# HERMAN ACUÑA, P.E.

## President, Member of Ryder Scott Board of Directors

Herman is experienced in management planning and decision-making processes amidst a climate of competition and risk. In addition to providing advice in the areas of economic analysis, strategic planning, negotiation strategies, contract evaluation and conflict resolution and coordinating large high-stake projects in the Caspian and Middle East regions, he is an expert in the evaluation of reserves and future income under a variety of fiscal terms and model contracts. Herman has also been involved with implementing Corporate Reserves Management Systems for several companies in his career.

Prior to joining Ryder Scott, he spent 10 years with Exxon Mobil. Herman has Bachelor's and Master's degrees with honors in Petroleum Engineering from the University of Tulsa. He is a registered engineer with the state of Texas.

## Contact Me

Herman_Acuna@ryderscott.com

713-751-5527

www.ryderscott.com

# $CO_2$ STORAGE ANALYSIS AND PERMITTING

By Herman Acuña

# CONTENT

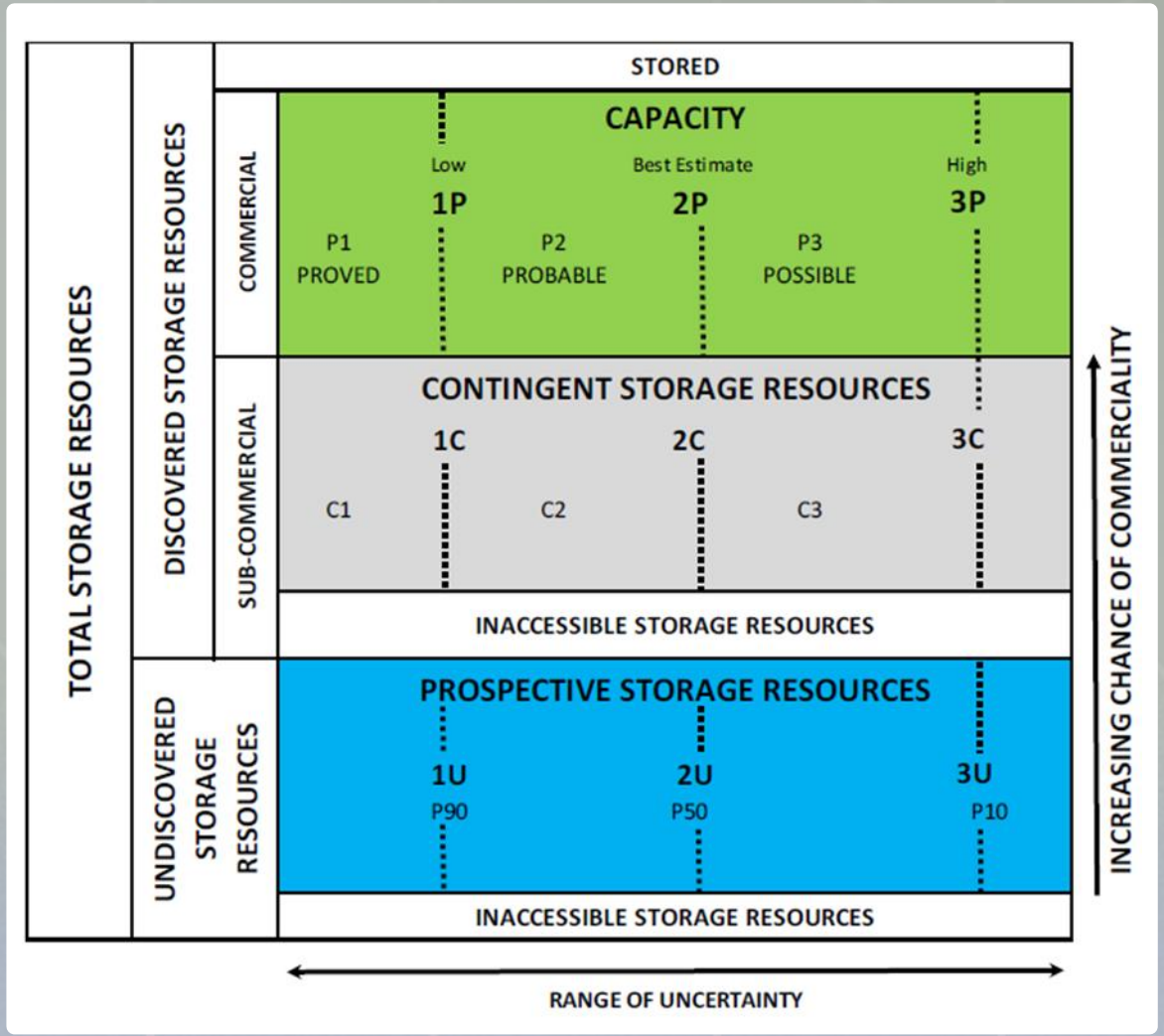
# WHAT IS EXPECTED FROM AN EVALUATOR

1. A quantification of the storage resources
2. An assessment of the technical uncertainty and maturity associated with those resources reflected in the classification and categorization of the reserves and resources.
   - Quantities cannot be directly measured – intrinsic uncertainty in the evaluations

- This requires experience and judgement in addition to the geologic and engineering technical analysis.
  - There is no silver bullet
- An evaluator provides two opinions:
  - A quantitative opinion (calculation)
  - A qualitative opinion (classification and categorization)

# SPE-SRMS DEFINITIONS

- Major Classes:
  - Stored,
  - Capacity,
  - Contingent Storage Resources
  - Prospective Storage Resources
  - Inaccessible Storage Resources



# $CO_2$ STORAGE ANALYSIS AND PERMITTING WORKFLOW

## Standard Sub-Surface & Project Analysis

### Geosciences

Fluid Volume Determination

Pore Volume Determination

Structure → Stratigraphic Framework → Rock Prop. Distribution → Fluid Prop. Distribution → Model Upscaling

### Reservoir Engineering

Simulation Model Initialization

Incorporate Static Model → $CO_2$ & Res. Fluid PVT → Saturation Tables → Comp. Model Formulation → Model Validation

### Drilling and Facilities

Well Design & Integrity

Facilities Specifications

### Other

CCS Access Rights

$CO_2$ Sources

P&A and Restoration

## CCS

**Geosciences**

- Geomechanical / Tectonics
- Characterize Confining Zones
- Characterize USDWs*

**Engineering**

- Geochemical Formulation
- Predictive Runs Qinj., Comp., P.
- $CO_2$ Plume & Mass Tracking

## Permitting

**Storage Boundaries**
- In-Time
- Stable

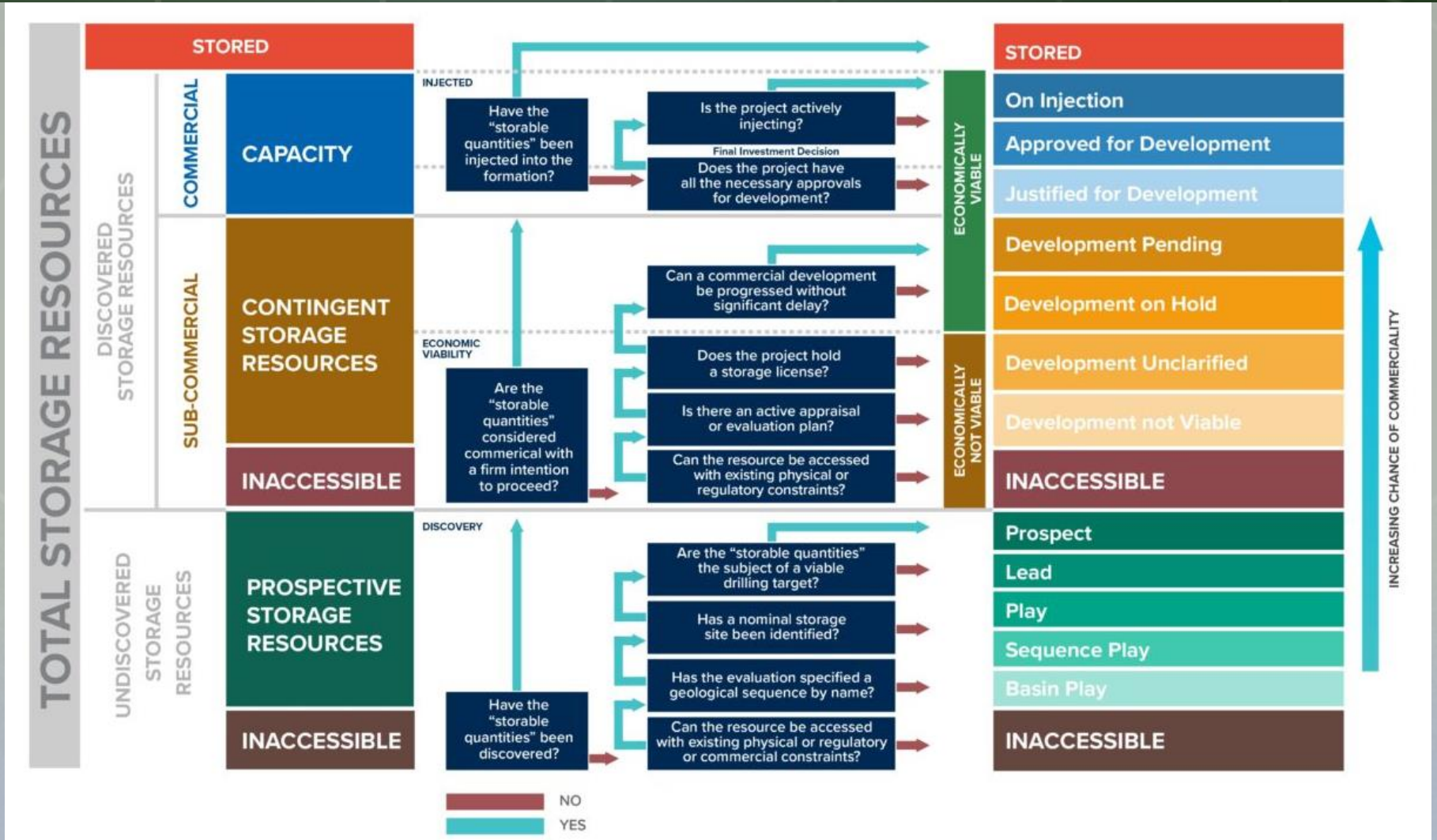
**Geologic Confinement**
- Struct. / Strat.
- Residual Sg
- Dynamic
- Adsorption
- Mineralization

**Area of Review (AOR)**
- Critical threshold P.
- Max. Plume Area

**Post Injection Monitoring**
- Corrective Action
- Emergency Response

* USDWs – Underground sources of drinking water

# SPE-SRMS PROJECT MATURATION




Source: Global CCS Institute

# HOW TO DEVELOP A CRITERIA FOR STORAGE CATEGORIZATION

- Industry has ample experience with the SPE-PRMS; however the practical application of the SPE-SRMS is still being developed.
- With limited experience and industry practice, evidence-based judgement becomes more important.
- Development of a uncertainty attribute/variable matrix may assist in the categorization of storage resources.
- Define corporate guidelines on how the uncertainty/variable matrix can provide guidance for the categorization of storage resources.

| Storage Quality | Seal Quality | $CO_2$ Density and Migration |
|---|---|---|
| Monitoring & Corrective Actions | Upside | Data Quality |

Ref.: STRATEGY-CCUS-WP21-SRAM-v1.docx

# STORAGE QUALITY

| | | | |
|---|---|---|---|
| Pore Volume wrt. Project Robustness | Large | Medium | Low |
| Reservoir Heterogeneity/Complexity | Low | Medium | High |
| Depth | 4,000'-6,800' | 2,500'-4,000'<br>6,800'-8,250' | <2,500'<br>>8,250' |
| Pore Pressure | Hydrostatic or Lower | | Overpressure |
| Thickness | >150 ft | | < 50 ft |
| Avg. Porosity | >25% | | <15% |
| Permeability | >500 mD | | <10 mD |
| Injectivity | High kh | Medium kh | Low kh |

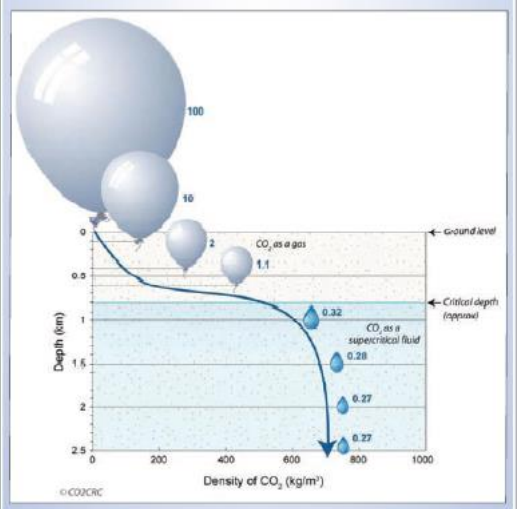



*Illustration of Effect of Pressure on $CO_2$. (Image courtesy of CO2CRC www.co2crc.com.au/imagelibrary/)*

# SEAL QUALITY

| | | | |
|---|---|---|---|
| Sealing Layer(s) to prevent flow to economic/environmental receptors | Multiple | More than one | One/Uncertain |
| Continuity | Proven Continuity | Interpreted Continuity | Poorly defined Continuity |
| Seal Heterogeneity/Complexity | Low | Medium | High |
| Composition | High clay content | | Silty, silt layers |
| Thickness | >300 ft | | < 150 ft |
| Faults | No Faults / Stable Tectonics | Minor Throw | Large Throw through Seal |
| Wells | No drilling through seal | Low Well Count / Verified Integrity | High Well Count / unknown Integrity |

# $CO_2$ DENSITY AND MIGRATION

| | | | |
|---|---|---|---|
| $CO_2$ Density | >450kg/m$^3$ | 450kg/m$^3$-<br>300kg/m$^3$ | 300kg/m$^3$<br>> |
| $CO_2$ Migration | Low Migration Risk | | Moderate Migration Risk |
| Wells | No drilling through seal | Low Well Count / Verified Integrity | High Well Count / unknown Integrity |

# MONITORING & CORRECTIVE ACTIONS

| | | | |
|---|---|---|---|
| Monitoring | Suitable Site & Program | | Difficult Site for Monitoring |
| Intervention | Effective / Low Impact | | Difficult / High Impact |
| Emergency | Effective / Low Impact | | Difficult / High Impact |

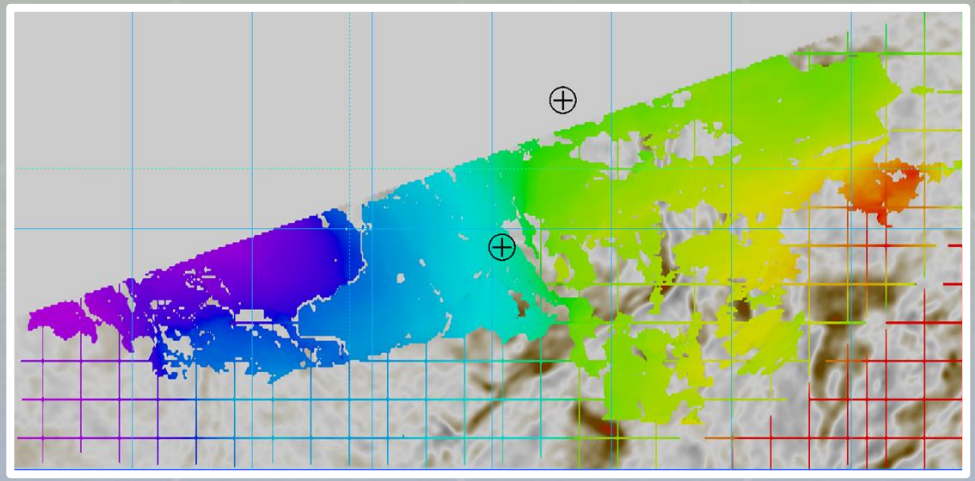
# UPSIDE

| | | | |
|---|---|---|---|
| Location | Suitable to other sinks & sources | Suitable to other Sources | Remote |
| Upside | Potential Hub Growth | | Single Opportunity |

# DATA QUALITY

| All Criteria | High Quality & Good Coverage | Adequate & Some Coverage Gaps | Low Quality & Sparse |
|---|---|---|---|

- Seismic Interpretation area  from 3D survey
- Exploration and Production wells are also displayed in black.
- Gridded surface and interpretation in colors
- Uncertainty and risk related to the extension and full closure of the reservoir area no cover in by the seismic

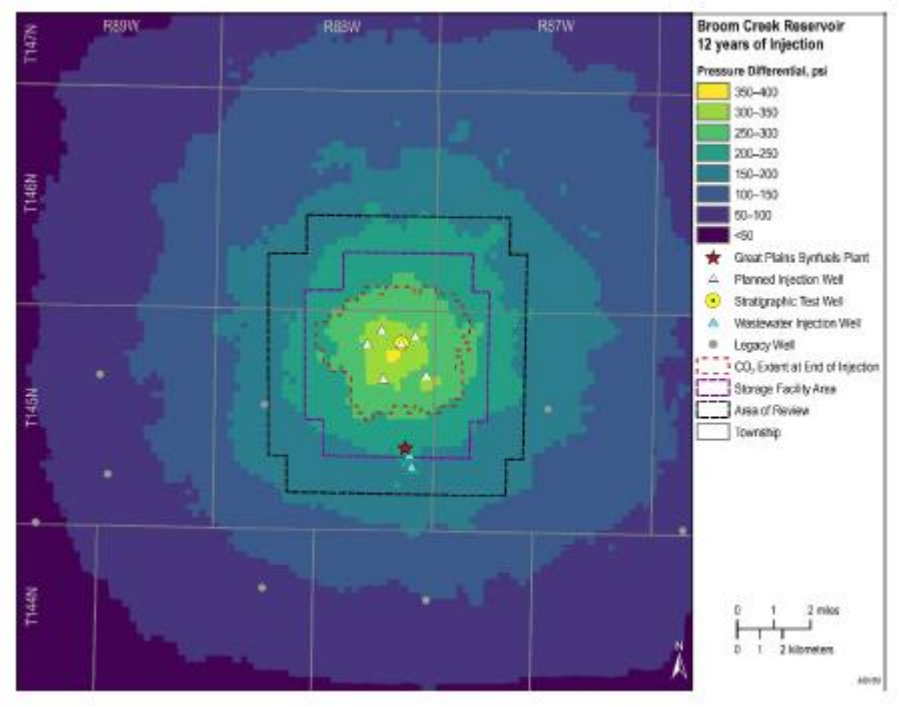


# CLASS VI APPLICATION CHECKLIST

- General Information
- Geologic Narrative/Site Characterization
- Planned Well Operations
- Area of Review (AoR) and Corrective Action Plan
- Testing and Monitoring Plan
- Injection Well Plugging Plan
- Post Injection Site Care (PISC) and Site Closure Plan
- Emergency and Remedial Response Plan
- Injection Well Construction Plan
- Pre-Operational Testing
- Financial Responsibility Demonstration
- Proposed Stimulation Plan
- Injection Depth Waiver Request

# UNDERGROUND SOURCES OF DRINKING WATER (USDW)

- Review analysis for the protection of underground sources of drinking water (USDWs)
- Area surrounding the storage project where USDWs may be endangered by the $CO_2$ project need to be delineated and analyzed (Area for Review or AOR)
- Protection of USDWs thus requires first an understanding of its characteristics within the AOR
  - Geology of the USDW
  - Hydrology of the USDW
- Protection measurements of the USDWs
  - Seals & impermeable rocks, pressures, hydrostatic equilibrium



# RISK BASED DELINEATION FOR AREA OF REVIEW (AOR) - PROTECTION OF USDWS

- Risk based delineation of the Area of Review (AoR) – Area endangered by vertical migration of $CO_2$
  - Minimum area should be the maximum area of the plume or the pressure front larger than original reservoir pressure
  - Examine pathways for migration to USDWs within the AoR that include legacy oil and gas wells, fractures and faults (including fault reactivation)
- Estimate the hydraulic heads generated within the AoR (hydraulic head maps)
  - As applicable, generate multiple scenarios based on reservoir properties uncertainties

# RISK BASED DELINEATION FOR AREA OF REVIEW (AOR) - PROTECTION OF USDWS

- **Regulatory compliance is not feasible where storage reservoirs are over-pressured relative to USDWs and thus hydrostatic equilibrium cannot be achieved.**
  - Determine potential sustainable leakage rate from existing pressures heads prior to injection (baseline leakage flow)
  - Determine potential incremental sustainable leakage rate from the pressure front generated by injection
- Generate incremental leakage maps to delineate the risk based AoR and define monitoring, emergency and remedial response plans accordingly
  - Pressure buildup vs. incremental cumulative leakage
  - Incremental leakage maps
- Evaluate the monitoring, corrective and emergency plans commensurate with the findings during the risk based AoR reviews

# POST INJECTION SITE RESTORATION AND FACILITIES ABANDONMENT

- Review the plans for site restoration and facilities abandonment
  - Well plugging and abandonment
  - Facilities decommissioning
  - Pipelines and flow lines abandonment
  - Abandonment of structures and buildings
  - Land reclamation

# MONITORING AND CORRECTIVE ACTION PLAN

- Review testing and monitoring plans for operational parameters and performance
  - Analysis of injected $CO_2$
  - Soil gas baselining & sampling
  - Ground water baselining & sampling
  - Corrosion monitoring & prevention
  - Well integrity
  - Injectivity and pressure testing
  - Leak detection systems (surface & storage reservoir)
  - Subsurface $CO_2$ plume and pressure monitoring
- Review plan for periodical reassessment of the AOR and corrective action plans
  - Operational and post-operational

| Monitoring Type | Equipment/Testing | Target Area |
|---|---|---|
| Analysis of $CO_2$ Stream | Compositional and isotopic analysis of the $CO_2$ stream | $CO_2$ compressors at the capture facility |
| Wellsite Flowline Leak Detection System | $H_2S$ detection stations, pressure gauges, and SCADA[1] system | Wellsite flowline to wellhead |
| Surface Corrosion | Ultrasonic testing of tubing test sections installed at wellheads | Wellsite flowline to well infrastructure |
| Downhole Corrosion | PMIT[2] and/or surface tubing inspection and USIT[3] (material wall thickness) | Downhole tubing and casing strings |
| Continuous Recording of Injection Pressure, Rate, and Volume | Flowmeters | Transmission line to well infrastructure |
| Well Annulus Pressure Between Tubing and Casing | Digital annular pressure gauges for continuous monitoring | Surface-to-reservoir (injection wells) |
| Internal and External Mechanical Integrity Testing | Tubing-casing annulus pressure testing (internal), USIT (internal and external) and temperature logs | Well infrastructure |
| Atmospheric | $H_2S$ detection stations | Outside of wellhead enclosures |
| Near-Surface | Compositional and isotopic analysis of soil gas profile stations and dedicated Fox Hills[1] monitoring wells | Vadose zone and lowest USDW |
| Direct Reservoir | Pulsed-neutron logs with temperature and pressure readings, pressure falloff testing, and surface pressure gauges | Storage reservoir and dissipation intervals |
| Indirect Reservoir | Time-lapse 2D seismic surveys and vertical seismic profiles (VSPs) | Entire storage complex |

# POST INJECTION MONITORING PLAN

- Review the plans for post injection monitoring which should be consistent in duration (minimum period) with plume stabilization simulation studies
  - Monitor change / permanence of stored volumes
  - $CO_2$ plume monitoring program
  - Soil ground sampling and monitoring
  - Well pressure measurements
  - Time lapse seismic
  - Reporting and submissions

# EMERGENCY REMEDIAL RESPONSE PLAN

- Plan should consist of robust detection mechanisms and response actions
- Document the resources (USDWs) that may be impacted in an emergency
- Document infrastructure that may be impacted in an emergency (wellheads, transmission lines, compressors, etc.)
- Identify Potential Emergency Events & confirm proposed detection mechanisms
  - Surface facilities failure
  - Well integrity failure
  - Monitoring equipment failure
  - Subsurface containment of $CO_2$ failure
  - Natural events (earthquakes, etc.)
- Review adequacy of the emergency response actions for the emergency events
- Review training and awareness programs

# OTHER CONTINGENCIES

- Verify that there are no pending contingences from:
  - Industrial activities
  - Extractive activities through wells or mining
  - Existing or planned infrastructure

# THANK YOU

RYDER SCOTT

SUSTAINABLE ENERGY CONSULTING

Herman_Acuna@ryderscott.com

Office Phone: +1-713-751-5527
Cell Phone: +1-832-788-6075

1100 Louisiana, Suite 4600
Houston, Texas 77002

www.ryderscott.com

Risk Assessment Feasibility Studies Economic Due Diligence United Nations Classification Framework
Utilization and Sequestration Authenticate Greenhouse Gas Assertions Surface and Sub-Surface Integration