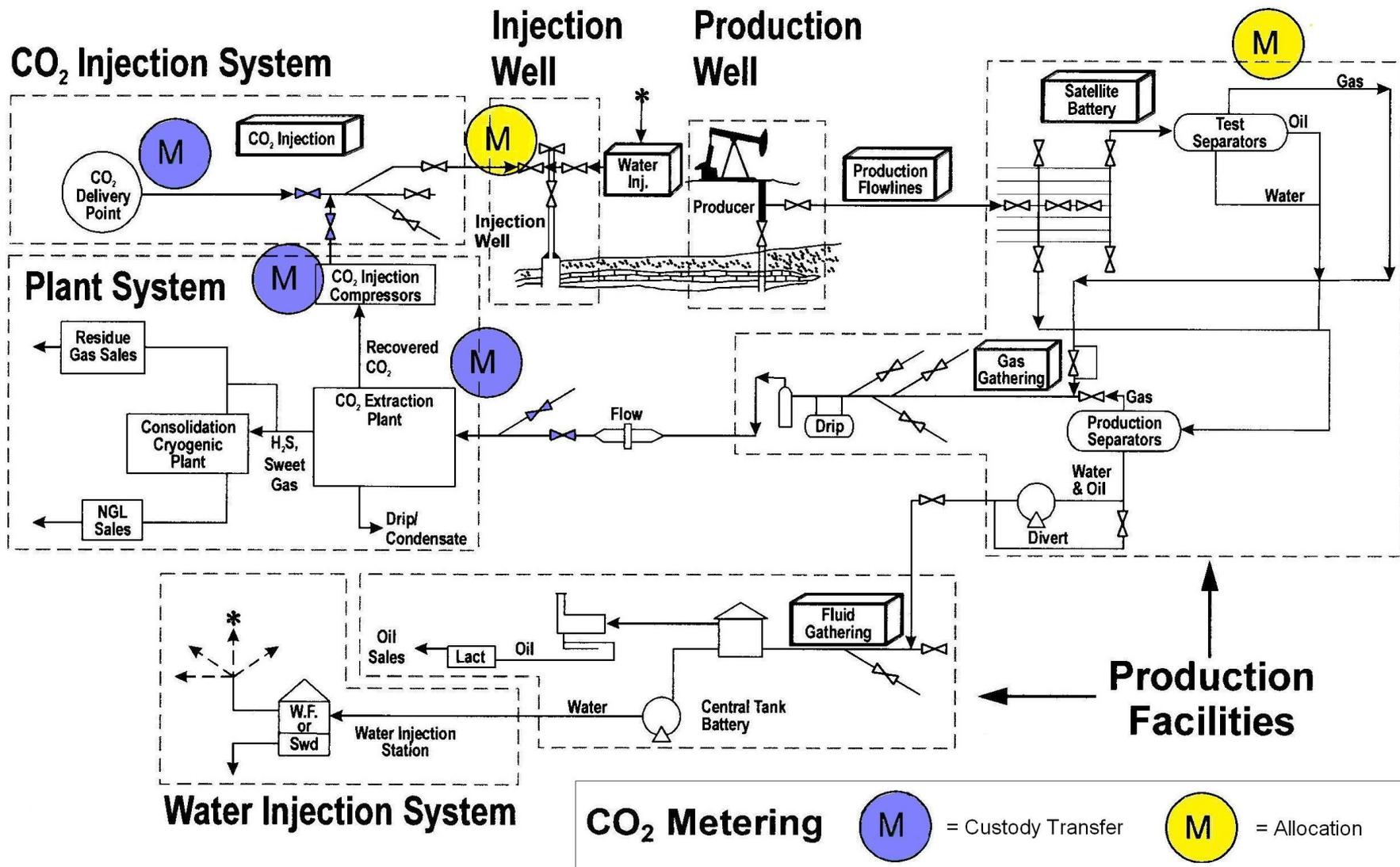
- CUSTODY TRANSFER
 - PURCHASE/SALE INVOLVED
 - USUALLY IN BULK
- ALLOCATION
 - MANY METERS REQUIRED
 - WHERE COST IS AN ISSUE

ALLOCATION METERS

- Non-custody Transfer
- On Lease
- Data for Reservoir Management
- Data for Lease Management and Control



CO₂ Flood Production Systems



Source: Practical Aspects of CO₂ Flooding, Figure 5.1

Recycling the CO₂



A Robust Example: West Texas CO₂ Processing Plant



Challenges

“Chipping Away at Some Myths”

- CO₂ Storage in CO₂ EOR is 50% or less (*This is non-factual but a CO₂ Retention Briefing for Another Day*)
- DSF CO₂ Storage Capacities are Very Limited
- CO₂ EOR Capacities are Negligible in the Large Scheme of Things (*A Briefing for Another Day*)
- Maximum Storage Pressures Must Stay Below Original Bottom Hole Pressures (*Safe Pressures are VERY site dependent – Many Examples of Effective Containment @ 2x Original Bottomhole Pressures*)
- It is Easy to Get the CO₂ out of the Reservoir



Interim Summary

So Why Do Sequestration Using EOR?

- Retention is Proven (*and VERY high in term of “new” CO₂*)
- Is, in fact, ‘*Commercially Subsidized*’ Storage
- Adds Jobs, Domestic Oil Production
- Avoids ‘Waste’ Perceptions with Public
- Provides a Bridge to Deep Saline Formations
- 90+% of Regulatory Infrastructure in Place



U.S. and State Policy Initiatives



National Initiatives (U.S.)

- UIC Class VI Rules
- CO₂ Declared a Pollutant
- Emission Sources Defined (>25,000 mtons/yr)
- Does not Discriminate Natural vs. Industrial Sources (Monitoring Implications for Both)
- (Comments on) Draft Rules on Sequestration (EPA Draft Reporting Rule, SubPart RR)



But First, Let's Specifically Talk About Texas for a Moment

Why?

Let's Qualify Texas



Texas* CO₂ Background

- Has 38 years of Experience with CO₂ Handling
- Injecting about 1.8 bcfpd (36 million {mm} tons/yr) of **new** CO₂, *Estimated ~2/3rds of world total*
- Recycling ~1,100 mmcfpd (22 mm tons/yr)
- Making 172,000 bopd (*20% of Tx oil total*)
- Injecting in over 5,000 wells (*78% U.S. total*)
- Producing from 7,000 wells in over 300,000 project acres (~500 sq miles)

* Tx hereby “Annexes” SE NM for these stats



Texas Regulatory Infrastructure

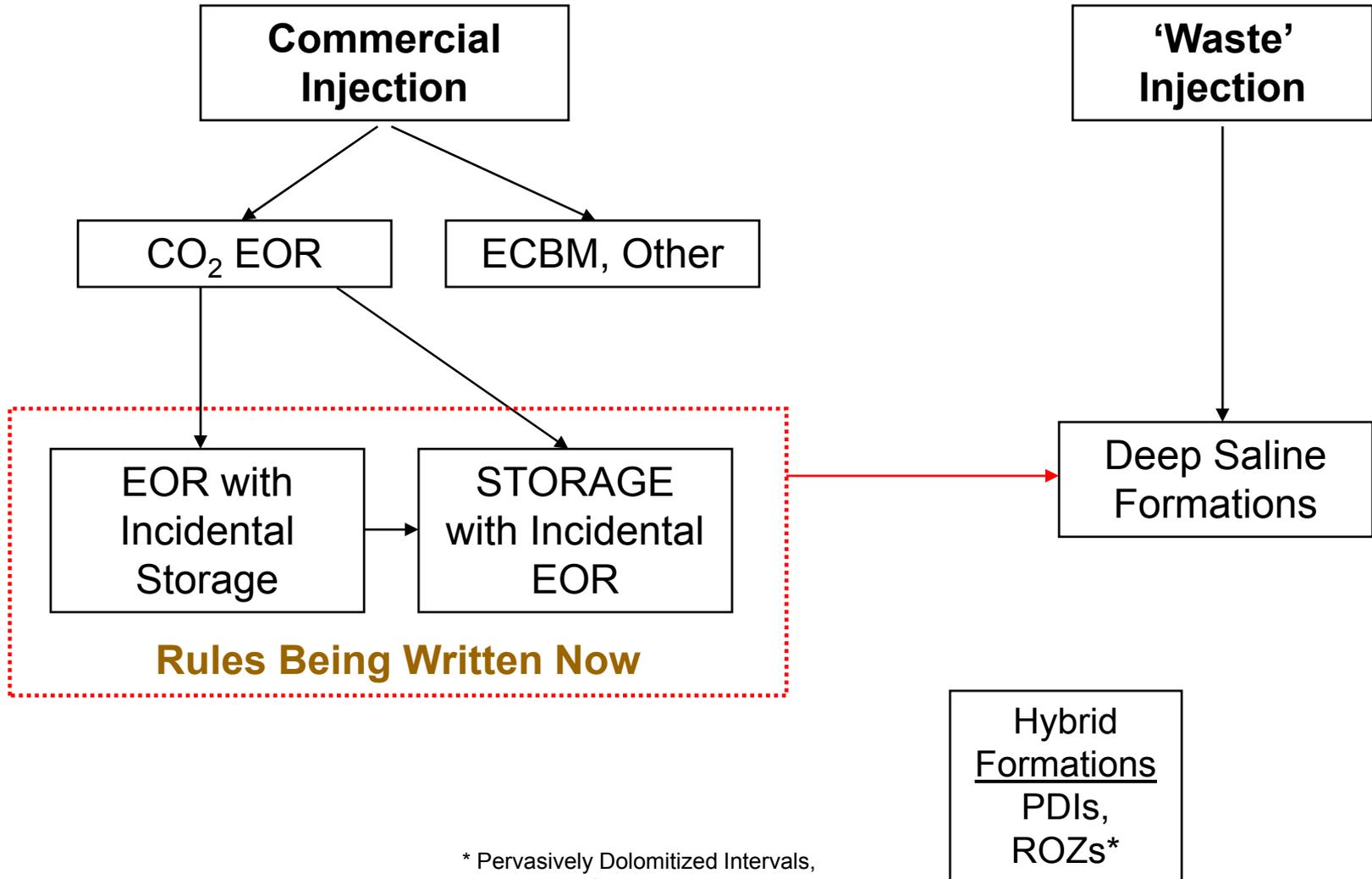
- Texas Railroad Commission (TRRC) has 80 years of regulatory oversight for almost all underground activity (injection & production)
- Texas Commission on Environmental Quality (TCEQ) has regulatory oversight for surface and USDWs

This question was posed in the last session (2009)

Is CCS a commercial injection activity or is it waste injection?



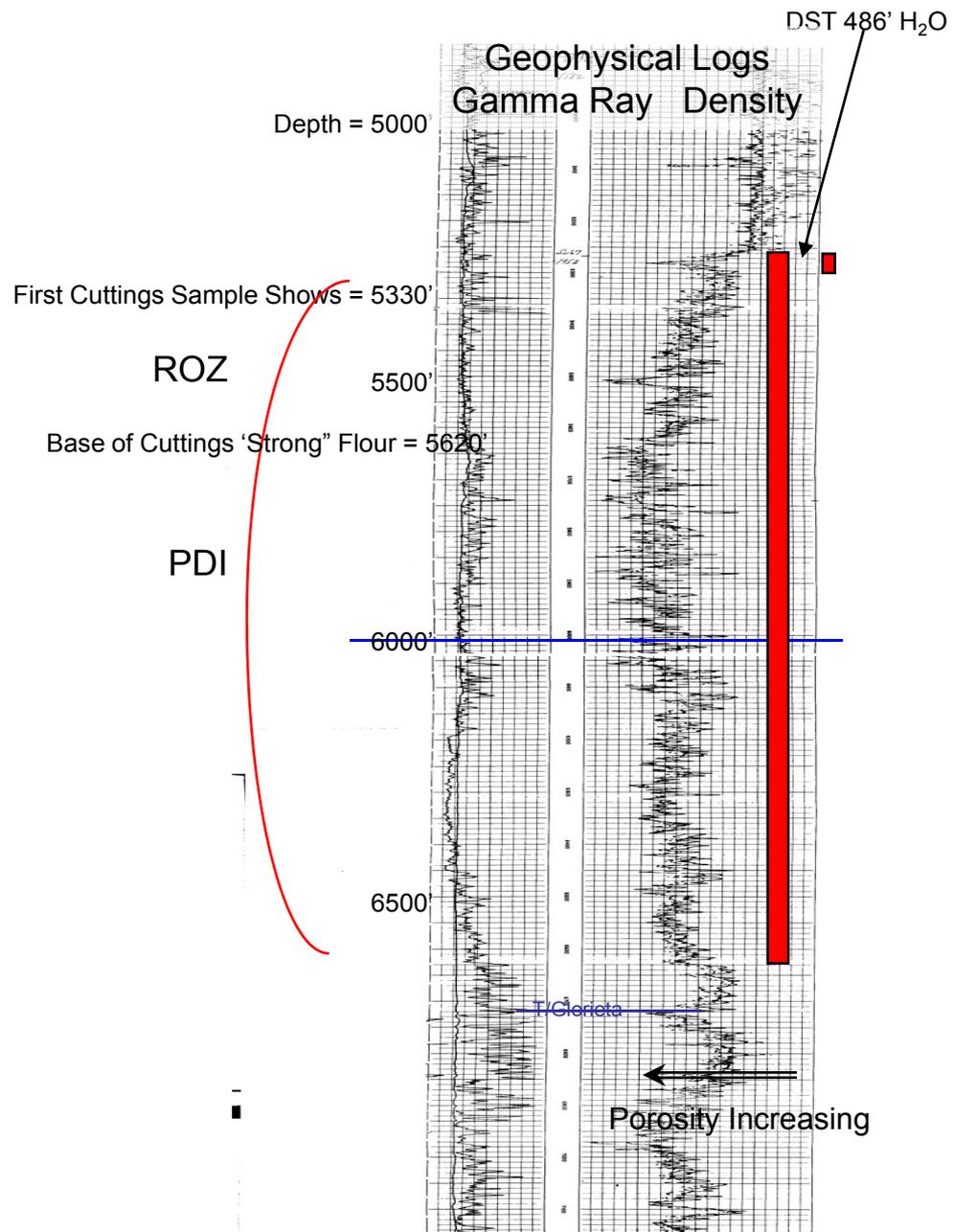
Types of CO₂ Injection



* Pervasively Dolomitized Intervals,
Residual Oil Zones

Northern Central Basin Platform Area

PDI/ROZ Type Log



Texas' Pathway Forward

- Write Rules for Storage with Incidental Oil Production (*TRRC to take lead, draft published in April*)
- Write Rules for Oil Production with Incidental Storage (*TRRC to take lead – draft by early winter*)
- Commissioned Inter-agency Study (w/ BEG) on How to Proceed with Waste Injection (Deep Saline Formations) – *They are meeting now*

Goal: Remove Obstacles for First Mover Projects

(Get policy in place to enable business development)



Other States

- North Dakota
- Wyoming
- Louisiana
- Others

Where and What Next?

The Future of Coal*: Is the U.S. 'Stuck' & Going Nowhere?

1. Technology bog? *Not really*
2. Storage Capacity Bog? *(Not in my head)*
3. Policy bog? *(Perhaps, but becoming less likely)*
4. Public Perception Bog *(An Ohio "Wake-up" Call?)*
5. Rights Aggregation bog? *Big Projects have huge footprints - How to Amass Rights?*
6. Transportation bog? *To get to Tier 1 Secure Sites*

* Coal used here as a proxy for a CO₂ emission stream industry



Final Summary

- In Several States, CO₂ EOR can be used as an enabling technology to move CCS forward
- Policies Acknowledging Storage while Injecting is Needed
- A Monitoring 'Overlay' for CO₂ EOR is Required to Demonstrate Stored Volumes;
 - Is Very Site Dependent
 - Won't be 100% of 'New' CO₂ Injected but will be a Very High Number



Supplemental (Federal) Policy Slides



Review Of EPA Draft Reporting Rule: Subpart RR*

April 2010

* As it is Believed to Affect On-going CO₂ EOR and
Commerciality of Concurrent EOR and CCS



Background

Natural Sourced CO₂

- Relationships and Contracts between Sellers and Users (Buyers) have not Considered Retention (or it's Companion, “ losses* ”) as factor in those Contracts
- Documentation and Proof of Numbers in those Documents will Require Monitoring Expenses
- Many, if not all, Contracts will Have to be Modified
- Effects on BAU CO₂ EOR will be a Function of How Onerous New Monitoring Requirements will Become

** Defined herein as the volume of CO₂ purchased but not sequestered*



Anthropogenic CO₂

- Same Comment as Naturally-sourced CO₂ for existing Contracts (Req'd Mods)
- Degree of Modification May be a Function of Whether Source Gets Anthropogenic Status (e.g., Nat'l Gas By-product, ethanol, fertilizer)
- These Subpart RR Rules are Set to Play a Huge Factor in those Pending and Future Contracts and perhaps, as a result, the commercial viability of those flood projects

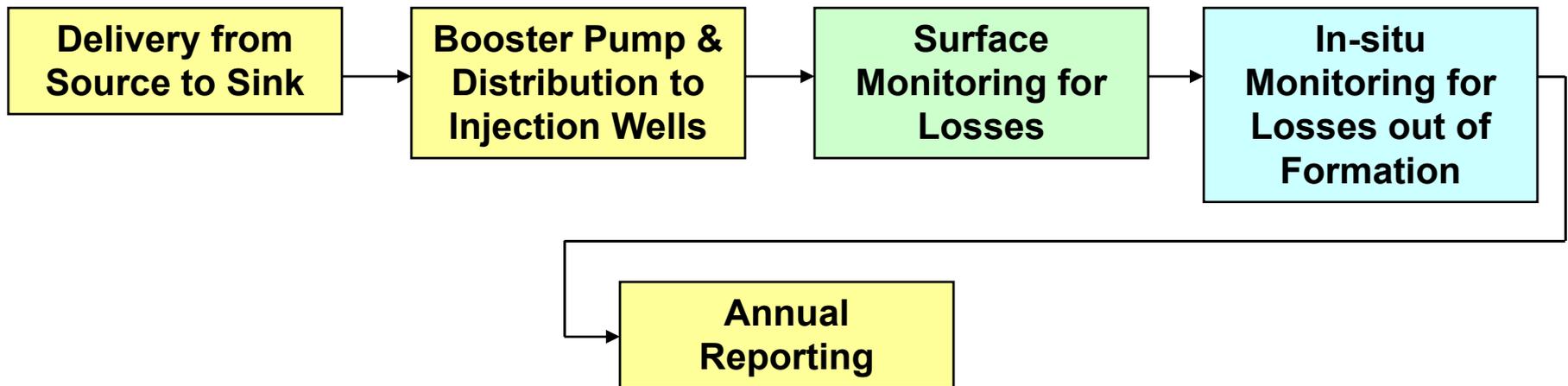


A Framework: The Critical Steps in Monitoring and Reporting

Steps in Monitoring/Reporting (1)

(as Seen at the Sink Site)

No Production (or Recycle)*

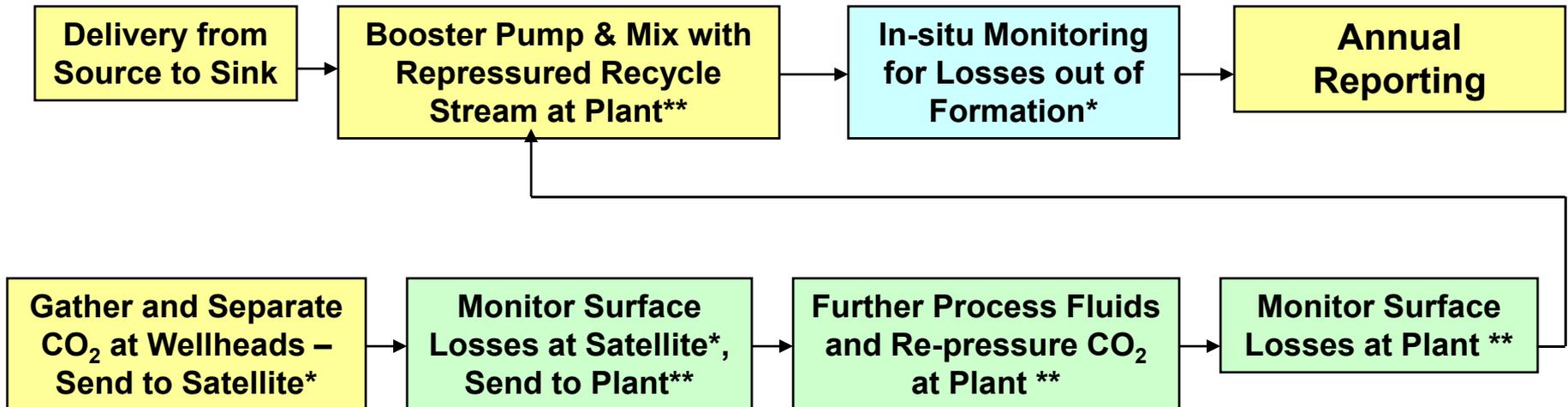


* *It should be noted that even a Deep Saline Injection Project may require production for purposes of Plume Management. If it does, the next chart applies*

Steps in Monitoring/Reporting (2)

(as Seen at the Sink Site)

With Production (and Recycle)



* *A collector location for multiple wells where fluids are Separated and Measured (Tested)*

** *The facility wherein all production fluids are gathered and fully processed*



With That as the Framework

How will the (draft) EPA reporting rules work?

- 1) Equation RR-1, Custody Transfer to Sink (Total Mass* Concentration)
- 2) Equation RR-2, Custody Transfer to Sink (conv to “standard conditions”)
- 3) Equation RR-3, Facility Aggregated Transfers
- 4) Equation RR-4, Mass Injected*concentration at each injection point
- 5) Equation RR-5, CO₂ Mass Injected above (conv to “stand. conditions”)
- 6) Equation RR-6, Aggregated Injection Mass

- 7) Equation RR-7, Produced Mass at gas-liquid separators (Satellites)
- 8) Equation RR-8, Above Masses Converted to Standard Conditions
- 9) Equation RR-9, Summed satellites measurements with consideration of pass through mass
- 10) Equation RR-10, MVA (emitted) Leakage Mass
- 11) Equation RR-11, Total Sequestered Mass Calculation (by Differences)
- 12) Equation RR-12, Same as above but for facilities not producing oil or gas

Considerations for producing back fluids; exempts deep saline fms for some reason?

Subpart RR Equations

$$CO_{2,v} = \sum_{p=1}^4 Q_{p,v} * C_{CO_{2,pv}} \quad (\text{Eq. RR-1})$$

$$CO_{2,v} = \sum_{p=1}^4 Q_{p,v} * D_{p,v} * C_{CO_{2,pv}} \quad (\text{Eq. RR-2})$$

$$CO_{2T} = \sum_{v=1}^Y CO_{2,v} \quad (\text{Eq. RR-3})$$

$$CO_{2,u} = \sum_{p=1}^4 Q_{p,u} * C_{CO_{2,pu}} \quad (\text{Eq. RR-4})$$

$$CO_{2,v} = \sum_{p=1}^4 Q_{p,v} * C_{CO_{2,pv}} \quad (\text{Eq. RR-1})$$

$$CO_{2I} = \sum_{u=1}^U CO_{2,u} \quad (\text{Eq. RR-6})$$

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * C_{CO_{2,pw}} \quad (\text{Eq. RR-7})$$

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * D_{p,w} * C_{CO_{2,pw}} \quad (\text{Eq. RR-8})$$

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * C_{CO_{2,pw}} \quad (\text{Eq. RR-7})$$

$$CO_{2E} = \sum_{x=1}^X CO_{2,x} \quad (\text{Eq. RR-10})$$

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad (\text{Eq. RR-11})$$

$$CO_2 = CO_{2I} - CO_{2E} - CO_{2FI} \quad (\text{Eq. RR-12})$$



Issues (1)

- **Industry Needs “One-stop Shopping”**
 - Meaning One Regulatory Body has Primacy*
 - Solves Most Problems of Competing Regulations (Is Becoming Acute as Regs (and Regulatory Agencies) Proliferate)
- **Who has Regulatory Primacy?**
 - Seems to us that too much emphasis on monitoring has the effect of minimizing the issue of security of storage; we don't think that serves sequestration very well
 - What about assuring good sites are chosen? Who does that? The Primary Subsurface Regulator Needs to have that responsibility above all else! “Regionality” is a huge risk
 - This is all about security of storage, primary subsurface enforcer needs to be that kind of regulator

* In U.S. in Most States, is probably too idealistic, one for subsurface and one for emissions (surface)



Issues (2)

- Item (eq) 12 exempts equations 7-11 from sequestration projects. For deep saline formation sequestration projects that produce fluids, those equations should pertain since they can have surface losses as well – current rule appears to exempt them since it is not oil/gas that they produce????
- CO₂ is a tough beast to measure precisely; one has to realize that a very high level of accuracy is impossible and significant uncertainties can exist
 - Accuracy of Measurement is currently required only at custody transfer points
 - Sequestration Reporting may attempt to change that wherein accuracy may be required at every measurement point
 - This will be very expensive to accommodate in a flood due to the multitude of measurement points



Further Backup Slides

CO₂ RETENTION

What is it?

- CO₂ Retention is the amount of CO₂ that has been injected in a reservoir that has remained in the reservoir

$$\frac{(CO_2 \text{ Injected} - CO_2 \text{ Produced})}{(CO_2 \text{ Injected}^*)}$$

- When monitoring a CO₂ flood it is typically plotted as Current (or Instantaneous) Retention and Cumulative Retention
- Retained CO₂ – Mobile vs. Immobile CO₂

* Note: Is Currently Defined as the “Total” (not just the purchased) Volumes Injected and Numbers therefore Look Artificially Low



CO₂ RETENTION

Why does it happen?

- CO₂ is Displacing Fluids and Lags Behind
- CO₂ Saturates Immobile/Mobile water
- CO₂ Can be Trapped in Smaller Pores/Channels After It Diffuses into Them
- CO₂ Can be Trapped by Water Blocking
- CO₂ Can 'Wet' the Rock



CO₂ RETENTION

Why do we care?

- EOR Projects – Retention Controls the Amount of Produced CO₂ & thus the Purchased CO₂ Volumes (typically not especially negative unless retention is very low - high retention requires more CO₂ purchases but usually means efficient sweep and a good flood)
- Carbon Capture & Storage – More of interest now - The Incidental Storage that occurs During Operations – What is Left (Retained) in the Formation

